NASA Breakthrough Propulsion Physics Workshop Proceedings

National Aeronautics and
Space Administration

Lewis Research Center

Acknowledgments

About the cover

This rendition, by artist Les Bossinas, depicts a hypothetical spacecraft with a "negative energy" induction ring, inspired by recent theories describing how space could be warped with negative energy to produce "warp drive" or "wormhole" transport to reach distant star systems.

FOREWORD

In August 1997, NASA sponsored a 3-day workshop to assess the prospects emerging from physics that may eventually lead to creating propulsion breakthroughs—the kind of breakthroughs that could revolutionize space flight and enable human voyages to other star systems. Experiments and theories were discussed regarding the coupling of gravity and electromagnetism, vacuum fluctuation energy, warp drives and wormholes, and superluminal quantum tunneling. Because the propulsion goals are presumably far from fruition, a special emphasis was to identify affordable, near-term, and credible research tasks that could make measurable progress toward these grand ambitions. This workshop was one of the first steps for the new NASA Breakthrough Propulsion Physics program led by the NASA Lewis Research Center. This program is funded out of the Advanced Space Transportation Program, managed by Marshall Space Flight Center.

The workshop, held in Cleveland, Ohio, featured 14 invited presentations about emerging physics (both optimistic and pessimistic viewpoints), 30 poster papers for provoking thought, and 6 parallel breakout sessions where participants generated a list of 95 candidate next-step research tasks.

In total, 84 participants attended the workshop, including 26 from industry, 18 from universities, 12 from government labs (including Los Alamos, Oak Ridge, Fermi, Brookhaven, and the Air Force Research Labs at Edwards and Kirtland), 16 from NASA (including Lewis, Langley, Marshall, Johnson, and the Jet Propulsion Laboratory). Twelve students also attended.

Several research approaches were identified during this workshop that serve as examples of affordable, near-term, and credible tasks that could make measurable progress toward these grand ambitions. The next step is to continue the exchange of information amongst interested researchers and to seek the funding necessary to support research.

Marc G. Millis
NASA Lewis Research Center

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WORKSHOP TEAM

Workshop Organizers

Marc G. Millis	Chairman	NASA Lewis
Richard Ziegfeld	Logistics chair	NYMA Inc.
Joseph A. Hemminger	Lead breakout session support volunteer	NASA Lewis

Proceedings

Marc G. Millis	NASA Lewis
Gary Scott Williamson	NASA Lewis

Breakout Sessions

Sheila G. Bailey	Group E facilitator	NASA Lewis
Michael P. Binder	Group B facilitator	NYMA Inc.
David Chato	Group D note-taker	NASA Lewis
Dane Elliott-Lewis	Group E note-taker	NASA Lewis summer student
Raymond G. Estrada	Group A note-taker	NASA Lewis summer student
Cynthia D. Forman	Group A facilitator	NASA Lewis
Jim Giomini	Group D facilitator	NASA Lewis
Scott Graham	Group F facilitator	NASA Lewis
Joseph A. Hemminger	Group B note-taker & computer coordinator	NASA Lewis
Grace Scales	Group C facilitator	NASA Lewis
Gary Scott Williamson	Group F note-taker	NASA Lewis
Edward Zampino	Group C note-taker	NASA Lewis

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Carl Lorenzo	Volunteer	NASA Lewis
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John Toma	Logistics support	NYMA Inc.
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Breakthrough Propulsion Physics Program Government Steering Group Members

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Dr. Warner A. Miller	DoE, Los Alamos National Lab
Dr. David Noever	NASA Marshall Space Flight Center
Dr. Jag J. Singh	NASA Langley Research Center

AGENDA

Monday   August 11, 1997

DAY 1	Tuesday, August 12, 1997	
8:30	Marc G. Millis	Welcome and Workshop Instructions
	Dennis J. Kucinich	Welcoming Address
9:00	Lawrence Krauss	1. Physics Possibilities and Practicalities of Propellantless Propulsion
9:30	Harold Puthoff	2. Can the Vacuum be Engineered for Spaceflight Applications?
10:00	*Break & Poster View*	
10:30	Raymond Chiao	3. Tunneling Times and Superluminality
11:10	John Cramer	4. Quantum Non-locality and Possible Superluminal Effects
11:40	Ron Koczor &	5. Experiments on the Possible Interaction of Rotating Type II YBCO Ceramic
	David Noever	Superconductors and the Local Gravity Field
12:30	*Lunch*	
1:30	Robert Forward	6. Dimensional Control of Casimir Energy
2:00	Bernhard Haisch	7. Implications of an Electromagnetic Quantum Vacuum Basis for Inertia
2:20	Alfonso Rueda	8. Inertial Mass as Reaction of the Vacuum to Accelerated Motion
2:40	Daniel C. Cole	9. Calculations on Electromagnetic ZPE Contributions to Mass & Perspectives
3:00	*Break & Poster View*	
3:30	Peter W. Milonni	10. Casimir Effect: Experimental Evidence and Implications
4:00	Hüseyin Yilmaz	11. The New Theory of Gravitation and the Fifth Test
4:30	Arkady Kheyfets	12. Hyper-Fast Interstellar Travel via a Modification of Spacetime Geometry
5:00	*Adjourn*	
7:00		Great Lakes Science Center and Star Trek Exhibit

DAY 2	Wednesday, August 13, 1997	
8:30	Frank J. Tipler III	13. Ultrarelativistic Rockets & the Ultimate Future of the Universe
9:00	George Miley	14. Overview of Empirical Evidence of Claims of Anomalous Energy Effects
9:30	*selected poster*	15. Selected Poster Introductions (4 min. each)
	authors	
10:00	Marc G. Millis	Breakout Group Instructions
10:15	*Poster Discuss Break*	*Poster authors at poster*
11:00	6 Parallel Breakouts	A. Begin brainstorming for propulsion & power ideas & curious effects
12:30	*Lunch*	
1:30	6 Parallel Breakouts	B. Continue brainstorming & identifying related physics issues & effects
3:00	*Break & Poster View*	
3:30	6 Parallel Breakouts	C. Brainstorming to identify critical unknowns or make-or-break issues
5:00	*Adjourn*	

DAY 3	Thursday, August 14, 1997	
8:30	6 Parallel Breakouts	D. Collect and discuss research task ideas, and begin ranking
10:00	*Break & Poster View*	
10:30	6 Parallel Breakouts	E. Research task idea ranking & wrap up
12:00	*Lunch*	
1:30	Plenary Group Rprts	Overview of Ranked Task Recommendations (each group presents 10 min. ea.)
3:00	Marc G. Millis	Closing Comments
3:30	*Adjourn*	

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Propellantless Propulsion: The Most Inefficient Way to Fly?

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ABSTRACT:

General Relativity offers in principle the tantalizing possibility of using the properties of spacetime in which spacetime is locally flat, but not globally so in order to allow one to apparently circumvent the constraints of special relativity on both the global speed of moving objects with respect to a distant set of inertial observers and also on the nature of energy in empty space. However, in spite of these tantalizing questions of principle, circumventing special relativity invariably requires matter which violates the weak, dominant, and strong energy conditions in general relativity. While it is quite possible that such material cannot be even be created on macroscopic scales, general arguments suggest that even if it were realizable, the energy requirements daunt those associated with any form of propulsion based on normal relativistic propellants. Moreover, arguments based on causality demonstrate that as far as practical space travel is concerned, one can never operationally travel faster than light, if the experimental setup time is included. Finally, the energy which might be extracted from the vacuum is in general infinitesmally small, and in any case is generically less than the energy input required. These arguments suggest that even if the use of spacetime for propellantless propulsion is not impossible in principle, it is likely to be useless in practice.

INTRODUCTION:

Interest in the possibility of using spacetime for propulsion purposes stems from three facts:

(1) The Rocket equation, which in its nonrelativistic form can be written

$$(M + P)/M = e^{\Delta V/C}$$

where the quantity on the left hand side is the ratio of the vehicles weight including propellant to the vehicle's dry weight, and ΔV is the desired velocity change of the rocket, while C is the propellant exhaust velocity, implies that to travel at relativistic final velocities, either an astronomical amount of fuel is needed, or a propellant traveling at light speed is required.

(2) Special Relativity requires $V < C$, while interstellar travel in a single human lifetime (for a distant observer) requires $V > C$.

(3) General Relativity implies that flat space intuition is incorrect in curved space. Thus, for example, the requirement (2) refers to local quantities, but not global quantities. As a result, global velocities greater than the speed of light are possible. An example is an Inflationary Universe (i.e. See Linde 1990), in which a non-zero vacuum energy density (VEV), given by $T_{\mu\nu} = \Lambda g_{\mu\nu}$ during the early universe leads to a period of exponential expansion, where distant objects, locally at rest with respect to the expansion move at relative speeds which exceed C.

As a result, numerous suggestions have been made for utilizing spacetime, including so-called Warp Drive, and extraction of Casimir energy. I shall now describe why these ideas are impotent.

WARP DRIVE: THE LEAST BANG FOR YOUR BUCK:

In 1994 it was shown (Alcubierre 1994) that a metric could be written down which was a solution of Einstein's equations, and in which the properties of Warp Drive on Star Tr:k (Krauss 1995) appeared to b; possible: superliminal travel with no time dilation. Alcubierre's metric has the form

$$ds^2 = -dt^2 + (dx - v_f f(r_s)dt)^2 + dy^2 - dz^2$$

wher v represents the velocity of the bubble containing a spacecraft, and f represents a function of finite support which essentially produces an expansion of space behind the spacecraft and a contraction behind it.

Alcubierre recognized that this metric involved an energy dens ty $T^{00} < 0$, which violates the weak and dominant energy conditions. This is similar to the requirement demonstrated by Morris and Thorne (Morris and Thorne 1988) that traversable wormholes require that the negative of the radial pressure exceed the energy density for the material holding the wormhole open. Normal classical matter does not have this property, although vacuum fluctuations can. Thus, the question becomes whether these kinds of exotic matter can be created in the laboratory, and if they can, at what cost.

In spite of the potential this idea holds out, two practical results suggest it cannot lead to viable methods of space travel.

(1) Recently Pfenning and Ford (Pfenning ind Ford 1997) have utilized qunatum inequality restrictions on negative energy density material to examine how large a practical warp bubble region is possible. They discovered that the negative energy material must be confined to a thin shell on the outskirts of the bubble (moving with velocity v) with thickness $\Delta \lesssim 100 \ v \ L_p$, where L_p is the Planck Length. As a result, the total energy required to maintain this configuration for a bubble of radius Ris, in leading approximation:

$$E = -\frac{2\pi}{3} v^2 \frac{R^2}{\Delta}$$

For a macroscpic bubble, of say 100 meters, this implies an energy requirement roughly 10 orders of magnitude greater than the total mass of the entire visible universe

(2) Even if the daunting energy requirements could be met, causality arguments imply that to travel 20 light years will always require at least 20 years. This point has not beer stressed in the literature to my knowledge, until recently (Krauss 1997). The reasoning is simple. In order to obtain the metric of Alcubierre, space must be filled with the proper configuration of energy. In order to do this, so that distant space knows when to contract, one must at the very least send a signal throughout the space to be warped. Thus, while the actual period of expansion and contraction can be arbitrarily fast, the setup time for the experiment is always such that the net result is that one cannot travel between two points fas er than the speed of light from the moment one decides to do the travelling.

VACUUM ENERGY: MU'H ADO ABOUT NOTHING

The fact that vacuum fluctuations exist in empty space has cause l interest in mining the vacuum for energy. There are two ways to do this: (a) If the vacuum has a non-zero energy density, this can be directly extracted via a phase transition. (b) by changing boundary conditions, so that the spectrum of vacuum fluctuations varies, one might can produce either non-zero forces, or non-zer» radiation from the vacuum. Unfortunately these ideas are not efficient, for the following reasons.

(1) The Casimir energy is EXTREMELY small. Between perfec ly conducting parallel plates, the change in vacuum energy produced by excluding certain vacuum modes lead; to a force per unit area of approximately:

$$F = \frac{\pi^2}{240 \, a^4}$$

where a is the distance between the places, and $h/2\pi = c = 1$ in these units. For macroscopic plates, this force is is so small as to be useless for propulsion of macroscopic masses, not to mention the special requirements to utilize this force.

(2)The upper limit on the vacuum energy density of the Universe which can be extracted on large scales, comes from a limit on the Cosmological Constant (Krauss 1997), of approximately $(10^{-3} eV)^4$. In order to levitate an average size human being in the earth's gravitational field with this energy density would require liberating the energy in a cubic volume the size of Manhattan.

(3) Utilizing spacetime curvature is vastly inefficient. Einstein's Equation: $G_{\mu\nu} = 8\pi G T_{\mu\nu}$ implies, because of the smallness of G, that the energy requirements to produce a curvature which might allow either Hawking radiation, or a Boguliubov transformation which would yield significant non-zero energy in a distant flat reference frame is incredibly large. Namely, the input energy required to produce the curvature always is greater than or equal to the energy which which can be so extracted. Again, the energy requirements are generally far larger than those associated with merely imparting a kinetic energy to an object comparable to its rest mass (i.e. to obtain relativistic velocities) via propulsion.

CONCLUSIONS

General Relativity makes certain questions of principle extremely interesting, including: can one manufacture negative energy configurations on macroscopic scales which might allow apparently superluminal travel, time travel, or observable energy from the vacuum? While these issues are of great interest for our fundamental physical understanding of the universe, they do not lead to practical methods of space travel with the kind of resources accessible in our civilization for the forseeable future. The energy requirements ALWAYS exceed those requirements associated with propulsion. As a result, propellantless propulsion, to the extent it is not ruled out by the laws of physics, nevertheless seems to be a gross waste of money in practice for realistic space travel at this time.

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Can the Vacuum be Engineered for Spaceflight Applications?
Overview of Theory and Experiments

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ABSTRACT

Quantum theory predicts, and experiments verify, that empty space (the vacuum) contains an enormous residual background energy known as zero-point energy (ZPE). Originally thought to be of significance only for such esoteric concerns as small perturbations to atomic emission processes, it is now known to play a role in large-scale phenomena of interest to technologists as well, such as the inhibition of spontaneous emission, the generation of short-range attractive forces (e.g., the Casimir force), and the possibility of accounting for sonoluminescence phenomena. ZPE topics of interest for spaceflight applications range from fundamental issues (where does inertia come from, can it be controlled?), through laboratory attempts to extract useful energy from vacuum fluctuations (can the ZPE be "mined" for practical use?), to scientifically-grounded extrapolations concerning "engineering the vacuum" (is "warp-drive" space propulsion a scientific possibility?). Recent advances in research into the physics of the underlying ZPE indicate the possibility of potential application in all these areas of interest.

INTRODUCTION

The concept "engineering the vacuum" was first introduced by Nobel Laureate T. D. Lee in his book *Particle Physics and Introduction to Field Theory*. As stated there: "The experimental method to alter the properties of the vacuum may be called vacuum engineering.... If indeed we are able to alter the vacuum, then we may encounter some new phenomena, totally unexpected." Recent experiments have indeed shown this to be the case.

With regard to space propulsion, the question of engineering the vacuum can be put succinctly: "Can empty space itself provide the solution?" Surprisingly enough, there are hints that potential help may in fact emerge quite literally out of the vacuum of so-called "empty space." Quantum theory tells us that empty space is not truly empty, but rather is the seat of myriad energetic quantum processes that could have profound implications for future space travel. To understand these implications it will serve us to review briefly the historical development of the scientific view of what constitutes empty space.

At the time of the Greek philosophers, Democritus argued that empty space was truly a void, otherwise there would not be room for the motion of atoms. Aristotle, on the other hand, argued equally forcefully that what appeared to be empty space was in fact a plenum (a background filled with substance), for did not heat and light travel from place to place as if carried by some kind of medium?

The argument went back and forth through the centuries until finally codified by Maxwell's theory of the luminiferous ether, a plenum that carried electromagnetic waves, including light, much as water carries waves across its surface. Attempts to measure the properties of this ether, or to measure the Earth's velocity through the ether (as in the Michelson-Morley experiment), however, met with failure. With the rise of special relativity which did not require reference to such an underlying substrate, Einstein in 1905 effectively banished the ether in favor of the concept that empty space constitutes a true void. Ten years later, however, Einstein's own development of the general theory of relativity with its concept of curved space and distorted geometry forced him to reverse his stand and opt for a richly-endowed plenum, under the new label *spacetime metric*.

It was the advent of modern quantum theory, however, that established the quantum vacuum, so-called empty space, as a very active place, with particles arising and disappearing, a virtual plasma, and fields continuously fluctuating about their zero baseline values. The energy associated with such processes is called zero-point energy (ZPE), reflecting the fact that such activity remains even at absolute zero.

THE VACUUM AS A POTENTIAL ENERGY SOURCE

At its most fundamental level, we now recognize that the quantum vacuum is an enormous reservoir of untapped energy, with energy densities conservatively estimated by Feynman and others to be on the order of nuclear energy densities or greater. Therefore, the question is, can the ZPE be "mined" for practical use? If so, it would constitute a virtually ubiquitous energy supp y, a veritable "Holy Grail" energy source for space propulsion.

As utopian as such a possibility may seem, physicist Robert Forward at Hughes Research Laboratories demonstrated proof-of-principle in a paper published in 1984, "Extracting Electrical Energy from the Vacuum by Cohesion of Charged Foliated Conductors." Forward's approach exploited a phenomenon called the *Casimir Effect*, an attractive quantum force between closely-spaced metal plates, named for its discoverer, H. G. B. Casimir of Philips Laboratories in the Netherlands. The Casimir force, recently measured with high accuracy by S. K. Lamoreaux at the University of Washington, derives from partial shielding of the interior region of the plates from the background zero-point fluctuations of the vacuum electromagnetic field. As shown by Los Alamos theorist Mi onni and his colleagues, this shielding results in the plates being pushed together by the unbalanced ZPE radiation pressures. The result is a corollary conversion of vacuum energy to some other form such as heat. Proof that such a process violates neither energy nor thermodynamic constraints can be found in a paper by D. Cole and myself published in 1993 under the title "Extracting Energy and Heat from the Vacuum."

Attempts to harness the Casimir and related effects for vacuum energy conversion are ongoing in our laboratory and elsewhere. The fact that its potential application to space propulsion has not gone unnoticed by the Air Force can be seen in its request for proposals for the FY-1986 Defense SBIR Program. Under entry AF86-77, *Air Force Rocket Propulsion Laboratory (AFRPL) Topic: Non-Conventional Propulsion Concepts* we find the statement: "Bold, new non-conventional propulsion concepts are solicited.... The specific areas in which AFRPL is interested include.... (6) Esoteric energy sources for propulsion including the zero point quantum dynamic energy of vacuum space."

Several experimental formats for tapping the ZPE for practical use are under investigation in our laboratory. An early one of interest is based on the idea of a Casimir pinch effect in non-neutral plasmas, basically a plasma equivalent of Forward's electromechanical charged-plate collapse (see Puthoff, 1990). The underlying physics is described in a paper submitted for publication by myself and M. Piestrup, and it is illustrative that the first of several patents issued to a consultant to our laboratory, K. R. Shoulders, contains the descriptive phrase "... energy is provided... and the ultimate source of this energy appears to be the zero-point radiation of the vacuum continuum."

Another intriguing possibility is provided by the phenomenon of sonoluminescence, bubble collapse in an ultrasonically-driven fluid which is accompanied by intense, sub-nanosecond light radiation. Although the jury is still out as to the mechanism of light generation. Nobelist Julian Schwinger has argued for a Casimir interpretation. Possibly related experimental evidence for excess heat generation in ultrasonically-driven cavitation in heavy water is claimed in an EPRI Report by George and Stringham of E-Quest Sciences, although attributed to a nuclear micro-fusion process. Work is under way in our laboratory to see if this claim can be replicated.

Yet another proposal for ZPE extraction is described in a patent issued to Mead and Nachamkin. The approach proposes the use of resonant dielectric spheres, slightly detuned from each other, to provide a beat-frequency downshift of the more energetic high-frequency components of the ZPE to a more easily captured form. We are discussing the possibility of a collaborative effort between us to determine whether such an approach is feasible.

Finally, an approach utilizing micro-cavity techniques to perturb the ground state stability of atomic hydrogen is under consideration in our lab. It is based on a 1987 paper of mine in which I put forth the hypothesis that the nonradiative nature of the ground state is due to a dynamic equilibrium in which radiation emitted due to accelerated electron ground state motion is compensated by absorption from the ZPE. If this hypothesis is true, there exists the potential for energy generation by the application of the techniques of so-called *cavity quantum electrodynamics (QED)*. In cavity QED, excited atoms are passed through Casimir-like cavities whose structure suppresses electromagnetic cavity modes at the transition

frequency between the atom's excited and ground states. The result is that the so-called "spontaneous" emission time is lengthened considerably (for example, by factors of ten), simply because spontaneous emission is not so spontaneous after all, but rather is driven by vacuum fluctuations. Eliminate the modes, and you eliminate the zero-point fluctuations of the modes, hence suppressing decay of the excited state. As stated in an April 1993 *Scientific American* review article on cavity QED, "An excited atom that would ordinarily emit a low-frequency photon cannot do so, because there are no vacuum fluctuations to stimulate its emission...." In its application to energy generation, mode suppression would be used to perturb the hypothesized dynamic ground-state absorption/emission balance to lead to energy release (patent pending).

An example in which Nature herself may have taken advantage of energetic vacuum effects is discussed in a model published by ZPE colleagues A. Rueda of California State University at Long Beach, B. Haisch of Lockheed-Martin, and D. Cole of IBM. In a paper published in the *Astrophysical Journal* in 1995, they propose that the vast reaches of outer space constitute an ideal environment for ZPE acceleration of nuclei and thus provide a mechanism for "powering up" cosmic rays. Details of the model would appear to account for other observed phenomena as well, such as the formation of cosmic voids. This raises the possibility of utilizing a "sub-cosmic-ray" approach to accelerate protons in a cryogenically-cooled, collision-free vacuum trap and thus extract energy from the vacuum fluctuations by this mechanism.

THE VACUUM AS THE SOURCE OF GRAVITY AND INERTIA

What of the fundamental forces of gravity and inertia that we seek to overcome in space travel? We have phenomenological theories that describe their effects (Newton's Laws and their relativistic generalizations), but what of their origins?

The first hint that these phenomena might themselves be traceable to roots in the underlying fluctuations of the vacuum came in a 1967 study published by the well-known Russian physicist Andrei Sakharov. Searching to derive Einstein's phenomenological equations for general relativity from a more fundamental set of assumptions, Sakharov came to the conclusion that the entire panoply of general relativistic phenomena could be seen as induced effects brought about by changes in the quantum-fluctuation energy of the vacuum due to the presence of matter. In this view the attractive gravitational force is more akin to the induced Casimir force discussed above, than to the fundamental inverse square law force between charged particles with which it is often compared. Although speculative when first introduced by Sakharov, this hypothesis has led to a rich and ongoing literature (including a contribution of my own in 1989) on quantum-fluctuation-induced gravity, a literature that continues to yield deep insight into the role played by vacuum forces.

Given an apparent deep connection between gravity and the zero-point fluctuations of the vacuum, a similar connection must exist between these self-same vacuum fluctuations and inertia. This is because it is an empirical fact that the gravitational and inertial masses have the same value, even though the underlying phenomena are quite disparate. Why, for example, should a measure of the resistance of a body to being accelerated, even if far from any gravitational field, have the same value that is associated with the gravitational attraction between bodies? Indeed, if one is determined by vacuum fluctuations, so must the other.

To get to the heart of inertia, consider a specific example in which you are standing on a train in the station. As the train leaves the platform with a jolt, you could be thrown to the floor. What is this force that knocks you down, seemingly coming out of nowhere? This phenomenon, which we conveniently label inertia and go on about our physics, is a subtle feature of the universe that has perplexed generations of physicists from Newton to Einstein. Since in this example the sudden-disquieting imbalance results from acceleration "relative to the fixed stars," in its most provocative form one could say that it was the "stars" that delivered the punch. This key feature was emphasized by the Austrian philosopher of science Ernst Mach, and is now known as Mach's Principle. Nonetheless, the mechanism by which the stars might do this deed has eluded convincing explication.

Addressing this issue in a 1994 paper entitled "Inertia as a Zero-Point Field Lorentz Force," Haisch, Rueda and I were successful in tracing the problem of inertia and its connection to Mach's Principle to the ZPE properties of the vacuum. In a sentence, although a uniformly moving body does not experience a drag

force from the (Lorentz-invariant) vacuum fluctuations, an *accelerated* body meets a resistance (force) proportional to the acceleration. By *accelerated* we mean, of course, accelerated relative to the fixed stars. It turns out that an argument can be made that the quantum fluctuations of distant matter structure the local vacuum-fluctuation frame of reference (see Puthoff, "Source...," 1989). Thus, in the example of the train the punch was delivered by the wall of vacuum fluctuations acting as a proxy for the fixed stars through which one attempted to accelerate.

The implication for space travel is this: *Given the evidence generated in the field of cavity QED (discussed above), there is experimental evidence that vacuum fluctuations can be altered by technological means. This leads to the corollary that, in principle, gravitational and inertial masses can also be altered.*

The possibility of altering mass with a view to easing the energy burden of future spaceships has been seriously considered by the Advanced Concepts Office of the Propulsion Directorate of the Phillips Laboratory at Edwards Air Force Base. Gravity researcher Robert Forward accepted an assignment to review this concept. His deliverable product was to recommend a broad, multi-pronged effort involving laboratories from around the world to investigate the inertia model experimentally.

After a one-year investigation Forward finished his study and submitted his report to the Air Force, who published it under the title *Mass Modification Experiment Definition Study*. The Abstract reads in part:

> ".... Many researchers see the vacuum as a central ingredient of 21st-Century physics. Some even believe the vacuum may be harnessed to provide a limitless supply of energy. This report summarizes an attempt to find an experiment that would test the Haisch, Rueda and Puthoff (HRP) conjecture that the mass and inertia of a body are induced effects brought about by changes in the quantum-fluctuation energy of the vacuum.... It was possible to find an experiment that might be able to prove or disprove that the inertial mass of a body can be altered by making changes in the vacuum surrounding the body."

With regard to action items, Forward in fact recommends a ranked list of not one but *four* experiments to be carried out to address the ZPF-inertia concept and its broad implications. The recommendations included investigation of the proposed "sub-cosmic-ray energy device" mentioned earlier, and the investigation of an hypothesized "inertia-wind" effect proposed by our laboratory and possibly detected in early experimental work by Forward and Miller, though the latter possibility is highly speculative at this point.

ENGINEERING THE VACUUM FOR "WARP DRIVE"

Perhaps one of the most speculative, but nonetheless scientifically-grounded, proposals of all is the so-called Alcubierre Warp Drive. Taking on the challenge of determining whether Warp Drive *a la* Star Trek was a scientific possibility, general relativity theorist Miguel Alcubierre of the University of Wales set himself the task of determining whether faster-than-light travel was possible within the constraints of standard theory. Although such clearly could not be the case in the flat space of special relativity, general relativity permits consideration of altered spacetime metrics where such a possibility is not *a priori* ruled out. Alcubierre's further self-imposed constraints on an acceptable solution included the requirements that no net time distortion should occur (breakfast on Earth, lunch on Alpha Centauri, and home for dinner with your wife and children, not your great-great-great grandchildren), and that the occupants of the spaceship were not to be flattened against the bulkhead by unconscionable accelerations.

A solution meeting all of the above requirements was found and published by Alcubierre in *Classical and Quantum Gravity* in 1994. The solution discovered by Alcubierre involved the creation of a local distortion of spacetime such that spacetime is expanded behind the spaceship, contracted ahead of it, and yields a hypersurfer-like motion faster than the speed of light as seen by observers outside the disturbed region. In essence, on the outgoing leg of its journey the spaceship is pushed away from Earth and pulled towards its distant destination by the engineered local expansion of spacetime itself. (For follow-up on the broader aspects of "metric engineering" concepts, one can refer to a paper published by myself in *Physics Essays* in 1996.) Interestingly enough, the engineering requirements rely on the generation of macroscopic, negative-energy-density, Casimir-like states in the quantum vacuum of the type discussed earlier. Unfortunately,

meeting such requirements is beyond technological reach without some unforeseen breakthrough, as emphasized by Pfenning and Ford in a recently submitted manuscript.

Related, of course, is the knowledge that general relativity permits the possibility of *wormholes*, topological tunnels which in principle could connect distant parts of the universe, a cosmic subway so to speak. Publishing in the *American Journal of Physics* in 1988, theorists Morris and Thorne initially outlined in some detail the requirements for traversible wormholes and have found that, in principle, the possibility exists provided one has access to Casimir-like, negative-energy-density quantum vacuum states. This has led to a rich literature, summarized recently in a 1996 book by Matt Visser of Washington University, St. Louis. Again, the technological requirements appear out of reach for the foreseeable future, perhaps awaiting new techniques for cohering the ZPE vacuum fluctuations in order to meet the energy-density requirements.

CONCLUSIONS

We began this discussion with the question: "Can the vacuum be engineered for spaceflight applications?" The answer is: "In principle, yes." However, engineering-wise it is clear that there is a long way to go. Given the cliché "a journey of 1000 miles begins with the first steps," it is also clear that we can take those first steps now in the laboratory. Given that Casimir and related effects indicate the possibility of tapping the enormous residual energy in the vacuum-fluctuation ZPE, and the demonstration in cavity QED that portions of the ZPE spectrum can be manipulated to produce macroscopic technological effects such as the inhibition of spontaneous emission of excited states in quantum systems, it would appear that the first steps along this path are visible. This, combined with newly-emerging concepts of the relationship of gravity, inertia and warp drive to properties of the vacuum as a manipulable medium, indicate yet further reaches of possible technological development, although requiring yet unforeseen breakthroughs with regard to the possibility of engineering vacuum fluctuations to produce desired results.

Where does this leave us? As we peer into the heavens from the depth of our gravity well, hoping for some "magic" solution that will launch our spacefarers first to the planets and then to the stars, we are reminded of Arthur C. Clarke's phrase that highly-advanced technology is essentially indistinguishable from magic. Fortunately, such magic appears to be waiting in the wings of our deepening understanding of the quantum vacuum in which we live.

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NEXT DOCUMENT

Quantum Optical Studies of Tunneling Times and Superluminality

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Abstract

Experiments at Berkeley and elsewhere which show that the process of tunneling is apparently superluminal will be reviewed. Conflicting theories for the tunneling time will be compared with experiment. The tunneling particle in the Berkeley experiment was the photon. The measurement of the tunneling time utilized a two-photon light source (spontaneous parametric down-conversion), a Hong-Ou-Mandel interferometer, and a coincidence counter of photon pairs. The tunnel barrier consisted of a photonic-bandgap medium excited at midgap. We find that the peak of the tunneling wave packet appeared on the far side of the barrier 1.47 ± 0.21 fs *earlier* than the peak of a wave packet which traveled an equal distance in air. However, Einstein causality is not violated.

Introduction

Tunneling, the quantum mechanical process by which a particle can penetrate a classically forbidden region of space, may appear to be well understood. The probability for a particle to penetrate a tunnel barrier is calculated in elementary textbooks on quantum mechanics. Furthermore, the tunneling process has been observed in numerous physical settings, and has been fruitfully utilized in various devices, e.g., the Esaki tunnel diode, the Josephson junction, and the scanning tunneling microscope. However, there remains an open problem concerning the time (or duration) of the tunneling process, which is still the subject of controversy. Various theories contradict each other in their predictions for "the tunneling time." Apart from its fundamental interest, a correct solution of this problem is important for determining the speed of devices which are based on tunneling. Hence we decided to perform an experiment which used the photon as the tunneling particle to *measure* this time.

It is very important in the tunneling time problem to state precisely at the outset the *operational* definition of the quantity being measured. For the tunneling time for our experiment, this definition is based on the following *Gedankenexperiment* (see Fig. 1). Suppose that a single parent particle (a photon) decays into two daughter particles (two photons), as in a radioactive decay. Suppose further that these two daughter particles have the same speed in the vacuum (i.e., c in our case), and that they were detected by means of two detectors placed at equal distances from the point of decay. There result simultaneous clicks at the two detectors, which could then be registered in a coincidence counter. Now suppose that we place a tunnel barrier in the path of one of the daughter photons. (The other daughter photon continues to travel unimpeded through the vacuum.) Of course, this would greatly diminish the coincidence count rate. However, whenever a tunneling event does occur, the *difference* in the time of arrival of the two daughters, as measured by the
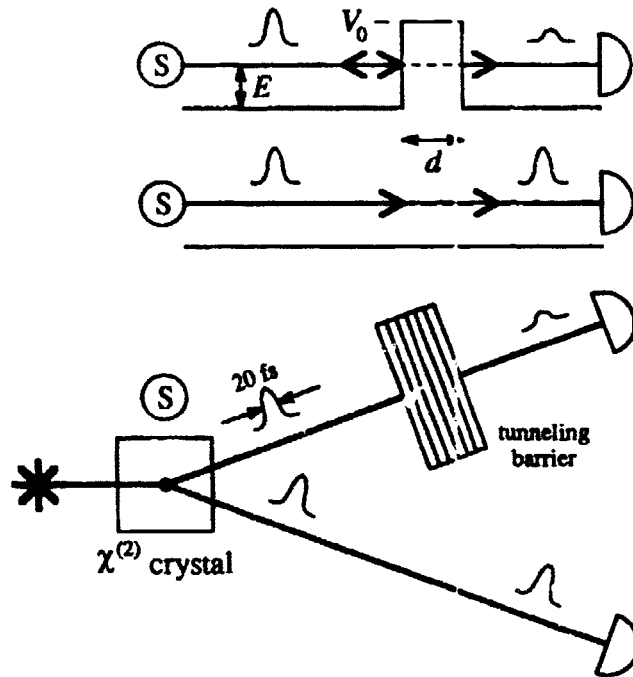
Figure 1: (Top): *Gedankenexperiment* to measure the tunneling time by means of two particles simultaneously emitted from a source S and detected by two equidistant detectors. (Bottom): Realization by a spontaneous parametric down-conversion source S, in which a parent photon decays into two daughter photons.

difference in the time of the clicks of the two detectors, constitute a precise definition for the tunneling time.

The question concerning the superluminality of the tunneling process can now also be precisely stated. Does the click of the detector which registers the arrival of the photon which traversed the tunnel barrier go off *earlier* or *later* (on the average) than the click of the detector which registers the arrival the photon which traversed the vacuum? If the tunnel barrier had simply been a thin piece of transparent glass, then the answer would obviously be "later," since the group velocity for a photon inside the glass would be *less* than the speed of light, and the group delay for the photon traversing the glass relative to that of the vacuum would be *positive*. However, if, as some tunneling-time theories predict, the tunneling process is superluminal, then the counterintuitive answer would be "earlier," since the effective group velocity for a photon inside the tunnel barrier would be *greater* than the speed of light, and the group delay for the photon traversing the barrier relative to that of the vacuum would be *negative*. Hence it is the *sign* of the relative time between the clicks in the two detectors which determines whether tunneling is subluminal or superluminal.

Presently, the best detectors for photons have picosecond-scale response times, which are still not fast enough to detect the femtosecond-scale time differences expected in our tunneling-time experiment. Hence it was necessary to utilize a Hong-Ou-Mandel interferometer, which has a femtosecond-scale temporal resolution for measuring the time difference between the travel times of the two photons traversing the two arms of the interferometer. By placing the tunnel barrier in one of these arms, a precise measurement of the delay due to tunneling could then be performed.

The barrier used in our experiment was a dielectric mirror in which periodic layers of alternately high and

low index media produce a photonic band gap at the first Brillouin zone edge. The problem of photon propagation in this periodic structure is analogous to that of the Kronig-Penney model for electrons propagating inside a crystal. In particular, near the midgap point on the first Brillouin zone edge, there exists due to Bragg reflection inside the periodic structure an evanescent (i.e., exponential) decay of the transmitted wave amplitude, which is equivalent to tunneling. One important feature of this kind of tunnel barrier is the fact that it is nondispersive near midgap, and therefore there is little distortion of the tunneling wave packet.

The reader may ask why Einstein causality is not violated by the superluminality of tunneling. It has been shown that this superluminal behavior is not forbidden by special relativity, since it is permissible for the group velocity to be faster than c, so long as Sommerfeld's front velocity remains exactly c, as is the case. For details, the reader is referred to Chiao and Steinberg [1997].

Tunneling Time Theories

Another strong motivation for performing experiments to measure the tunneling time was the fact that there were many conflicting theories for this time (see the reviews by Hauge and Stovneng [1989] and by Landauer and Martin [1994]). It suffices here to list the three main contenders:

(1) The Wigner time (i.e., "phase time" or "group delay").

(2) The Büttiker-Landauer time (i.e., "semiclassical time").

(3) The Larmor time (with Büttiker's modification).

The Wigner time calculates how long it takes for the peak of a wave packet to emerge from the exit face of the tunnel barrier relative to the time the peak of the incident wave packet arrives at the entrance face. Since the peak of the wave packet in the Born interpretation is the point of highest probability for a click to occur (see the above *Gedankenexperiment*), it is natural to expect this to be the relevant time for our experiment. This calculation is based on an asymptotic treatment of tunneling as a scattering problem, and utilizes the method of stationary phase to calculate the position of the peak of a wave packet. The result is simple: this tunneling time is the derivative of the phase of the tunneling amplitude with respect to the energy of the particle.

The Büttiker-Landauer time is based on a different *Gedankenexperiment*. Suppose that the height of the tunnel barrier is perturbed sinusoidally in time. If the frequency of the perturbation is very low, the tunneling particle will see the instantaneous height of the barrier, and the transmission probability will adiabatically follow the perturbation. However, as one increases the frequency of the perturbation, at some characteristic frequency the tunneling probability will no longer be able to adiabatically follow the rapidly varying perturbation. It is natural to define the tunneling time as the inverse of this characteristic frequency. The result is again simple: for opaque barriers, this tunneling time is the distance traversed by the particle (i.e., the barrier width d) divided by the absolute value of the velocity of the particle $|v|$. (In the classically forbidden region of the barrier, this velocity is imaginary, but its characteristic size is given by the absolute value).

The Larmor time is based on yet another *Gedankenexperiment*. Suppose that the tunneling particle had a

spin magnetic moment (e.g., the electron) Suppose further that a magnetic field were applied to region of the barrier, but only to that region. Then the angle of precession of the spin of the tunneling particle is a natural measure of the tunneling time. However, Büttiker noticed that in addition to this Larmor precession effect, there is a considerable tendency for the spin to align itself either along or against the direction of the magnetic field during tunneling, since the energy for these two spin orientations is different. The *total* angular change of the tunneling particle's spin divided by the Larmor precession frequency is Büttiker's Larmor time.

One consequence of the Wigner time is the Hartman effect, in which the tunneling time saturates for opaque barriers, and approaches a finite limiting value as d becomes large. The apparent superluminality of tunneling is a consequence of this effect, since as d is increased, there is a point beyond which the saturated value of the tunneling time is exceeded by the vacuum traversal time d/c, and the particle appears to have tunneled faster than light.

By contrast, the Büttiker-Landauer theory predicts a tunneling time which increases linearly with d for opaque barriers, as one would expect classically. For a rectangular barrier with a height $V_0 << mc^2$, the effective velocity $|v|$ is always less than c. However, for the periodic structure which we used in our experiment, the effective velocity $|v|$ at midgap is infinite, which is a behavior even more superluminal than that predicted by the Wigner time. This fact makes it easy to distinguish experimentally between these two theories of the tunneling time. However, we hasten to add that the Büttiker-Landauer time may not apply to our experimental situation, as the *Gedankenexperiment* on which it is based is quite different from the one relevant to our experiment.

Büttiker's Larmor time predicts a tunneling time which is independent of d for thin barriers, but which asymptotically approaches a linear dependence on d in the opaque barrier limit, where it coincides with the Büttiker-Landauer time. In our first experiment it was impossible to distinguish experimentally between this time and the Wigner time. Only in our second experiment could these two theories be clearly distinguished from one another.

The Berkeley Experiments

The Two-photon Light Source

Spontaneous parametric down-conversion was the light source used in our experiments (Steinberg, Kwiat, and Chiao [1993]; Steinberg and Chiao [1995]). An ultraviolet (UV) beam from an argon laser operating at a wavelength of 351 nm was incident on a crystal of potassium dihydrogen phosphate (KDP), which was a $\chi^{(2)}$ nonlinearity. During the process of parametric down-conversion inside the crystal, a rainbow of many colors was generated in conical emissions around the ultraviolet laser beam, in which one parent UV photon broke up into two daughter photons, conserving energy and momentum. The KDP crystal was cut with an optic axis oriented so that the two degenerate (i.e., equal energy) daughter photons at a wavelength of 702 nm emerged at a small angle relative to each other. We used two pinholes to select out these two degenerate photons. The size of these pinholes determined the bandwidth of the light which passed through them, and the resulting single-photon wavepackets had temporal widths around 20 fs and a bandwidth of around 6 nm in wavelength.

The Tunnel Barrier

The tunnel barrier consisted of a dielectric mirror with eleven quarter-wavelength layers of alternately high index material (titanium oxide with $n = 2.22$) and low index material (fused silica with $n = 1.45$). The total thickness of the eleven layers was 1.1 μm. This implied an *in vacuo* traversal time across the structure of 3.6 fs. Viewed as a photonic bandgap medium, this periodic structure had a lower band edge located at a wavelength of 800 nm and an upper band edge at 600 nm. The transmission coefficient of the two photons which were tuned near midgap (700 nm) was 1%. Since the transmission had a broad minimum at midgap compared to the wave packet bandwidth, there was little pulse distortion. The Wigner theory predicted at midgap a tunneling delay time of 2 fs, or an effective tunneling velocity of $1.8c$. The Büttiker-Landauer theory predicted at midgap an infinite effective velocity, which implies a zero tunneling time.

The Hong-Ou-Mandel interferometer

To achieve the femtosecond-scale temporal resolutions necessary for measuring the tiny time delays associated with tunneling, we brought together these two photons by means of mirrors so that they impinged simultaneously at a beam splitter, before they were detected in coincidence detection. There resulted a narrow null in the coincidence count rate as a function of the relative delay between the two photons, a destructive interference effect first observed by Hong, Ou, and Mandel [1987]. The narrowness of this coincidence minimum, combined with a good signal-to-noise ratio, allowed a measurement of the relative delay between the two photons to a precision of ± 0.2 fs.

A simple way to understand this two-photon interference is to apply Feynman's rules for the interference of indistinguishable processes. Consider two photons impinging simultaneously on a 50/50 beam splitter followed by two detectors in coincidence detection. When two simultaneous clicks occur at the two detectors, it is impossible even in principle to tell whether both photons were reflected by the beam splitter or whether both photons were transmitted through the beam splitter. In this case, Feynman's rules tell us to add the probability amplitudes for these two indistinguishable process, and then take the absolute square to find the probability. Thus the probability of a coincidence count to occur is given by $|r^2 + t^2|^2$, where r is the complex reflection amplitude for one photon to be reflected, and t is the complex transmission amplitude for one photon to be transmitted. For a lossless beam splitter, time-reversal symmetry leads to the relation $t = \pm ir$. Substituting this into the expression for the coincidence probability, and using the fact that $|r| = |t|$ for a 50/50 beam splitter, we find that this probability vanishes.

Experimental Setup and Data

A schematic of the apparatus we used to measure the tunneling time is given in Fig. 2. The delay between the two daughter photons was adjustable by means of the "trombone prism" mounted on a Burleigh inchworm system, and was measured by means of a Heidenhein encoder with a 0.1 μm resolution. A *positive* sign of the delay due to a piece of glass was determined as corresponding to a motion of the prism *towards* the glass. The multilayer coating of the dielectric mirror (i.e., the tunnel barrier) was evaporated on only half of the glass mirror substrate. This allowed us to translate the mirror so that the beam path passed either through the tunnel barrier in an actual measurement of the tunneling time, or through the uncoated half of the substrate in a control experiment. In this way, one could obtain data with and without the barrier in the
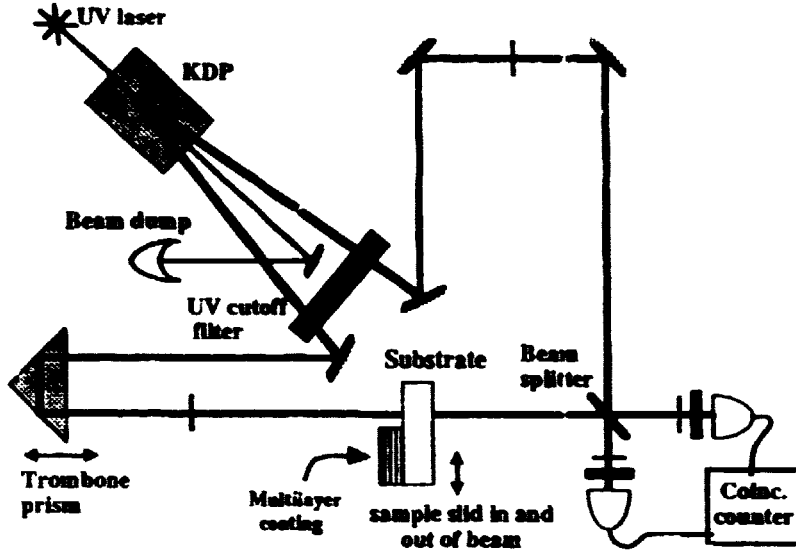
Figure 2: Schematic of the Berkeley experiments to measure the tunneling time.
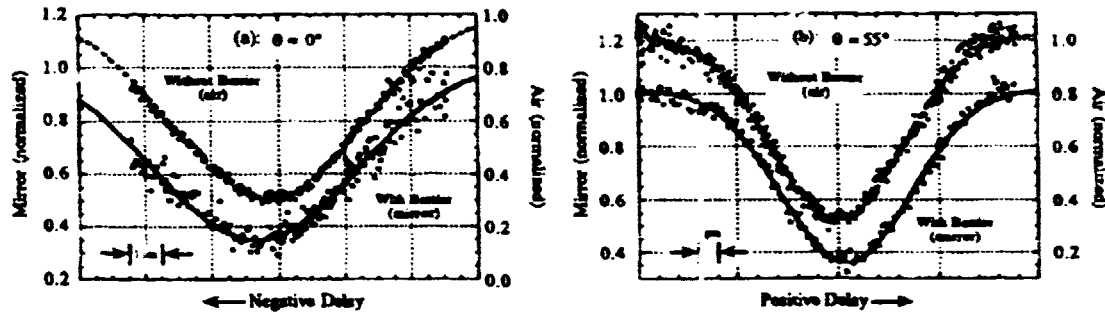
Figure 3: (a) Coincidence rate vs delay (i.e., the position of the trombone prism in Fig. 2) with and without the tunnel barrier (mirror) in the beam path at normal incidence. (b) The same with the mirror tilted towards Brewster's angle.

beam, i.e., a direct comparison between the delay through the tui neling barrier and the delay for traversing an equal distance in air. The normalized data obtained in this fashion is shown in Fig. 3(a), with the barrier oriented at normal incidence ($\theta = 0°$). Note that the coincidence minimum with the tunnel barrier in the beam is shifted to a *negative* value of delay relative to that without the barrier in the beam. This negative shift indicates that the tunneling delay is superluminal.

To double-check the sign of this shift, which is crucial for the interpretation of superluminality, we tilted the mirror towards Brewster's angle for the substrate ($\theta = 56°$) where there is a very broad minimum in the reflection coefficient as a function of angle. Near Brewster's angle this minimum is so broad that it is not very sensitive to the difference between the high and low indices of the successive layers of dielectrics. Thus to a good approximation, the reflections from all layers vanish simultaneously near this angle. Hence the Bragg reflection responsible for the band gap disappears, and the evanescent wave behavior and the tunneling behavior seen near normal incidence disappears. The dielectric mirror should then behave like a thin piece of transparent glass with a *positive* delay time relative to that of the vacuum. Detailed calculations
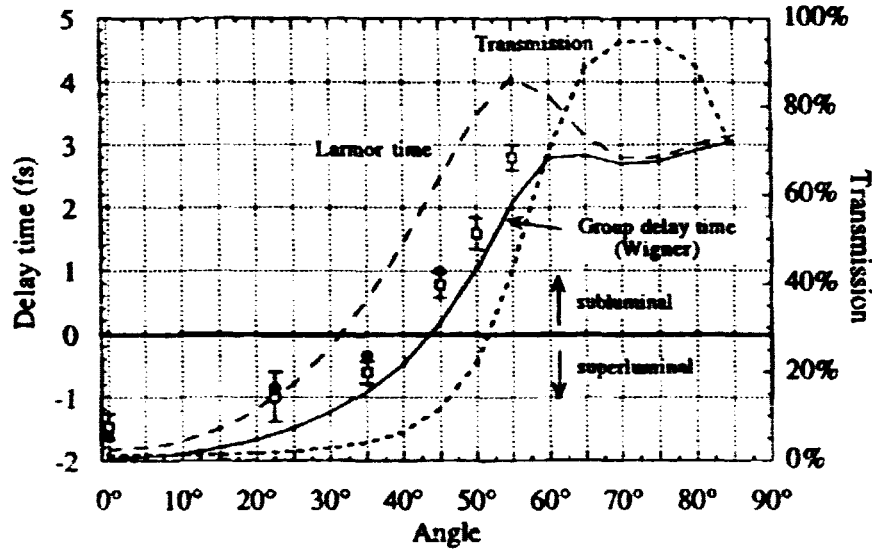
Figure 4 Temporal shifts of the minima seen in data such as in Fig. 3 plotted as a function of incidence angle, compared with the theoretical predictions of the Wigner time (solid curve) and of Büttiker's Larmor time (long-dashed curve). The transmission vs incidence angle (short-dashed line). All curves are for p-polarization.

not using the above approximations also show that at $\theta = 55°$, the sign of the shift should indeed revert to its normal positive value.

The data taken in p-polarization at $\theta = 55°$ is shown in Fig. 3(b). The reversal of the sign of the shift is clearly seen. Hence, if we had made a mistake in the sign of the shift in Fig. 3(a), so that the observed shift were actually subluminal, then the observed shift in Fig. 3(b) must be superluminal. Thus one is confronted with a choice of the data either in Fig. 3(a) or in Fig. 3(b) as showing a superluminal effect. Since we know that the delay in normal dielectrics as represened by Fig. 3(b) should be subluminal, this implies that the tunneling delay in Fig. 3(a) should be superluminal. Therefore the data in Fig. 3(a) implies that after traversing the tunnel barrier, the peak of a photon wave packet arrived 1.47 ± 0.21 fs earlier than it would had it traversed only vacuum.

Another reason for tilting the mirror is that one can thereby distinguish between the Wigner time and Büttiker's Larmor time. as they differ considerably in the region near the band edge, which occurs near Brewster's angle. This can be seen in Fig. 4, where there is a considerable divergence as the band edge is approached between the solid line representing the theoretical prediction of the Wigner time, and the long-dashed line representing that of Büttiker's Larmor time. The data points in Fig. 4 seem to rule out Büttiker's Larmor time (although again we hasten to add that this theory may not apply to our experiment). The agreement with Wigner's theory is better, but there are discrepancies which are not understood.

Other experiments confirming the superiuminality of tunneling have been performed in Cologne, Florence, and Vienna (Enders and Nimtz [1993], Ranfagni et al. [1993], Spielmann et al. [1994]). The Cologne and Florence groups performed microwave experiments, and the Vienna group performed a femtosecond laser experiment. All these groups have confirmed the Hartman effect. One of these groups (Heitmann and Nimtz

[1994]) has claimed to have sent Mozart's 40th symphony at a speed of 4.7c through a microwave tunnel barrier 114 mm long consisting of a periodic dielectric structure similar to our dielectric mirror. However, the further implication that their experiment represents a violation of causality is in our opinion unfounded (Chiao and Steinberg [1997]).

Recently, an experiment indicating the simultaneous existence of two tunneling times was performed in Rennes (Balcou and Dutriaux [1997]). In frustrated total reflection (FTIR), the tunneling of photons through an air gap occurs between two glass prisms when a light beam is incident upon this gap beyond the critical angle. The Rennes group observed in FTIR both a lateral *displacement* of the tunneling beam of light and an angular *deflection* of this beam. These two effects were interpreted as evidence for two different tunneling times that simultaneously occurred in the same tunneling barrier. The lateral displacement is related to the Wigner time, and the angular deflection is related to the Büttiker-Landauer time. As evidence for this, they cited the saturation of the beam displacement (the Hartman effect), and the linear increase of the beam deflection, as the gap was increased.

Conclusions

The experiments at Berkeley and elsewhere thus indicate that the tunneling process is superluminal. In our opinion, this does not imply that one can send a signal (i.e., information) faster than light, despite claims to the contrary by Heitmann and Nimtz [1994]. The group velocity cannot be identified as the signal velocity of special relativity by which a cause can be connected to its effect. Rather, it is Sommerfeld's front velocity which exclusively plays this role, and we believe that it is this latter velocity which should be identified as the true signal velocity (Chiao and Steinberg [1997]).

Although the controversies amongst the various tunneling theories have not yet been fully resolved by experiment, a good beginning has been made in this direction. In particular, it is now clear that one cannot rule out the Wigner time simply on the grounds that it yields a superluminal tunneling time. It also appears that there may be more than one tunneling time, and that different experiments with different operational definitions of this time may lead to different results. Hopefully, the role of time in quantum mechanics will be further elucidated by these studies.

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Quantum Nonlocality and the Possibility of Superluminal Effects

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ABSTRACT:

EPR experiments demonstrate that standard quantum mechanics exhibits the property of *nonlocality*, the enforcement of correlations between separated parts of an entangled quantum systems across spacelike separations. Nonlocality will be clarified using the transactional interpretation of quantum mechanics and the possibility of superluminal effects (e.g., faster-than-light communication) from nonlocality and non-linear quantum mechanics will be examined.

1. BELL'S THEOREM AND QUANTUM NONLOCALITY

Albert Einstein disliked quantum mechanics, as developed by Heisenberg, Schrödinger, Dirac, and others, because it had many strange features that ran head-on into Einstein's finely honed intuition and understanding of how a proper universe ought to operate. Over the years he developed a list of objections to the various peculiarities of quantum mechanics. At the top of Einstein's list of complaints was what he called "spooky actions at a distance". Einstein's "spookiness" is now called *nonlocality*, the mysterious ability of Nature to enforce correlations between separated but entangled parts of a quantum system that are out of speed-of-light contact, to reach faster-than-light across vast spatial distances or even across time itself to ensure that the parts of a quantum system are made to match. To be more specific, *locality* means that isolated parts of any quantum mechanical system out of speed-of-light contact with other parts of that system are allowed to retain definite relationships or correlations only through memory of previous contact. *Nonlocality* means that in quantum systems correlations not possible through simple memory are somehow being enforced faster-than-light across space and time. Nonlocality, peculiar though it is, is a fact of quantum systems which has been repeatedly demonstrated in laboratory experiments.

In 1935 Einstein, with his collaborators Boris Podolsky and Nathan Rosen, published a list of objections to quantum mechanics which has come to be known as "the EPR paper" [1], in which they lodged three complaints against quantum mechanics, one of which was *nonlocality*. The EPR paper argued that "no real change" could take place in one system as a result of a measurement performed on a distant second system, as quantum mechanics requires.

A decades-long uproar in the physics literature followed the publication of the EPR paper. The founders of quantum mechanics tried to come to grips with the EPR criticisms, and a long inconclusive battle ensued. EPR supporter David Bohm introduced the notion of a "local hidden variable" theory, a partially reformulated alternative to orthodox quantum mechanics that would replace quantum mechanics with a theoretical structure omitting the paradoxical features to which the EPR paper had objected. In Bohm's hidden-variable alternative, all correlation were established locally at sub-light speed.

Working physicists, however, paid little attention to hidden variable theories. Bohm's approach was far less useful than orthodox quantum mechanics for calculating the behavior of physical systems.

Since it was apparently impossible to resolve the EPR/hidden-variable debate by performing an experiment, physicists tended to ignore the whole controversy. The EPR objections were considered problems for philosophers and mystics, not Real Physicists.

In 1964 this perception changed. John S. Bell, a theoretical physicist working at the CERN laboratory in Geneva, proved an amazing theorem which demonstrated that certain experimental tests could distinguish the predictions of quantum mechanics from those of any local hidden-variable theory [2,3]. Bell, following the lead of Bohm, had based his calculations not on measurements of position and momentum, the focus of Einstein's arguments, but on measurements of the states of polarization of photons of light.

Excited atoms often produce two photons in a process called a "cascade" involving two successive quantum jumps. Because of angular momentum conservation, if the atom begins and ends with no net angular momentum, the two photons must have correlated polarizations. When such photons travel in opposite directions, angular momentum conservation requires that if one of the photons is measured to have some definite polarization state, the other photon is required by quantum mechanics to have *exactly* the same polarization state, no matter what measurement is made. Such correlated photon pairs are said to be in an "entangled" quantum states. Experimental tests of Bell's theorem, often called "EPR experiments", usually use entangled photons from such an atomic cascade.

EPR experiments measure the coincident arrival of two such photons at opposite ends of the apparatus, as detected by quantum-sensitive photomultiplier tubes after each photon has passed through a polarizing filter or splitter. The photomultipliers at opposite ends of the apparatus produce electrical pulses which, when they occur at the same time, are recorded as a "coincidence" or two photon event. The rate $R(\theta)$ of such coincident events is measured when the two polarization axes are oriented so as to make a relative angle of θ. Then θ is changed and the rate measurement is repeated until a complete map of $R(\theta)$ vs. θ is developed.

Bell's theorem deals with the way in which the coincidence rate $R(\theta)$ of an EPR experiment changes as θ starts from zero and becomes progressively larger. Bell proved mathematically that for all local hidden-variable theories $R(\theta)$ must decrease linearly (or less) as θ increases, i.e., the fastest possible decrease in $R(\theta)$ is proportional to θ. On the other hand quantum mechanics predicts that the coincidence rate is $R(\theta) = R(0) \cos^2(\theta)$, so that for small θ it will decrease roughly as θ^2. Therefore, quantum mechanics and Bell's Theorem make qualitatively different predictions about EPR measurements.

When two theories make such distinctly different predictions about the outcome of the same experiment, a measurement can be performed to test them. For quantum mechanics and Bell's theorem this crucial EPR experiment was performed first in 1972 by Freedman and Clauser[4], who demonstrated a 6σ (six standard deviation) violation of Bell's inequality. A decade later the Aspect group in France performed a series of elegant "loophole closing" experiments that demonstrated 46σ violations of Bell's inequality [5,6]. In these experiments the predictions of quantum mechanics were always confirmed, and very significant violations of the Bell Inequalities are demonstrated.

When the first experimental results from EPR experiments became available, they were widely interpreted as a demonstration that hidden variable theories must be wrong. This interpretation changed when it was realized that Bell's theorem assumed a *local* hidden variable theory, and that *nonlocal* hidden variable theories can also be constructed that violate Bell's theorem and agree with the experimental measurements. The assumption made by Bell that had been put to the test, therefore, was the assumption of *locality*, not the assumption of hidden variables. Locality, as promoted by Einstein, was found to be in conflict with experiment.

Or to put it another way, the intrinsic nonlocality of quantum mechanics has been demonstrated by the experimental tests of Bell's theorem. It has been experimentally demonstrated that nature arranges

the correlations between the polarization of the two photons by some faster-than-light mechanism that violates Einstein's intuitions about the intrinsic locality of all natural processes. What Einstein called "spooky actions at a distance" are an important part of the way nature works at the quantum level. Einstein's faster-than-light spooks cannot be ignored.

A clarification about the nature of nonlocality is perhaps appropriate here. Locality in the form of memory could explain the correlation of photon polarizations for any one choice of measurements, e.g., vertical vs. horizontal polarization. It is the freedom of the observer to measure using many different polarization axes (or even circular rather than linear polarization) that leads to the need for nonlocality. To put it another way, if you were constructing a classical science-museum simulation of an EPR experiment (not using actual photons), you would need signal wires running from each measurement to the other to make the simulation operate as quantum mechanics does. Nature seems to have such wires, but we are not allowed to use them.

2. NONLOCALITY AND THE TRANSACTIONAL INTERPRETATION OF QUANTUM MECHANICS

Quantum mechanics (QM) was invented in the late 1920's when an embarrassing body of new experimental facts from the microscopic world couldn't be explained by the accepted physics of the period. Heisenberg, Schrödinger, Dirac, and others used a remarkable combination of intuition and brilliance to devise clever ways of "getting the right answer" from a set of arcane mathematical procedures. They somehow accomplished this without understanding in any basic way what their mathematics really meant. The mathematical formalism of quantum mechanics is now trusted by all physicists, its use clear and unambiguous. But even now, six decades later, its meaning remains controversial.

The part of the theory that gives meaning to the mathematical formalism is called the *interpretation*. For quantum mechanics there are several competing interpretations, with no general consensus as to which should be used. The orthodox interpretation of quantum mechanics used (sparingly) in most physics textbooks was developed primarily by Bohr and Heisenberg and is called *the Copenhagen interpretation* (CI). It takes a "don't ask -- don't tell" approach to the formalism which focuses exclusively on the outcomes of physical measurements and which forbids the practitioner from asking questions about possible underlying mechanisms that produce the observed effects.

The nonlocality of the quantum mechanics formalism is a source of some difficulty for the Copenhagen interpretation. It is accommodated in the CI through Heisenberg's "knowledge interpretation" which views the quantum mechanical state vector (ψ) as a mathematically-encoded description of the state of observer knowledge rather than as a description of the objective state of the system observed. For example, in 1960 Heisenberg wrote, *"The act of recording, on the other hand, which leads to the reduction of the state, is not a physical, but rather, so to say, a mathematical process. With the sudden change of our knowledge also the mathematical presentation of our knowledge undergoes of course a sudden change."* The knowledge interpretation's account of state vector collapse and nonlocality as changes in knowledge is internally consistent, but it is rather subjective, intellectually unappealing, and the source of much of the recent misuse of the Copenhagen interpretation (e.g., "observer-created reality").

An more objective alternative interpretation of the quantum mechanics formalism is the *transactional interpretation* (TI) proposed a decade go by the author. A reprint of the original paper[7,8] can be found on the web at *http://www.npl.washington.edu/ti.*

The transactional interpretation, a leading alternative to the Copenhagen interpretation, uses an explicitly nonlocal transaction model to account for quantum events. This model describes any quantum event as a space-time "handshake" executed through an exchange of retarded waves (ψ) and advanced waves ($\psi*$) as symbolized in the quantum formalism. It is generalized from the time symmetric Lorentz-

Dirac electrodynamics introduced by Dirac and on "absorber theory" as originated by Wheeler and Feynman[9,10]. Absorber theory leads to exactly the same predictions as conventional electrodynamics, but it differs from the latter in that it employs a two-way exchange, a "handshake" between advanced and retarded waves across space-time leading to the expected transport of energy and momentum.
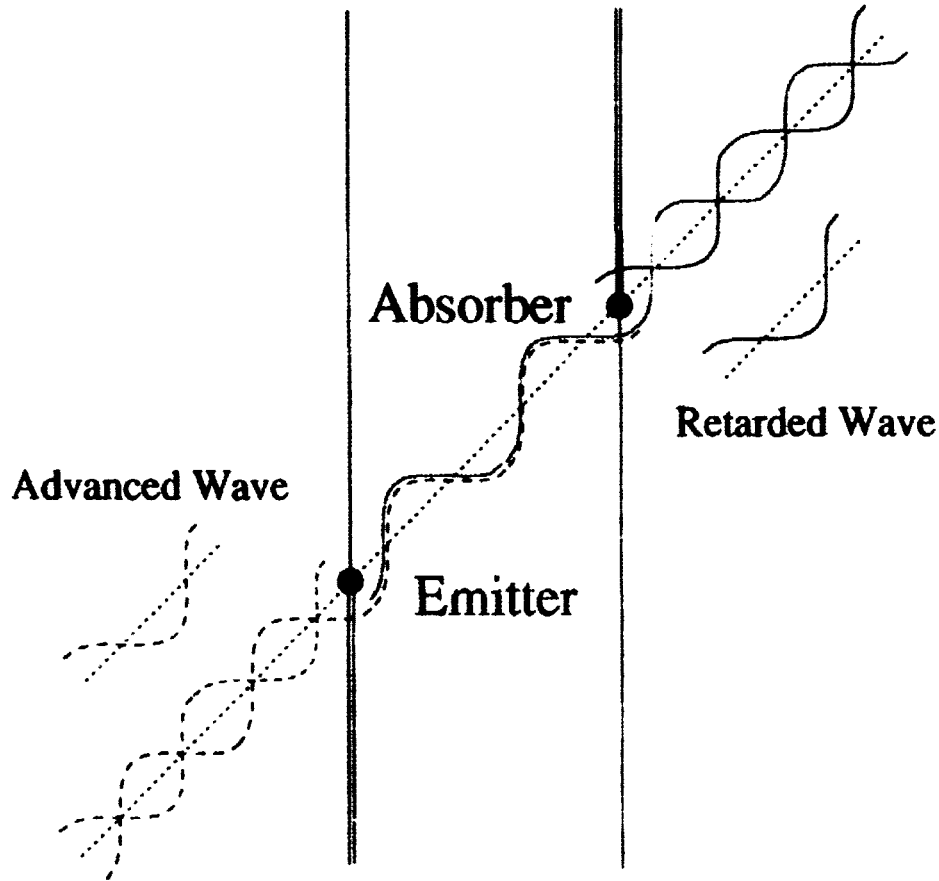
Fig. 1 Schematic of an advanced-retarded transaction

This advanced-retarded handshake, illustrated schematically in Fig. 1, is the basis for the transactional interpretation of quantum mechanics. It is a two-way contract between the future and the past for the purpose of transferring energy, momentum, etc, while observing all of the conservation laws and quantization conditions imposed at the emitter/absorber terminating "boundaries" of the transaction. The transaction is explicitly nonlocal because the future is, in a limited way, affecting the past (at the level of enforcing correlations).

To accept the Copenhagen interpretation one must accept the intrinsic positivism of the approach and its interpretation of solutions of a simple second-order differential equation combining momentum, mass, and energy as a mathematical description of the knowledge of an observer. Similarly, to accept the transactional interpretation it is necessary to accept the use of ad anced solutions of wave equations for retroactive confirmation of quantum event transactions, which smacks of backwards causality. No interpretation of quantum mechanics comes without conceptual baggage that some find unacceptable.

With the advanced waves employed in the transactional interpretation it is easy to account for nonlocal effects. Fig. 2 shows a transactional diagram of an EPR experiment, which in the TI involves twin handshakes between both measurements (D_1 and D_2) and the source (SO). The two-link transaction can only satisfy energy, momentum, and angular momentum conservation laws if the measurement outcomes at D_1 and D_2 match when the same measurement is made. Thus, the correlation between measurement outcomes is enforced, not across a spacelike interval, but across negative ($\psi*$) and positive (ψ) lightlike intervals (if the EPR experiment uses photons). Therefore, the nonlocality of quantum mechanics is readily accounted for by the transactional interpretation.
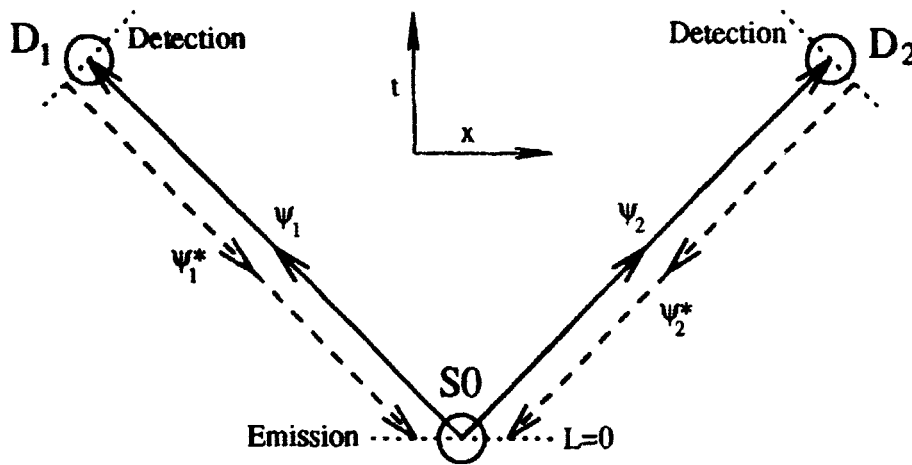
Fig. 2 Transactional diagram of an EPR experiment.

From one perspective the advanced-retarded wave combinations used in the transactional description of quantum behavior are quite apparent in the Schrödinger-Dirac formalism itself, so much so as to be almost painfully obvious. Wigner's time reversal operator is, after all, just the operation of complex conjugation, and the complex conjugate of a retarded wave is an advanced wave. What else, one might legitimately ask, could the ubiquitous $\psi*$ notations of the quantum wave mechanics formalism possibly denote except that the time reversed (or advanced) counterparts of normal (or retarded) ψ wave functions are playing an important role in a quantum event? What could an overlap integral combining y with $\psi*$ represent other than the probability of a transaction through an exchange of advanced and retarded waves? At minimum it should be clear that the transactional interpretation is not a clumsy appendage gratuitously grafted onto the formalism of quantum mechanics but rather a description which, after one learns the key to the language, is found to be graphically represented within the quantum wave mechanics formalism itself.

Can quantum nonlocality be used for faster-than-light or backward-in-time communication? Perhaps, for example, a message could be telegraphed from one measurement site of the EPR experiment to the other through a judicious choice of which measurement was performed. The simple answer to this question is "No!". Eberhard has used the standard formalism of quantum mechanics to prove a theorem demonstrating the impossibility of such nonlocal superluminal communication [11,12]. Briefly, the quantum operators characterizing the separated measurements always commute, no matter which measurement is chosen, so non-local information transfer is impossible. Nature's superluminal telegraph cannot be diverted to mundane human purposes.

3. NONLINEAR QUANTUM MECHANICS
AND SUPERLUMINAL LOOPHOLES

This prohibition against superluminal communication, as stated above, is a part of standard quantum mechanics. However, this prohibition is broken if quantum mechanics is allowed to be slightly "non-linear", a technical term meaning that when quantum waves are superimposed they may generate a small cross-term not present in the standard formalism. Steven Weinberg, Nobel laureate for his theoretical work in unifying the electromagnetic and weak interactions, investigated a theory which introduces small non-linear corrections to standard quantum mechanics [13]. The onset of non-linear behavior is seen in other areas of physics, e.g., laser light in certain media, and, he suggested, might also be present but unnoticed in quantum mechanics. Weinberg's non-linear QM subtly alters certain properties of the standard theory, producing new physical effects that can be detected through precise measurements.

Two years after Weinberg's non-linear QM theory was published, Joseph Polchinski published a paper demonstrating that Weinberg's non-linear corrections upset the balance in quantum mechanics that prevents superluminal communication using EPR experiments [14]. Through the new non-linear effects, separate measurements on the same quantum system begin to "talk" to each other and faster-than-light and/or backward-in-time signaling becomes possible. Polchinski describes such an arrangement as an "EPR telephone".

The Weinberg/Polchinski work had implications that are devastating for the Copenhagen representation of the wave function as "observer knowledge". Polchinski has shown that a tiny non-linear modification transforms the "hidden" nonlocality of the standard QM formalism into a manifest property that can be used for nonlocal observer-to-observer communication. This is completely inconsistent with the Copenhagen "knowledge" interpretation.

Thus, the Copenhagen interpretation is not "robust" because it is inconsistent with a tiny modification of the standard formalism. The transactional interpretation, on the other hand, can easily accommodate this modification of the formalism and is robust enough to be tested and verified (or falsified) by the same effect. If quantum mechanics has any detectable nonlinearity, we get a faster-than-light and backwards-in-time telephone.

But *is* quantum mechanics non-linear? Atomic physics experiments have been used by several experimental groups to test Weinberg's non-linear theory. So far, these tests have all been negative, indicating that any non-linearities in the quantum formalism are extremely small, if they exist at all. These negative results are not surprising, however, because the atomic transitions used involve only a few electron-volts of energy. If quantum mechanics does have non-linear properties, they would expected to depend on energy and to appear only at a very high energy scale and particularly at the highest energy densities. Weinberg-Polchinski tests should be made, if possible, with the highest energy particle accelerators. Perhaps then we can find out what connections might be made with Polchinski's EPR telephone.

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NEXT DOCUMENT

Granular Superconductors and Gravity

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35812

As a Bose condensate, superconductors provide novel conditions for revisiting previously proposed couplings between electromagnetism and gravity. Strong variations in Cooper pair density, large conductivity and low magnetic permeability define superconductive and degenerate condensates without the traditional density limits imposed by the Fermi energy ($\sim 10^{-6}$ g cm^3). Recent experiments have reported anomalous weight loss for a test mass suspended above a rotating Type II, YBCO superconductor, with a relatively high percentage change (0.05-2.1%) independent of the test mass' chemical composition and diamagnetic properties. A variation of 5 parts per 10^4 was reported above a stationary (non-rotating) superconductor. In experiments using a sensitive gravimeter, bulk YBCO superconductors were stably levitated in a DC magnetic field and exposed without levitation to low-field strength AC magnetic fields. Changes in observed gravity signals were measured to be less than 2 parts in 10^8 of the normal gravitational acceleration. Given the high sensitivity of the test, future work will examine variants on the basic magnetic behavior of granular superconductors, with particular focus on quantifying their proposed importance to gravity.

Extending the early experiments on gravity and electromagnetic effects by Faraday [1] and Blackett [2], Forward [3] first proposed unique gravitational tests for superconductors in an electromagnetic field: "Since the magnetic moment and the inertial moment are combined in an atom, it may be possible to use this property to convert time-varying electromagnetic fields into time-varying gravitational fields."

Recent experiments [4-5] have reported that for a variety of different test masses, a Type-II, high temperature (YBCO) superconductor induces anomalous weight effects (0.05-2% loss). A single-phase, dense bulk superconducting ceramic of $YBa_2Cu_3O_{7-d}$ was helu at temperatures below 60 K, levitated over a toroidal solenoid, and induced into rotation using coils with rotating magnetic fields. This phenomenon has no explanation in the standard gravity theories.

Without superconductor rotation, a weight loss of 0.05% was reported, a relatively large value which has been attributed to buoyancy corrections [6] or air currents [7] until further details of the experiment elaborated upon measurements in closed glass tubes encased in a stainless steel box. Three theoretical explanations have been put forward to account for a possible gravitational cause: shielding [4], absorption via coupling to a Bose condensate [5, 8] and a gravito-magnetic force [9-11]. The symmetry requirements of each explanation are different, as are the need for magnetic fields or superconductor rotation; most notably an absorption mechanism (based on an instability in the quadratic part of the Euclidean gravitational action in the presence of a Bose condensate [5,8]) may not require an external EM field (except to generate density fluctuation in the Cooper pairs), while gravitomagnetic effects in the ion lattice [9-11] depend on a time-varying gravito-magnetic potential, $\partial A_g / \partial t$. Careful experiments must identify and isolate the relative importance of thermal, magnetic, and any gravitational components.

Superconducting Disk

To achieve large area superconductors, two configurations were employed. A

bulk, melt-textured YBCO disk (10 cm diameter, 1.25 cm height) was used with mostly square-like multidomains [12] with sizes up to 5 mm^2. The disk levitated 2-6 cm above a cylindrically symmetric, permanent magnet ($<B>=0.52$ T) with one central south pole and four peripheral north poles. Both the vertical and horizontal inhomogeneity of the magnetic field pins magnetic flux lines in the superconductor, damps oscillations and levitates rigidly within a continuous range of possible stable positions and orientations. A second set of 4 parallel pole AC magnets (B=600 Gauss; characteristic oscillation time of 0.75 s) did not levitate (but induced AC resistive losses in) the superconductor. Thus gravitational results were reported for both DC and low field strength AC effects on bulk YBCO superconductors.

Melt-texturing [see e.g. 13] was based on solidification of the Y-123 phase through the peritectic temperature (1020 C in air) following the reaction

$$Y_2BaCuO_5 + liquid\ phase \rightarrow YBa_2Cu_3O_x.$$
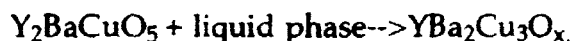
The second configuration introduced a compatible base dimension (15 cm x 20 cm) comparable to the actual footprint of the gravity measurement. An array of 48 single-domain YBCO hexagons (2.03 cm x 0.63 cm thick) was machined with a central hole and fabricated into a network. The surface of the hexagonal samples were examined using SEM (Fig. 1). To maximize the levitation force, the single domain hexagons showed high critical current densities (10^4 A/cm2 at 77K in a 1 T field) and when field cooled, a maximum trapped field of over 0.4 T in the presence of a 2 T applied field [13]. The hexagons were melt-processed using a top-seeded technique and nucleated at the surface of a flat $Nd_{1+x}Ba_{2-x}Cu_3O_y$ single crystal and epitaxially grown with a favorable temperature gradient. Diminishing gains in levitation force are observed for thicknesses >0.5 cm. Microcracks [14] from over 70 thermal cyclings introduce <3% variation in the levitation force F, where above the first critical field, H_{c1}, the force F otherwise depends on processing technique, a geometric factor, A, the critical current density, J, and the size of the shielding current loop, r, as:

$$F = \int A\ J\ r\ grad\ H\ dV \qquad\qquad (1).$$

Further increases in the repulsive force, F, depend on increasing J or r.

Instrumentation

Magnetic flux density was measured to 2 T with a Hall effect device unidirectionally over a sensing area of 0.093 cm^2. Gravity was computer-monitored using a modified LaCoste-Romberg gravimeter [15]. The instrument reports very small changes in the gravitational force acting on a mechanical spring-mass. Gravitational changes are expressed as the electrical force (measured as voltage) required to maintain the spring-mass system at a predetermined position (the null point). The dimensions of the gravimeter's base were 38 cm x 26 cm, with instrumental resolution in the variation of gravity of one part per 10 billion (resolution, 10^{-7} cm s^{-2}; repeatability, 10^{-6} cm s^{-2}; average operating conditions, >5x10^{-6} cm s^{-2}). The observed gravity value includes tidal corrections varying with time and location (measured on 8-satellite GPS [15], where an error of one mile [one minute of latitude or longitude] or equivalently one minute in time will cause an error of 1 μGal (10^{-6} cm s^{-2}) in the tidal correction). Approximately 1 μGal of error results from a 9 arc second leveling error, which is automatically calculated and off-level corrections are included in the final value The instrument's range is 5 x10^{-3} cm s^{-2} without resetting the counter, which would correspond in the present experiments to full scale readings for less than one part per million variation in gravity [16]. Instantaneous gravity was recorded at 1 s intervals and displayed with a variable averaging time interval of 1-15 s. Calibration was done using the USAF Gravity Reference Disk for a local absolute measurement, then relative tests were conducted: 1) height variation (1 m) of the gravimeter altitude (~300 microGal/m); 2) uncorrected and corrected tidal measurements over 12 hours; 3) thermal constancy for internal instruments (+<0.3 C) during a 20 C external temperature variation. The results of these three calibration steps are shown in Fig. 2.

Vibration, buoyancy and thermal isolation

The mass-spring system is insensitive to longitudinal and transverse vibration and the instrument was placed on large concrete blocks to isolate the

vertical direction from background disturbances. The instrument box is sealed from outside air to avoid any small apparent change in the buoyancy of the mass and beam with air pressure; in the event of leakage, a buoyancy compensator is added as counterweight to the balance arm and its mass/volume ratio removes 98% of any change in atmospheric pressure should the sensor enclosure leak. The gravimeter is temperature compensated with a thermistor heating circuit at 53.7 C; the box itself is thermostated externally and internally. When placed 5 inches above a 1 liter straight-walled dewar of boiling liquid nitrogen (77K), thermal variations were monitored at <0.05 C for internal temperature and <0.70 C for external temperature in the course of 0.8 hours.

Magnetic isolation

To maintain relative magnetic isolation, few ferrous metal parts are used. The meter is demagnetized, then installed in a double μ metal shield (magnetic saturation >0.75 T). In some measurements, a 1.3 cm thick iron plate (1 m x 1 m) was used as a base plate separating the gravimeter from the magnet and superconductor; iron's high magnetic permeability diverts or shunts the magnetic flux. Measured flux reductions at the instrument were approximately 1/10 the unshielded value for 0.5 T permanent magnets. Without magnetic leakage, the nearly quadratic decay of a DC magnetic field was also accounted for using spatial isolation.

Geometric Constraints

Magnetic levitation forces depend on the magnet and superconductor geometry, as does the apparent lack of a height dependence for observations of changes in the gravitational force above a superconductor [4-5]. Above the permanent (0.4-0.5 T) magnets, the flux intensity decays quadratically to a value of 50-120 Gauss at the gravimeter when leveled 23 cm above the magnet and 18 cm above the YBCO disk or array. The superconductor was either field cooled (FC tc 77 K using liquid N_2) in contact with the magnets (flux-trapping) or zero field cooled (ZFC or flux excluding) and then stably levitated in a foam walled cryostat to an average height of 2-6 cm.

For both FC and ZFC superconductors, a reductive protocol [17] can separate the thermal, magnetic, and superconductive contributions, while the gravimeter remains stationary and a wheeled platform is moved beneath it. This protocol has the additional feature of excluding eddy currents from influencing the gravity measurement, since the magnetic field is not AC over the relevant time scale. The magnitudes of the various contributions to an apparent gravity change are summarized succintly below.

As indicated in Figure 3, vibration is measured with an empty platform moved underneath the gravimeter (<1-3×10^{-6} cm s^{-2}); cryogenic contributions to instrument drift are measured with an open cryostat of boiling liquid nitrogen moved underneath the gravimeter (15 cm below the baseplate, $<2\times10^{-6}$ cm s^{-2}); magnetic contributions are measured with the magnets alone moved underneath the gravimeter ($<6\times10^{-6}$ cm s^{-2}); cryogenic YBCC superconductor contributions are measured with a zero field cooled disk moved underneath the gravimeter in the absence of any magnetic effects ($<2\times10^{-6}$ cm s^{-2}); and finally the static (non-rotating) but magnetically pinned superconductor contributions are measured with both the zero field cooled and field cooled disk or array moved underneath the gravimeter (<2-5×10^{-6} cm s^{-2}). When measured multiple times, the effects of each contribution are seen as a series of step functions with a repeatable offset which constrains its relative importance. Using a similar protocol measured AC effects using the parallel pole magnets showed a similar but smaller influence (Fig. 4).

Discussion

Error Analysis

Error analysis is critical to this experiment. The reports from Podkletnov range from a 0.05% to 2% peak weight loss. For their 5.48 g silicon dioxide test mass, these values correspond in absolute values to 2.74 to 109.6 mg. These values are large relative to traditional gravity experiments, which have reported no gravity shielding to one part in 10 billion for a variety of materials. For comparison, a standard level, electronic toploading balance has specifications of: repeatability, ≤0.5

mg; linearity $<\pm 2$ mg; temperature drift sensitivity 3ppm/C; and readability to 1 mg. Built-in vibration damping and a draft shield enhance repeatability to nearly an order of magnitude below the level required to see the lowest weight loss (2.74) on Podkletnov's original test mass. Since the effects are reported as the same order of magnitude for different masses and materials, even more massive samples can bring a laboratory scale test of gravity into the unconventional, but accessible realm of a low-cost balance. Environmental compensation for electromagnetic and temperature effects are a prerequisite however for reporting meaningful results.

Summary of Effects and Explanations

Probable

Unidentified electromagnetic interaction

1. Pinned flux lines rotating with the disc coupled to small diamagnetism in the weight (control: direct independent measurement and error limits for 110 mg weight loss)

2. Electromagnetic effects on an electro-optic balance (control: sensitive torsion pendulum or gravitometer)

3. Radio-frequency effects on unshielded weight (although in one experiment, the measured weight loss persists in the absence of R-F fields)

Unidentified interactions between gravity and superconductors

1. Quantum gravity (Modanese, Max Planck Institute, 1996)

2. Generalized Meissner effect in moving superconductor (Schiff and Barnhill (1966); DeWitt (1966); Li; Torr; Peng, UAH ,1988, 1990, 1991, 1992,1993)

3. Dense, degenerate matter (Bose-Einstein condensate inside superconductor, Forward, 1963)

More Mundane

1. Air currents due to enclosed cryogenic temperature differences (control: vacuum)

2. Drags and convective effects from rotation affecting the sample on the balance (control: disk balance and vacuum)

Any apparent gravitational contribution of the superconductor can be derived by subtracting the contribution of the magnet and superconductor together from the magnet alone; however, since the relative gravimeter responds (weakly, <2-5×10^{-6} cm s^{-2}) to the magnetic field, the uniquely superconductive contribution must combine any gravitational effect with the diamagnetic shielding of the magnets by the YBCO superconductor itself (~20-90% shielding of the field depending on hysteresis during cooling and magnetization). In any case, the maximum

contribution to a change in gravity of a static superconductor in a constant magnetic field was measured as less than 2 parts in 10^8 of the normal gravitational acceleration.

This measurement extends an approximately 4-5 order of magnitude improvement over that previously obtained with the use of an opto-electronic balance [4-5] instrumented without either thermal or magnetic compensation.

An important question remains unreso ved, namely whether any small magnitude of gravity variation has a theoretical explanation. Among the three possible theories (shielding, absorption, or gravitomagnetic counterforces), these results are more relevant to an absorption mechanism based on local density fluctuations. This interpretation is not particularly sensitive to the magnetic field configurations, which the experiments reported here are not optimized to probe. It is an open question whether the fluctuations of carrier density in superconductors at transition, would be sufficient to perturb any gravitational coupling and thus induce a signal. Regardless of the relative orders of magnitude, a coupling term (quadratic) to Euclidean gravity based on the Bose condensate and radial absorption does not necessarily require either rotation or a magnetic field to induce density fluctuations in the Cooper pairs, particularly in the limit of in inite conductivity.

Relative to a gravito-magnetic force [9-11; 18] which depends more particularly on an AC magnetic drive or source term, $\partial A_g / \partial t$, the static case more strongly constrains interpretations based on either simple material shielding [4-5] or absorption of gravity [8]. In concordance with the Schiff-Barnhill and DeWitt effects [18], the residual internal electric and magnetic field generated (by lattice distortions arising from the solid's tendency internally to counteract gravity) do not go to zero at the onset of superconductivity. DeWitt describes the result as "free-floating electrons," but in any case, the linear combinations of electromagnetic terms are the relevant terms to describe. The coupled role of ion lattice distortion in a gravity field modifies both the internal electric field (Shiff-Barnhill effect) and the internal magnetic field (DeWitt effect), much akin to a gravitational analog to the Zeeman

shift. Thus the gravitomagnetic permeability is persistant and finite, while the magnetic permeability goes to zero. In mks units, the gravitomagnetic field, Bg, has dimensionality of 1/time and equals the precessional angular velocity for the ions or "quasi-bodies" possessing spin. If an appropriate geometry arises that can induce organized (partially aligned) or precessional ion motion, then any observed gravitomagnetic field strength (2%?) will experimentally translate to a proportional contribution from any non-zero angular momenta, including ions, vortices or larger percolation centers. Vortices also can possess spin angular momentum (in Type II superconductors) and can be regarded as a quasi-body; they should also be subject to precession. The rotating verion of this experiment will be reported in subsequent work.

Criteria for Future Work

Some further considerations for deductive experiments should include a mapping of the various effects and their potential artifacts.

Absorption vs. Shielding of Gravity

Appropriate geometries should test for weight loss above and below the superconductor. An absorption mechanism can be speculated to lead to weight loss in the neighborhood of the superconductor (including below and to the sides), while a strict shielding or shadow effect would lead to no weight loss except directly above the disk.

Height dependence

The suprising lack of height dependence in Podkletnov's results poses a number of problems for theoretical interpretation. **The reported weight loss did not change within one part in a thousand over a distance ranging from 10 cm to 3 m. A traditional $1/r^2$ force would be expected, on the contrary, to vary over 3 orders of magnitude over this distance.** Unless the length scale of any proposed force field is exceedingly long, then the interaction would not correspond to any traditional electromagnetic, gravitational or gravitomagnetic description. In the linear

approximation, the gravitomagnetic force shares a similar Maxwellian description. The usual picture would ascribe much longer characteristic lengths to gravitomagnetism, but would share the same characteristic decay as the EM field.

Buoyancy and convection

There is some incongruity reported between the various groups on the effects of air pressure on the weight measurement. Since the first dramatic observations by Podkletnov involved rising aerosol particles, considerable attention must be paid to the effects of buoyancy, air currents and thermal convection. These effects should be eliminated by taking the weight measurement under vacuum conditions, which has the additional feature of excluding any stray ultrasonic or buoyancy corrections. Podkletnov has noted a 2% drop in air pressure n a cylindrical air space above the superconductor, although Modanese interprets the latest set of weight measurments as occuring under vacuum conditions. The buoyancy corrections under lower atmospheric pressure would account for weigh: loss and have a long history in gravity experiments as giving analous conclusions. Bull (1995) has treated these effects in the context of the Finland experiment. A simple test of convective effects is either temperature control cr variation in the aerodynamic shape (cross-section) of the test mass while keeping the same material and mass. Moldable wax provides a convenient way to vary independently the shape, while keeping material and mass constant.

Electromagnetic coupling

With time-varying magnetic fields, the production of eddy currents can produce substantial levitation effects; induced diamagnetic effects should be measured independently, but different materials of the same mass will typically produce several orders of magnitude difference in the repulsive force. Relatively low cost shielding foils are commercially available with specifications of 1/1000 reductions in electrostatic (Cu or Al foil laminates), electromagnetic (Ni or Fe foil laminates) and stray radio-freq. fields (Cu/Al foil laminates). Thus an intelligently

nested isolation box is essential to meaninful interpretation of the results.

Decoupling changes in the gravity from changes in mass in the weight measurement

One method to decouple changes in mass from any measured changes in the gravitational acceleration is called the Wilberforce pendulum, named after Lionel Robert Wilberforce (1861-1944), a demonstrator at the Cavendish Laboratory in Cambridge, England around the turn of the century. It consists of a mass suspended from above by a spring. Such a pendulum has three modes of oscillation: 1) the ordinary swinging mode, 2) an oscillation along the axis of the spring and 3) a torsional (twisting) mode. If the resonant frequencies of the second two modes are nearly identical and one mode is initially excited, the other mode will slowly acquire energy, and the energy will slowly transfer back and forth between the modes.

The swinging mode of the Wilberforce pendulum is independent of test mass, but depends on gravitational acceleration. A change in the angular frequency above the superconductor would indicate direct variation in gravity. The angular frequency of the swinging mode is given by $(g/L)^{1/2}$, where $g = 9.8$ m/s^2 and L is the length of the pendulum. The spring reciprocation mode is idenpendent of gravitational acceleration, but inversely proportional to the square root of mass. A change in the oscillation frequency of the spring above the superconduc or would indicate direct variation of the test mass value. The frequency of the spring oscillation is given by $(k/m)^{1/2}$, where k is the spring constant and m is the mass supported by the spring. Finally, the torsional frequency is given by $(K/I)^{1/2}$, where K is the torsional constant and I is the moment of inertia of the suspended mass. Usually the moment of inertia is controlled by having several bolts threaded into the mass in a symmetric arrangement. Nuts threaded on the bolts can then be moved back and forth to change the moment of inertia without altering the mass. Thus the two frequencies can be made nearly equal.

If there were no coupling between the modes, the energy in each mode would

remain constant, ignoring friction, and the modes could be excited in any combination with no subsequent interaction. In reality, the stretching of the spring produces a small torque that excites the torsional mode. The torsional mode, in turn, alternately stretches and compresses the spring, exciting the spring mode. The necessity of having the frequencies nearly equal is that the coupling between the modes is small, and thus the energy must be transferred over a number of cycles. The effect is quite impressive if the frequencies are carefully adjusted. This is an example of a harmonic oscillator driven at its resonant frequency by a small driving force and provides an exotic, but potentially novel way to clarify interpretation of the results in the event of a measured weight loss.

In addition to superconductors, other Bose condensates such as superfluid helium have been investigated for gravitomagnetic field exclusion [19], but the low thermal conductivity of helium limits measurable power transfer from an AC magnetic field by several orders of magnitude below a YBCO superconductor.

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calibrated along the 10-station Rocky Mountain Calibration range established by NOAA, Edcon and the Colorado School of Mines over known gravity values extending across 220 milli-Gals (0.22 cm s⁻²) in 50, 20, and 5 milli-Gal increments, with 3-7 micro-Gal standard deviations. To validate instrument operation, an absolute gravity measurement was additionally calibrated from USAF gravity disk reference values (airport Huntsville, AL) and an 8-satellite global positioning reading for the test site as latitude 34.654244 and longitude -86.663638 at an altitude of 116 m. above sea level.

[16]. For comparison, 10^{-3} cm s⁻² is the relative gravitational influence of a 5-storey office block (perturbing mass) at a distance of 1 m. Equivalently a 2% variation in the gravitational force would require 2×10^4 copies of such a perturbing mass. Using the radial dependence of the gravitational inverse square law, 1 m displacement in height corresponds to approximately a change in measured gravitational acceleration of 3×10^{-4} cm s⁻², such that for example, a 2% variation in the gravitational force would correspond to a vertical displacement of the test mass equal to approximately 10^2 km.

[17] This method is the inverse technique employed in traditional gravity surveys where the gravimeter is moved to different stations; instead an apparent gravity perturbation is introduced to a stationary meter by moving the components of the superconductor, magnets and cryostat individua ly to the measuring apparatus. In all cases, internal temperature stability was maintained ±0.05 C. The effect of the increased mass beneath the gravimeter can be calculated as much less than the instrument resolution (<10^{-8} cm s⁻²) and confirmed using room-temperature, non-magnetic test mass.

[18]. Later work has generalized the Meissner effect in a gravitational field as a superconductive analog of a Zeeman shift. Schif and Barnhill (Bull. Am. Phys. Soc. 11, (1966), 96) and DeWitt (Phys. Rev. Lett. 16, (1966), 1092) showed that it is not the electrical and magnetic fields which vanish inside a superconductor, but the linear combination of the internal fields plus a gravitational component. This additional

term lends itself to "free-floating" electrons which have effects on the background of lattice ions. Li and Torr [refn. 8-11] proposed that a superconductor's London moment and the absence of charge separation lends to high angular momenta for rotating ions such that calculated gravito-magnetic effects can arise as the electron velocity v is replaced by the velocity of the lattice. Using the London moment, large values for conductivity (which define the superconducting state) coupled to the resulting low magnetic permeability observed in the Meissner effect lend to a coupling between a dense contribution of high angular momenta ions and gravitomagnetism. In the superconductive limit, the calculation depends sensitively on the vanishing magnetic, but finite gravitomagnetic permeabilities and the ion's much larger gyromagnetic ratio (m/e) compared to the electronic Cooper pairs.

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Fig. 1 Scanning electron microscopy of hexagonal, single-domain YBCO superconductor at increasing magnificantion. Surface machining textures the domain.

Gravimeter Calibration

1 M Height Variation in Gravity

Response to 20 C Thermal Perturbation

12- Hour Solar/Lunar Tide
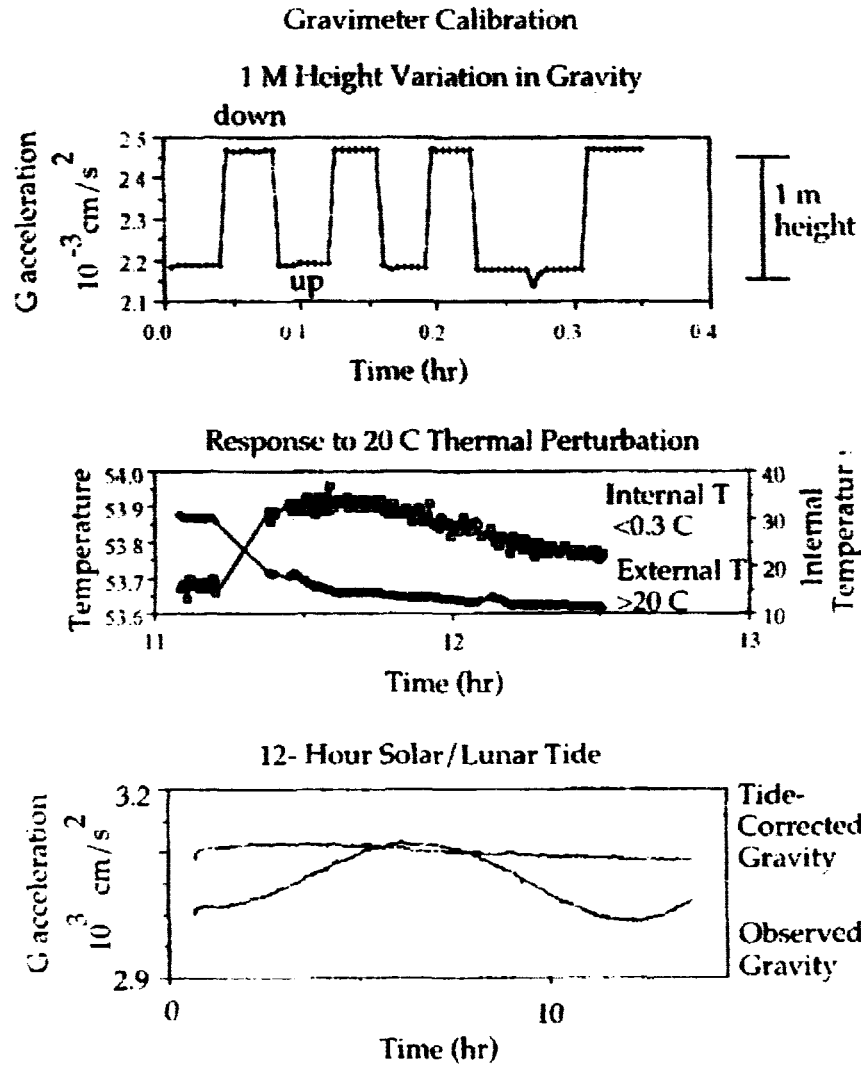
Fig. 2. Calibration and proof-testing gravimeter: 1) altitude variation of 1 m and resulting gravity change (3.08×10^{-4} cm/s^2 per m altitude); 2) thermal constancy of gravimeter interior during 20 C external temperature change; 3) solar and lunar tide during long duration reading (12 hr).
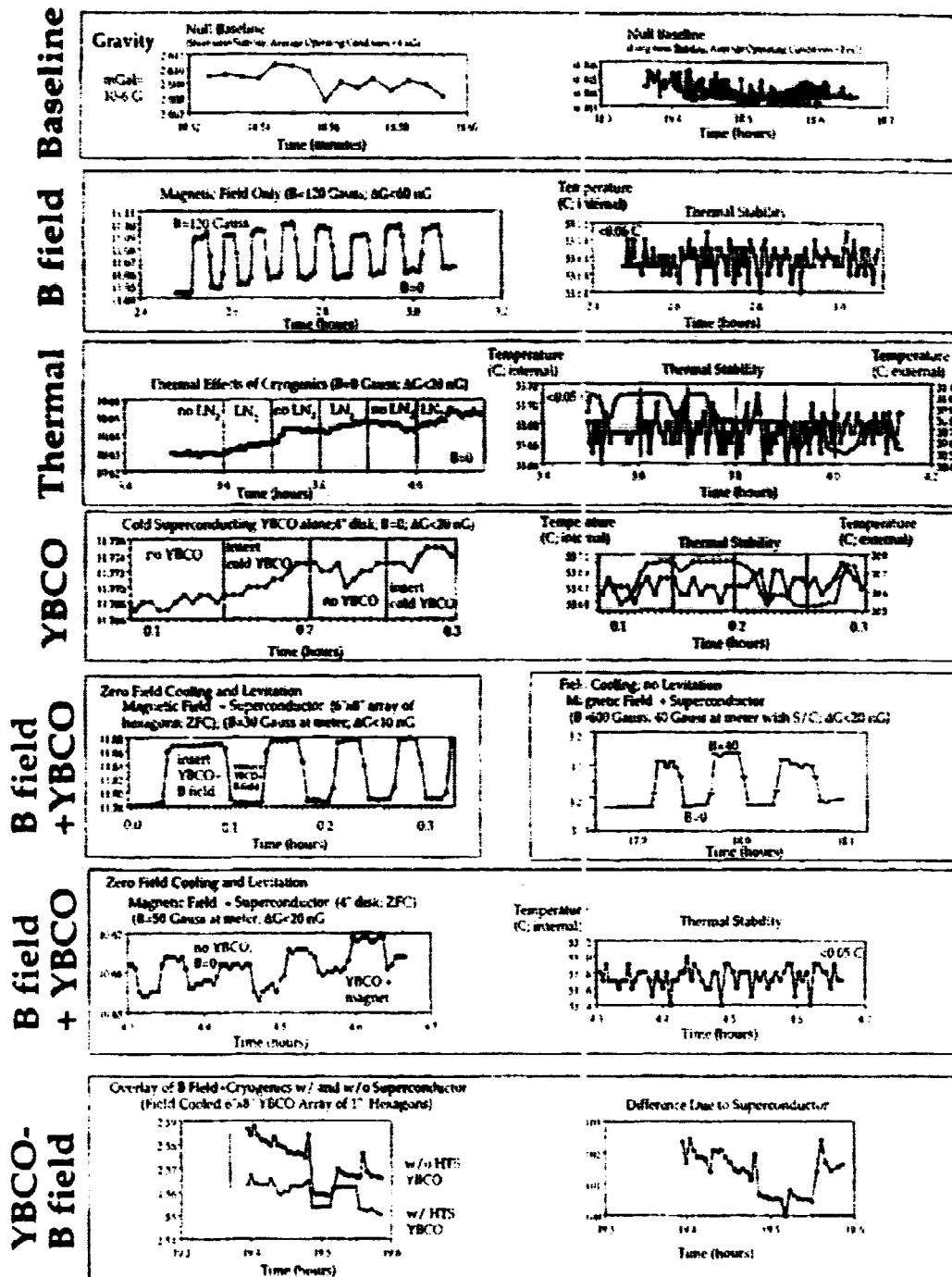
Fig. ~. Experimental results for measured DC-magnetic field and gravimeter fluctuations (baseline plus magnetic, thermal and superconductive contributions). If not otherwise indicated the vertical axis is apparent gravity in units of milli-Gals or 10^{-3} cm s^{-2}. See text for protocol details.
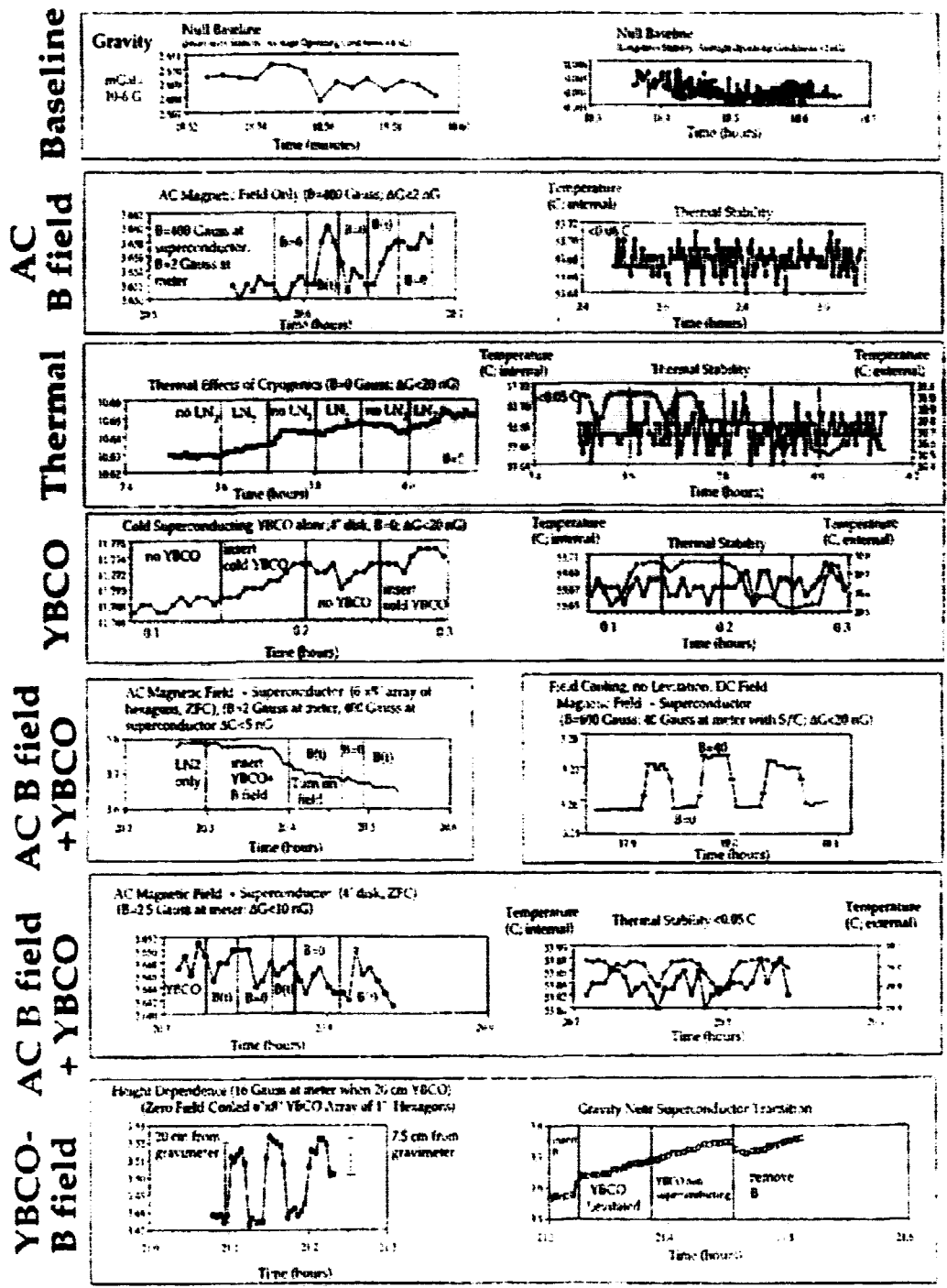
Fig. 4. Experimental results for measured AC-magnetic field and gravimeter fluctuations (baseline plus magnetic, thermal and superconductive contributions). If not otherwise indicated the vertical axis is apparent gravity in units of milli-Gals or 10^{-3} cm s^{-2}. See text for protocol details.

NEXT
DOCUMENT

Apparent Endless Extraction of Energy from the Vacuum by Cyclic Manipulation of Casimir Cavity Dimensions

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ABSTRACT:

In 1983, Ambjørn and Wolfram produced plots of the energy density of the quantum mechanical electromagnetic fluctuations in a volume of vacuum bounded by perfectly conducting walls in the shape of a rectangular cavity of dimensions a_1, a_2, and a_3, as a function of the ratios a_2/a_1 and a_3/a_1. Portions of these plots are double-valued, in that they allow rectangular cavities with the same value of a_2/a_1, but different values of a_3/a_1, to have the same total energy. Using these double-valued regions of the plots, I show that it is possible to define a "Casimir Vacuum Energy Extraction Cycle" which apparently would allow for the endless extraction of energy from the vacuum in the Casimir cavity by cyclic manipulation of the Casimir cavity dimensions.

INTRODUCTION:

One of the yet untapped possible sources of energy for advanced propulsion systems is the quantum mechanical electromagnetic fluctuation energy in the vacuum of empty space. Since the electromagnetic fluctuation energy exists everywhere except inside conductors, such an energy source could be tapped anywhere the using vehicle goes. This paper describes a method of cyclically manipulating the dimensions of a Casimir cavity which appears to result in the extraction of energy from the vacuum contained within the Casimir cavity during one · portion of the cycle, without the need to supply energy back into the Casimir cavity vacuum during the other portions of the cycle which return the cavity dimensions to their original state.

CASIMIR CAVITY ENERGY:

One of the macroscopically observable effects of the electromagnetic fluctuations of the vacuum predicted by the theory of quantum electrodynamics, are the forces produced by the vacuum fluctuation energy on the conducting walls of a "Casimir cavity". Casimir (1948) predicted that the vacuum between two conducting metal plates would have less energy than a similar region of vacuum not bounded by conducting plates. He also predicted that the two uncharged conducting plates would experience an attractive force. Those forces were measured by Lamoreaux (1997), and they agreed with the Casimir predictions to within 5%. The two closely-spaced conducting plates of the standard Casimir experiment are an extreme example of a more general Casimir cavity such as a sphere or box. For this paper we will concentrate on rectangular Casimir cavities, where the two closely-spaced conducting plates would be replaced with a rectangular cavity in the shape of a pizza box.

The energy density of the electromagnetic vacuum fluctuation energy in a rectangular Casimir cavity has been calculated in detail by Ambjørn and Wolfram (A&W 1983). They assumed an empty, perfectly conducting, rectangular box of dimensions a_1, a_2, and a_3. They then calculated the "energy divided by volume" of the vacuum in the box for the case of a number of different theoretically possible fields. The case we will use is when the vacuum inside the cavity contains the quantum mechanical fluctuations of a "massless vector field". We will assume that the A&W phrase "energy divided by volume" is equivalent to "energy density", and that the phrase "massless vector field" is the electromagnetic field.

A&W (1983) found that the energy density in a Casimir cavity can be either positive, negative, or zero, depending upon the shape of the cavity. When

they plotted curves of constant energy density as a function of the ratio of two of the sides with respect to the third, or a_2/a_1 vs. a_3/a_1, they produced the plot of Figure 1. The dark region to the lower left indicates cavity shapes with a positive energy density, while the lighter region to the upper right indicates cavity shapes with a negative energy density. The zero energy density curve runs from $a_2/a_1=3.3$ on one axis to $a_3/a_1=3.3$ on the other axis.
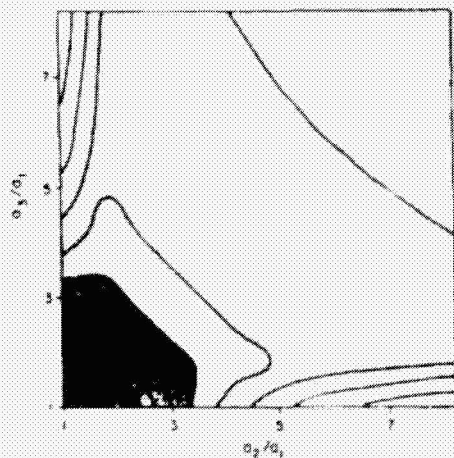
Fig. 1 - Plots of Constant Energy Density in a Rectangular Cavity of Dimensions a_1, a_2, and a_3.

VARIABLE CAVITY VOLUME:

One of the more interesting aspects of the A&W plot are the convoluted, reentrant shapes of the constant energy density curves, especially in the negative energy region. These variations with cavity shape are not understood. As I will show later, they may give us a "handle" on extracting energy from the vacuum.

The zero energy density curve of Fig. 1 is of fundamental importance. Not only is the energy density zero for all Casimir cavity shapes on that curve, but the total energy in all the Casimir cavities with those shapes is also zero, no matter how big or small the scale of the cavity dimensions. The variation in shape, volume, and surface area of these special zero-energy Casimir cavity shapes is quite significant. As shown in Fig. 2, they range from a minimum volume "bread box" with relative dimensions of 1 x 1 x 3.3, volume of 3.3, and surface area of 8.6; through a "shoe box" with relative dimensions of 1 x 1.75 x 3.4, volume of 5.95, and surface area of 21.35; to a maximum volume "cake box" with dimensions of 1 x 2.6 x 2.6, volume of

6.76, and surface area of 23.92. Why these specific shapes have zero energy density is unknown. Also shown in Fig. 2 is a cube, which has the smallest volume and the maximum positive energy density.
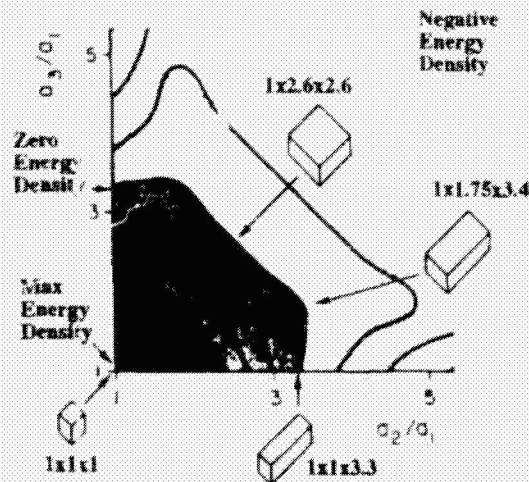
Fig. 2 - Variation of Cavity Shapes Along the Zero Energy Density and Zero Total Energy Curves.

In an effort to understand the shapes of the constant energy density curves, I calculated some constant volume and constant surface area curves and compared them with the zero and first negative value constant energy density curves. As can be seen in Fig. 3, the central portions of the constant energy density curves approximate a constant volume or constant surface area line, but deviate greatly when two of the dimensions are significantly smaller than the third.
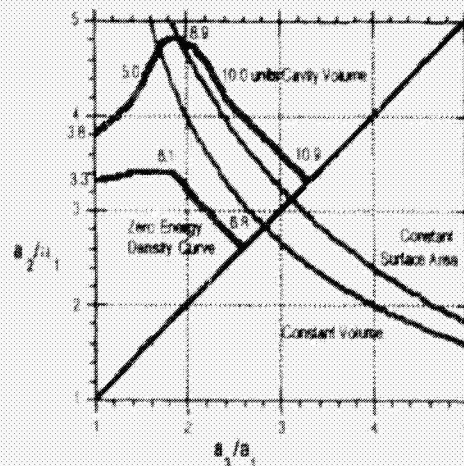
Fig. 3 - Constant Volume and Surface Area Lines

CASIMIR VACUUM ENERGY EXTRACTION CYCLE:

There are many conceivable vacuum energy extraction cycles which can be conjured up from studying Fig. 1, but the most convincing Casimir Vacuum Energy Extraction Cycle uses the zero energy density curve. The minimum volume rectangular cavity which lies on the zero energy density curve is the rectangle with relative dimensions of 1 x 3.3 x 1. Since the energy density of this cavity is zero, then the total energy in the volume is zero, independent of the scale of the cavity. The vacuum inside this cavity shape seems to be similar to that of an unbounded vacuum.

We will now cyclically manipulate the dimensions of the cavity as shown in Fig. 4. We start with the cavity shape $a_1=1$, $a_2=3.3$, $a_3=1.0$. Holding a_1 and a_2 constant, we make an infinitesimal increase in the cavity dimension a_3 from 1.0 to 1.0+. This should require no energy since the Casimir energy in the cavity is zero, which usually means the forces on the walls of the cavity are zero. We have now moved into the region of the plot where the energy density in the cavity is positive. According to the usual interpretation, a positive energy density in a Casimir ... produces an outward or repulsive force on the walls the Casimir cavity. We now permit the walls ... rmining the dimension a_3 to continue to move outward under the repulsive Casimir force. During this forced expansion mode, we can use either mechanical or electrical (Forward 1984) means to extract energy from the moving walls.
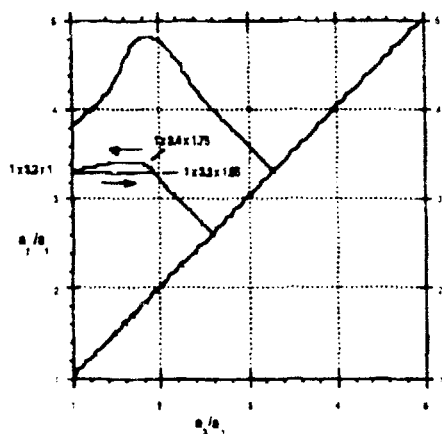
Fig. 4 - Zero Energy Cur e Casimir Cycle

The outward force on the walls will grow larger as a_3 increases, then smaller, until a_3 reaches the point 1.85, but all during the change from 1.0 to 1.85, the force on the wall is outward, and energy can be extracted from the forcefully moved wall during that part of the cycle. Since the force on the wall is produced by the positive Casimir energy density of the vacuum, one can draw the conclusion that the energy extracted came from the vacuum.

With the shape of the cavity now at $a_1=1$, $a_2=3.3$, $a_3=1.85$, we are back to a cavity shape which is on the zero constant energy density curve. With zero energy density and zero total energy in the Casimir cavity, there should be zero force on the walls. We now hold a_1 constant at 1.0, and decrease a_3 from 1.85 to 1.75, while at the same time increasing a_2 from 3.3 to 3.4, in such a way as to have the shape of the resultant Casimir cavity always remain on the zero energy density curve. Since the forces on the wall are zero, no energy should be required to move those walls. We are now at the Casimir cavity shape given by $a_1=1.0$, $a_2=3.4$, $a_3=1.75$. We now continue the cycle by holding a_1 at 1.0, and decreasing a_3 from 1.75 to 1.0, while at the same time decreasing a_2 from 3.4 to 3.3 in such a manner that each intermediate shape corresponds to a point along the zero energy density curve. Since there is zero energy density in the Casimir cavity, there should be zero force on the walls and no energy should be required to move the walls during this portion of the cycle. We have now reached the beginning shape of $a_1=1.0$, $a_2=3.3$, and $a_3=1.0$ and completed the cycle. During one portion of the cycle, when the walls determining a_3 were allowed to expand from 1.0 to 1.85 under the outward Casimir force, we were able to extract energy from the vacuum electromagnetic fluctuations in the Casimir cavity. During the rest of the cycle, when the shape of the Casimir cavity was adjusted so that the shape followed the zero constant energy density curve, there should be no Casimir forces on the walls of the cavity. If so, no energy was required to move the walls and no energy was returned to the cavity.

We thus seem to have identified a "Casimir Vacuum Energy Extraction Cycle" which obtains energy from the vacuum during one portion of the cycle, but is not required to return that energy during the remaining portions of the cycle, thus endlessly extracting energy from the vacuum with each cycle completed. This is an extraordinary conclusion if it is true. Extraordinary conclusions require extraordinary precautions during analysis as well as extraordinary proof obtained by

extremely careful experimental measurements. It could be the anomalous result was obtained because of either sloppy plotting by A&W (1983) or by my reading of more into their plots than is warranted. If one looks at the original plot of Fig. 1, the zero energy density line is very thick. Although it looks like the curve is double-valued at either $a_2/a_1=3.3$ or $a_2/a_1=3.3$, it could be that the actual data is always single-valued for all values of a_2 and a_1. In contradistinction, the negative energy density curves are definitely double-valued, so the zero energy density curve is also probably double-valued. It is also possible that the A&W calculations are wrong, and the double-valued curves of constant negative energy density are wrong, and should look more like the single-valued quarter-circles seen in the positive energy density region. The recent calculations of Hacyan, et al. (1993), which generally agree with those of A&W, make that unlikely.

T.A.N.S.T.A.A.F.L ALERT!!!:

"There Ain't No Such Thing As A Free Lunch" - This deliberately-illiterate "catch phrase" from one of Heinlein's books applies equally well to bar lunch counters, stock markets, grocery check-out stands, and physics. But... using the accepted theories and models for the behavior of Casimir cavities under the influence of the quantum mechanical electromagnetic fluctuations of the vacuum, I have described a method of manipulating the shape of a Casimir cavity in a cyclical manner so that I can extract either electrical or mechar cal energy from the forces acting on the walls of the Casimir cavity, while at the same time periodically returning the Casimir cavity to its original state. Since such a procedure would generate more energy that it uses, it is highly probable that something is wrong. The most likely candidate is that the Casimir forces on the individual walls of a cavity with zero total energy are not zero. But I know of no reference to this. There may be other explanations.

CONCLUSIONS:

We have constructed a physics paradox using the presently accepted theories of the electromagnetic fluctuations of the vacuum. The resolution of that paradox, at a minimum, could lead us to a better understanding of the electromagnetic fluctuations of the vacuum, or, at a maximum, could provide an essentially unlimited supply of energy for space propulsion.

There is new physics to be learned in the accurate study of the electromagnetic fluctuations of the vacuum in Casimir cavities. Microelectronic fabrication techniques can construct the microscopic and sub-microscopic conducting wall cavities needed to put the existing theories to an accurate test. What are needed are some good ideas for experiments, backed up by good theoretical models for those experiments, which will produce numerical estimates which can then be checked by careful experiments.

ACKNOWLEDGMENTS:

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DOCUMENT

The Zero-Point Field and the NASA Challenge to Create the Space Drive

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ABSTRACT:

This NASA Breakthrough Propulsion Physics Workshop seeks to explore concepts that could someday enable interstellar travel. The effective superluminal motion proposed by Alcubierre (1994) to be a possibility owing to theoretically allowed space-time metric distortions within general relativity has since been shown by Pfenning and Ford (1997) to be physically unattainable. A number of other hypothetical possibilities have been summarized by Millis (1997). We present herein an overview of a concept that has implications for radically new propulsion possibilities and has a basis in theoretical physics: the hypothesis that the inertia and gravitation of matter originate in electromagetic interactions between the zero-point field (ZPF) and the quarks and electrons constituting atoms. A new derivation of the connection between the ZPF and inertia has been carried through that is properly co-variant, yielding the relativistic equation of motion from Maxwell's equations. This opens new possibilites, but also rules out the basis of one hypothetical propulsion mechanism: Bondi's "negative inertial mass," appears to be an impossibility.

INTRODUCTION:

The objective of this NASA Breakthrough Propulsion Physics Workshop is to explore ideas ranging from extrapolations of known technologies to hypothetical new physics which could someday lead to means for interstellar travel. One concept that has generated interest is the proposal by Alcubierre (1994) that effectively superluminal motion should be a possibility owing to theoretically allowed space-time metric distortions within general relativity. In this model, motion between two locations could take place at effectively hyperlight speed without violating special relativity because the motion is not *through* space at $v > c$, but rather within a space-time distortion: somewhat like the "stretching of space" itself implied by the Hubble expansion. Alcubierre's concept would indeed be a "warp drive." Unfortunately Pfenning and Ford (1997) demonstrated that, while the theory may be correct in principle, the necessary conditions are physically unattainable. In "The Challenge to Create the Space Drive" Millis (1997) has summarized a number of other possibilities for radically new propulsion methods that could someday lead to interstellar travel if various hypothetical physics concepts should prove to be true. Seven different propulsion concepts were presented therein: three involved hypothetical collision sails and four were based on hypothetical field drives.

The purpose of this paper is to discuss a new physics concept that no longer falls in the category of "purely hypothetical," but rather has a theoretical foundation and is relevant to radically new propulsion schemes: the zero-point field (ZPF) as the basis of inertia and gravitation. On the basis of this concept we can definitively rule out one of the hypothesized propulsion mechanisms since the existence of negative inertial mass is conclusively shown to be an impossibility. On the other hand a differential space sail becomes a distinct possiblity. More importantly, though, the door is theoretically open to the possibility of manipulation of inertia and gravitation of matter since both properties are shown to stem at least in part from electrodynamics. This raises the stakes considerably as Arthur C. Clarke (1997) writes in his novel, *3001* referring to the ZPF-inertia concept of Haisch, Rueda and Puthoff (1994; hereafter HRP):

> An "inertialess drive," which would act exactly like a controllable gravity field, had never been discussed seriously outside the pages of science fiction until very recently. But in 1994 three American physicists did exactly this, developing some ideas of the great Russian physicist Andrei Sakharov.

THE ZERO-POINT FIELD FROM PLANCK'S WORK:

In the year 1900 there were two main clouds on the horizon of classical physics the failure to measure the motion of the earth relative to the ether and the inability to explain blackbody radiation. The first problem was resolved in 1905 with the publication of Einstein's "Zur Elektrodynamik bewegter Körper" in the journal *Annalen der Physik*, proposing what has come to be known as the special theory of relativity. It is usually stated that the latter problem, known as the "ultraviolet catastrophe," was resolved in 1901 when Planck, in "Über das Gesetz der Energieverteilung im Normalspektrum" in the same journal, derived a mathematical expression that fit the measured spectral distribution of thermal radiation by hypothesizing a quantization of the average energy per mode of oscillation, $\epsilon = h\nu$.

The actual story is somewhat more complex (cf. Kuhn 1978). Since the objective is to calculate an electromagnetic spectrum one has to represent the electromagnetic field in some fashion. Well-known theorems of Weyl allow for an expansion in countably many infinite electromagnetic modes (e.g. Kurokawa 1958). Every electromagnetic field mode behaves exactly as a linear harmonic oscillator. The Hamiltonian of a one-dimensional oscillator has two terms, one for the kinetic energy and one for the potential energy:

$$H = \frac{p^2}{2m} - \frac{Kx^*}{2}.$$

(1)

The classical equipartition theorem states that each quadratic term in position or momentum contributes $kT/2$ to the mean energy (e.g. Peebles 1992). The mean energy of each mode of the electromagnetic field is then $< E > = kT$. The number of modes per unit volume is $(8\pi\nu^2/c^3)d\nu$ leading to the Rayleigh-Jeans spectral energy density $(8\pi\nu^2/c^3)kTd\nu$ with its ν^2 divergence (the ultraviolet catastrophe).

In his "first theory" Planck actually did more than simply assume $\epsilon = h\nu$. He considered the statistics of how "P indistinguishable balls can be put into N distinguishable boxes." (Milonni 1994) So Planck anticipated the importance of the fundamental indistinguishability of elementary particles. With those statistics, the average energy of each oscillator becomes $< E > = \epsilon/(\exp(\epsilon/k^T) - 1)$. Assuming that $\epsilon = h\nu$ together with the use of statistics appropriate to indistinguishable energy elements then led to the spectral energy distribution consistent with measurements, now known as the Planck (or blackbody) function:

$$\rho(\nu, T)d\nu = \frac{8\pi\nu^2}{c^3} \left(\frac{h\nu}{e^{h\nu/kT} - 1} \right) d\nu.$$

(2a)

Contrary to the cursory textbook history, Planck did not immediately regard his $\epsilon = h\nu$ assumption as a new fundamental law of physical quantisation; he viewed it rather as a largely *ad hoc* theory with unknown implications for fundamental laws of physics. In 1912 he published his "second theory" which led to the concept of zero-point energy. The average energy of a thermal oscillator treated in this fashion (cf. Milonni 1994 for details) turned out to be $< E > = h\nu/(\exp(h\nu/kT) - 1) + h\nu/2$ leading to a spectral energy density:

$$\rho(\nu, T)d\nu = \frac{8\pi\nu^2}{c^3} \left(\frac{h\nu}{e^{h\nu/kT} - 1} + \frac{h\nu}{2} \right) d\nu.$$

(2b)

The significance of this additional term, $h\nu/2$, was unknown. While this appeared to result in a ν^3 ultraviolet catastrophe in the second term. In the context of present-day stochastic electrodynamics (SED; see below) that is interpreted as not to be the case, because this component now refers not to measurable excess radiation from a heated object, but rather to a uniform, isotropic background radiation field that cannot be directly measured because of its homogeneity. Planck came to the conclusion that the zero-point energy would have no experimental consequences. It could be thought of as analogous to an arbitrary additive constant for potential energy. Nernst (1916), on the other hand, took it seriously and proposed that the Universe might actually contain enormous amounts of zero-point energy.

Work on zero-point energy in the context of classical physics was essentially abandoned at this stage as the development of quantum mechanics, and then quantum electrodynamics (QED), took center stage. However the parallel concept of an electromagnetic quantum vacuum soon emerged.

THE ZERO-POINT FIELD FROM QUANTUM PHYSICS:

For a one-dimensional harmonic oscillator of unit mass the quantum-mechanical Hamiltonian analagous to Eq. (1) may be written (cf. Loudon 1983)

$$\hat{H} = \frac{1}{2}(\hat{p}^2 + \omega^2\hat{q}^2),\tag{3}$$

where $\hat{p}$ and $\hat{q}$ are momentum and position operators respectively. Linear combination of the $\hat{p}$ and $\hat{q}$ result in the ladder operators, also known as destruction (or lowering) and creation (or raising) operators respectively:

$$\hat{a} = (2\hbar\omega)^{-1/2}(\omega\hat{q} + i\hat{p}),\tag{4a}$$

$$\hat{a}^\dagger = (2\hbar\omega)^{-1/2}(\omega\hat{q} - i\hat{p}).\tag{4b}$$

The application of the destruction operator on the nth eigenstate of a quantum oscillator results in a lowering of the state, and similarly the creation operator results in a raising of the state:

$$\hat{a}|n\rangle = n^{1/2}|n - 1\rangle,\tag{5a}$$

$$\hat{a}^\dagger|n\rangle = (n + 1)^{1/2}|n + 1\rangle,\tag{5b}$$

It can be seen that the number operator has the $|n\rangle$ states as its eigenstates as

$$\hat{N}|n\rangle = \hat{a}^\dagger\hat{a}|n\rangle = n|n\rangle.\tag{5c}$$

The Hamiltonian or energy operator of Eq. (3) becomes

$$\hat{H} = \hbar\omega\left(\hat{N} + \frac{1}{2}\right) = \hbar\omega\left(\hat{a}^\dagger\hat{a} + \frac{1}{2}\right).\tag{6}$$

The ground state energy of the quantum oscillator, $|0\rangle$, is greater than zero, and indeed has the energy $\frac{1}{2}\hbar\omega$,

$$\hat{H}|0\rangle = E_0|0\rangle = \frac{1}{2}\hbar\omega|0\rangle,\tag{7}$$

and thus for excited states

$$E_n = \left(n - \frac{1}{2}\right)\hbar\omega.\tag{8}$$

Now let us turn to the case of classical electromagnetic waves. Plane electromagnetic waves propagating in a direction $\mathbf{k}$ may be written in terms of a vector potential $\mathbf{A_k}$ as

$$\mathbf{E_k} = i\omega_k\{\mathbf{A_k}\exp(-i\omega_k t + i\mathbf{k}\cdot\mathbf{r}) - \mathbf{A_k^*}\exp(i\omega_k t - i\mathbf{k}\cdot\mathbf{r})\},\tag{9a}$$

$$\mathbf{B_k} = i\mathbf{k}\times\{\mathbf{A_k}\exp(-i\omega_k t + i\mathbf{k}\cdot\mathbf{r}) - \mathbf{A_k^*}\exp(i\omega_k t - i\mathbf{k}\cdot\mathbf{r})\},\tag{9b}$$

Using generalized mode coordinates analogous to momentum (P_k) and position (Q_k) in the manner of Eqs. (4ab) above one can write $\mathbf{A_k}$ and $\mathbf{A_k^*}$ as

$$\mathbf{A_k} = (4\epsilon_0 V\omega_k^2)^{-\frac{1}{2}}(\omega_k Q_k + iP_k)\hat{\epsilon}_k,\tag{10a}$$

$$\mathbf{A_k^*} = (4\epsilon_0 V\omega_k^2)^{-\frac{1}{2}}(\omega_k Q_k - iP_k)\hat{\epsilon}_k.\tag{10b}$$

where $\hat{e}_k$ is the polarization unit vector and V the cavity volume. In terms of these variables, the single-mode phase-averaged energy is

$$< E_k > = \frac{1}{2}(P_k^2 + \omega_k^2 Q_k^2).$$ (11)

Note the parallels between equations (10) and (4) and equations (1) and (3). Just as mechanical quantisation is done by replacing position, x, and momentum, p, by quantum operators $\hat{x}$ and $\hat{p}$, so is the "second" quantisation of the electromagnetic field accomplished by replacing A with the quantum operator $\hat{A}$, which in turn converts E into the operator $\hat{E}$, and B into $\hat{B}$. In this way, the electromagnetic field is quantized by associating each k-mode (frequency, direction and polarisation) with a quantum-mechanical harmonic oscillator. The ground-state of the quantised field has the energy

$$< E_{k,0} > = \frac{1}{2}(P_{k,0}^2 + \omega_k^2 Q_{k,0})^2 = \frac{1}{2}\hbar\omega_k$$ (12)

that originates in the non-commutative algebra of the creation and annihilation operators. It is as if there were on average half a photon in each mode.

ZERO-POINT FIELD IN STOCHASTIC ELECTRODYNAMICS:

A common SED treatment (cf. Boyer 1975 and references therein; also the comprehensive review of SED theory by de la Peña and Cetto 1996) has been to posit a zero-point field (ZPF) consisting of plane electromagnetic waves whose amplitude is exactly such as to result in a phase-averaged energy of $\hbar\omega/2$ in each mode (k,σ), where we now explicitly include the polarisation, c. After passing to the continuum such that summation over discrete modes of propagation becomes an integral (valid when space is unbounded or nearly so) this can be written as:

$$\mathbf{E}^{ZP}(\mathbf{r},t) = \text{Re} \sum_{\sigma=1}^{2} \int d^3k \hat{e}_{k,\sigma} \left[\frac{\hbar\omega_k}{8\pi^3\epsilon_0}\right]^{\frac{1}{2}} \exp(i\mathbf{k}\cdot\mathbf{r} - i\omega_k t + i\theta_{k,\sigma}),$$ (13a)

$$\mathbf{B}^{ZP}(\mathbf{r},t) = \text{Re} \sum_{\sigma=1}^{2} \int d^3k (\hat{k} \times \quad \left[\frac{\hbar\omega_k}{8\pi^3\epsilon_0}\right]^{\frac{1}{2}} \exp(i\mathbf{k}\cdot\mathbf{r} - i\omega_k t + i\theta_{k,\sigma}),$$ (13b)

where $\theta_{k,\sigma}$ is the phase of the waves. The stochasticity is entirely in the phase of each wave: There is no correlation in phase between any two plane electromagnetic waves k and k', and this is represented by having the $\theta_{k,\sigma}$ phase random variables independently and uniformly distributed between 0 and 2π.

DAVIES-UNRUH EFFECT:

In connection with "Hawking radiation" from evaporating black holes, Davies (1975) and Unruh (1976) determined that a Planck-like component of the ZPF will arise in a uniformly-accelerated cordinate system with constant proper acceleration $\mathbf{a}$ (where $|\mathbf{a}| = a$) having an effective temperature,

$$T_a = \frac{\hbar a}{2\pi c k}.$$ (14)

This temperature is negligible for most accelerations. Only in the extremely large gravitational fields of black holes or in high-energy particle collisions can this become significant. This effect has been studied using both quantum field theory (Davies 1975, Unruh 1976) and in the SED formalism (Boyer 1980). For the classical SED case it is found that the spectrum is quasi-Planckian in T_a. Thus for the case of no true external thermal radiation ($T = 0$) but including this acceleration effect (T_a), equation (2b) becomes

$$\rho(\nu, T_a)d\nu = \frac{8\pi\nu^2}{c^3}\left[1 + \left(\frac{a}{2\pi c\nu}\right)^2\right]\left[\frac{h\nu}{2} + \frac{h\nu}{e^{h\nu/kT_a} - 1}\right]d\nu.$$ (15)

where the acceleration-dependent pseudo-Planckian component is placed after the $h\nu/2$ term to indicate that except for extreme accelerations (e.g. particle collisions at high energies) this term is very small. While these additional acceleration-dependent terms do not show any spatial asymmetry in the expression for the ZPF spectral energy density, certain asymmetries do appear when the electromagnetic field interactions with charged particles are analysed, or when the momentum flux of the ZPF is calculated. The ordinary plus a^2 radiation reaction terms in Eq. (12) of HRP mirror the two leading terms in Eq. (15).

NEWTONIAN INERTIA FROM ZPF ELECTRODYNAMICS:

The HRP analysis resulted in the apparent derivation of Newton's equation of motion, $\mathbf{F} = m\mathbf{a}$, from Maxwell-Lorentz electrodynamics as applied to the ZPF. In that analysis it appeared that the resistance to acceleration known as inertia was in reality the electromagnetic Lorentz force stemming from interactions between a charged particle (such as an electron or a quark) and the ZPF, i.e. it was found that the stochastically-averaged expression $< \mathbf{v}_{osc} \times \mathbf{B}^{ZP} >$ was proportional to and in the opposite direction to the acceleration $\mathbf{a}$. The velocity $\mathbf{v}_{osc}$ represented the internal velocity of oscillation induced by the electric component of the ZPF, $\mathbf{E}^{ZP}$, on the harmonic oscillator. For simplicity of calculation, this internal motion was restricted to a plane orthogonal to the external direction of motion (acceleration) of the particle as a whole. The Lorentz force was found using a perturbation technique; this approach followed the method of Einstein and Hopf (1910a, b). Owing to its linear dependence on acceleration we interpreted this resulting force as Newton's inertia reaction force on the particle.

The analysis can be summarised as follows. The simplest possible model of a structured particle (which, borrowing Feynman's terminology, we referred to as a parton) is that of a harmonically-oscillating point charge ("Planck oscillator"). Such a model would apply to electrons or to the quarks constituting protons and neutrons for example. (Given the peculiar character of the strong interation that it increases in strength with distance, to a first approximation it is reasonable in such an exploratory attempt to treat the three quarks in a proton or neutron as independent oscillators.) This Planck oscillator is driven by the electric component of the ZPF, $\mathbf{E}^{ZP}$, to harmonic motion, $\mathbf{v}_{osc}$, assumed for simplicity to be in a plane. The oscillator is then forced by an external agent to undergo a constant acceleration, $\mathbf{a}$, in a direction perpendicular to that plane of oscillation, i.e. perpendicular to the $\mathbf{v}_{osc}$ motions. New components of the ZPF will appear in the frame of the accelerating particle having a similar origin to the terms in equation (15). The leading term of the acceleration-dependent terms is taken; the electric and magnetic fields are transformed into a constant proper acceleration frame using well-known relations. The Lorentz force arising from the acceleration-dependent part of the $\mathbf{B}^{ZP}$ acting upon the Planck oscillator is calculated. This is found to be proportional to the imposed acceleration. The constant of proportionality is interpreted as the inertial mass, m_i, of the Planck oscillator. The inertial mass, m_i, is a function of the Abraham-Lorentz radiation damping constant of the oscillator and of the interaction frequency with the ZPF,

$$m_i = \frac{\Gamma h \nu_0^2}{2\pi c^2},$$ (16)

where we have written ν_0 to indicate that this may be a resonance rather than the cutoff assumed by HRP. Since both Γ and ν_o are unknown we can make no absolute prediction of mass values in this simple model. Nevertheless, if correct, the HRP concept substitutes for Mach's principle a very specific electromagnetic effect acting between the ZPF and the charge inherent in matter. Inertia is an acceleration-dependent electromagnetic (Lorentz) force. Newtonian mechanics would then be derivable in principle from Maxwell's equations. Note that this coupling of the electric and magnetic components of the ZPF via the technique of Einstein and Hopf is very similar to that found in ordinary electromagnetic radiation pressure.

THE RELATIVISTIC EQUATION OF MOTION AND ZPF ELECTRODYNAMICS:

The physical oversimplification of an idealized oscillator interacting with the ZPF as well as the mathematical complexity of the HRP analysis are understandable sources of skepticism, as is the limitation to Newtonian mechanics. A relativistic form of the equation of motion having standard covariant properties has been obtained (Rueda and Haisch 1997a,b). To understand how this comes about, it is useful to back up to fundamentals.

Newton's third law states that if an agent applies a force to a point on an object, at that point there arises an equal and opposite force back upon the agent. Were this no the case, the agent would not experience the process of exerting a force and we would have no basis for mechanics. The law of equal and opposite contact forces is thus fundamental both conceptually and perceptually, but it is legitimate to seek further underlying connections. In the case of a stationary object (fixed to the earth, say), the equal and opposite force can be said to arise in interatomic forces in the neighborhood of the point of contact which act to resist compression. This can be traced more deeply still to electromagnetic interactions involving orbital electrons of adjacent atoms or molecules, etc.

A similar experience of equal and opposite forces arises in the process of accelerating (pushing on) an object that is free to move. It is an experimental fact that to accelerate an object a force must be applied by an agent and that the agent will thus experience an equal and opposite reaction force so long as the acceleration continues. It appears that this equal and opposite reaction force also has a deeper physical cause, which turns out to also be electromagnetic and is specifically due to the scattering of ZPF radiation. Rueda and Haisch (1997a,b) demonstrate that from the point of view of the pushing agent there exists a net flux (Poynting vector) of ZPF radiation transiting the accelerating object in a direction necessarily opposite to the acceleration vector. The scattering opacity of the object to the transiting flux creates the back reaction force customarily called the inertia of the object. Inertia is thus a special kind of electromagnetic drag force, namely one that is acceleration-dependent since only in accelerating frames is the ZPF perceived as asymmetric. In stationary or uniform-motion frames the ZPF is perfectly isotropic with a zero net Poynting vector.

The relativistic form of the equation of motion results because, from the point of view of the agent, the accelerating object has a velocity dependent proper volume due to length contraction in the direction of motion which modifies the amount of scattering of ZPF flux that takes place within the object.

The physical interpretation that springs from this analysis is the following. In stationary or uniform-motion frames the interaction of a particle with the ZPF will result in random oscillatory motions. Fluctuating charged particles will produce dipole scattering of the ZPF which may be parametrised by an effective scattering spectral coefficient $\eta(\omega)$ that depends on frequency. Owing to the relativistic transformations of the ZPF, in an accelerated frame the interactions between a particle and the field acquire a definite direction, i.e. the "scattering" of ZPF radiation generates a directional resistance force. This directional resistance force is proportional to and directed against the acceleration vector for the subrelativistic case and it proves to have the proper relativistic generalisation.

GRAVITATION:

If inertial mass, m_i, originates in ZPF-charge interactions, then, by the principle of equivalence so must gravitational mass, m_g. In this view, gravitation would be a force originating in ZPF-charge interactions analogous to the HRP inertia concept. Sakharov (1968) was the first to conjecture this interpretation of gravity. If true, gravitation would be unified with the other forces: it would be a manifestation of electromagnetism.

The general relativistic mathematical treatment of gravitation as a space-time curvature works extremely well. However if it could be shown that a different theoretica basis can be made analytically equivalent to space-time curvature, with its prediction of gravitational lensing, black holes, etc. this may reopen the possibility that gravitation should be viewed as a force. The following points are worth noting: (1) spacetime curvature is inferred from the propagation of light; (2) general relativity and quantum physics are at present irreconcilable, therefore something substantive is either wrong or missing in our understanding of one or both; (3) the propagation of gravitational waves is not rigorously consistent with space-time curvature. (The issue revolves around whether gravitational waves can be made to vanish in a properly chosen coordinate system. The discovery of apparent gravitational energy loss by the Hulse-Taylor pulsar provides indirect evidence for the existence of gravitational waves. Theoretical developments and calculations have not yet been performed to examine whether an approach based on the Sakharov (1968) ideas would predict gravitational waves, but the coordinate ambiguities of GR should not appear in a ZPF-referenced theory of gravitation.)

There were some early pioneering attempts, inspired by Sakharov's conjecture, to link gravity to the vacuum from a quantum field theoretical viewpoint (by Amati, Adler and others, see discussion and references in Misner, Thorne and Wheeler [1973]) as well as within SED. The first step in developing Sakharov's conjecture in any detail within the classical co·text of nonrelativistic SED was the work of Puthoff (1989). Gravity is treated as a residuum force in the manner of the van der Waals forces. Expressed in the most rudimentary way this can be viewed as follows. The electric component of the ZPF causes a given charged particle to oscillate. Such oscillations give rise to secondary electromagnetic fields. An adjacent charged particle will thus experience both the ZPF driving forces causing it to oscillate, and in addition forces due to the secondary fields produced by the ZPF-driven oscillations of the first particle. Similarly, the ZPF-driven oscillations of the second particle will cause their own secondary fields acting back upon the first particle. The net effect is an attractive force between the particles. The sign of the charge does not matter: it only affects the phasing of the interactions. Unlike the Coulomb force which, classically viewed, acts directly between charged particles, this interaction is mediated by extremely minute propagating secondary fields created by the ZPF-driven oscillations, and so is enormously weaker than the Coulomb force. Gravitation, in this view, appears to be a long-range interaction akin to the van der Waals force.

The ZPF-driven ultrarelativistic oscillations were named Zitterbewegung by Schrödinger. The Puthoff analysis consists of two separate parts. In the first, the energy of the Zitterbewegung motion is equated to gravitational mass, m_g (after dividing by c^2). This leads to a relationship between m_g and electrodynamic parameters that is identical to the HRP inertial mass, m_i, apart from a factor of two. This factor of two is discussed in the appendix of HRP, in which it is concluded that the Puthoff m_g should be reduced by a factor of two, yielding $m_i = m_g$ precisely.

The second part of Puthoff's analysis is more controversial. He quantitatively examines the van der Waals force-like interactions between two driven oscillating dipoles and derives an inverse square force of attraction. This part of the analysis has been challenged by Carlip (1993), to which Puthoff (1993) has responded, but, since problems remain (Danley 1994), this aspect of the ZPF-gravitation concept requires further theoretical development, in particular the implementation of a fully relativistic model.

Clearly the ZPF-inertia and the ZPF-gravitation concepts must stand or fall together, given the principle of equivalence. However, that being the case, the Sakharov-Puthoff-type gravity concept does legitimately refute the objection that "the ZPF cannot be a real electromagnetic field since the energy density of this field would be enormous and thereby act as a cosmological constant, Λ, of enormous proportions that would curve the Universe into something microscopic in size." This cannot happen in the Sakharov-Puthoff view. This situation is clearly ruled out by the elementary fact that, in this view, the ZPF cannot act upon itself to gravitate. Gravitation is not caused by the mere presence of the ZPF, rather by secondary motions of charged particles driven by the ZPF. *In this view it is impossible for the ZPF to give rise to a cosmological constant.* (The possibility of non-gravitating vacuum energy has recently been investigated in quantum cosmology in the framework of the modified Born-Oppenheimer approximation by Datta [1995].)

The other side of this argument is of course that as electromagnetic radiation is not made of polarisable entities one might naively no longer expect deviation of light rays by massive bodies. We speculate however that such deviation will be part of a fully relativistic theory that besides the ZPF properly takes into account the polarization of the Dirac vacuum when light rays pass through the particle-antiparticle Dirac sea. It should act, in effect, as a medium with an index of refraction modified in the vicinity of massive objects. This is very much in line with the original Sakharov (1968) concept. Indeed, within a more general field-theoretical framework one would expect that the role of the ZPF in the inertia and gravitation developments mentioned above will be played by a more general quantum vacuum field, as was already suggested in the HRP appendix.

SUMMARY OF FOUR TYPES OF MASSES AND IMPOSSIBILITY OF NEGATIVE MASS:

The proposed ZPF perspective associates very definite charged particle-field interactions with each of the four fundamental masses: inertial mass, active vs. passive gravitational mass and relativistic rest mass. It is important to be clear on the origin and interrelation of these "masses" when considering something as fundamental as the possibility of altering inertial (or gravitational) mass.

Inertial mass is seen as the reaction force due to the asymmetry of the perceived ZPF in any accelerated frame. A flux of ZPF radiation arises in an accelerated frame. When this flux is scattered by the charged particles (quarks or electrons) within any object a reaction force is generated proportional to the acceleration and to the proper volume of the object. This immediately rules out any science-fiction-like possibility of "negative mass" (not to be confused with anti-matter) originally hypothesized by Bondi (1957). If an observer moves to the right, the perceived motion of the surroundings must be to the left. There is no other rational possibility. Thus the flux scattering which is the physical basis of inertia must be directed against the motion since the (accelerated) motion is into the flux: an object being accelerated must push back upon the accelerating agent because from the point of view of the object the radiation is coming toward it, which in turn points back upon the accelerating agent.

Active gravitational mass is attributed to the generation of secondary radiation fields as a result of the ZPF-driven oscillation. Passive gravitational mass is attributed to the response to such secondary radiation fields. Finally, the relativistic rest mass in the $E = mc^2$ relation reflects the energy of the ZPF-induced *Zitterbewegung* oscillations. Mass is the manifestation of energy in the ZPF acting upon charged particles to create forces.

THE NEED FOR A QUANTUM DERIVATION:

Clearly a quantum field theoretical derivation of the ZPF-inertia connection is highly desirable. Another approach would be to demonstrate the exact equivalence of SED and QED. However as shown convincingly by de la Peña and Cetto (1996), the present form of SED is no. compatible with QED, but modified forms could well be, such as their own proposed "linear SED." Another step in the direction of reconciling SED and QED is the proposed modification of SED by Ibison and Haisch (1996), who showed that a modification of the standard ZPF representation (Eqs. 13a and 13b) can exactly reproduce the statistics of the electromagnetic vacuum of QED. This gives us confidence that the SED basis of the inertia and gravitation concepts is a valid one.

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Inertial Mass Viewed as Reaction of the Vacuum to Accelerated Motion

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ABSTRACT:

Preliminary analysis of the momentum flux (or of the Poynting vector) of the classical electromagnetic version of the quantum vacuum consisting of zero-point radiation impinging on accelerated objects as viewed by an inertial observer suggests that the resistance to acceleration attributed to inertia may be a force of opposition originating in the vacuum. This analysis avoids the *ad hoc* modeling of particle-field interaction dynamics used previously by Haisch, Rueda and Puthoff (1994) to derive a similar result. This present approach is not dependent upon what happens at the particle point but on how an external observer assesses the kinematical characteristics of the zero-point radiation impinging on the accelerated object. A relativistic form of the equation of motion results from the present analysis.

INTRODUCTION:

It was recently proposed [by Haisch, Rueda and Puthoff(1994), henceforth HRP], that the inertial property of matter could originate in interactions between electromagnetically interacting particles at the level of their most fundamental components (e.g., electrons, quarks) ar¹ the quantum vacuum (QV). This general idea is a descendent of a conjecture of Sakharov (1968) for the case of gravity that can be extended by the principle of equivalence to the case of inertia. In the accompanying paper (Haisch and Rueda, 1997), we give more references and further discussion pertinent to this point. The approach of stochastic electrodynamics (SED) was used in HRP to study the classical dynamics of a highly idealized model of a fundamental particle constituent of matter (that contained a "parton", i.e., a surrogate for a very fundamental particle component) responding to the driving forces of the so-called classical electromagnetic zero-point field (ZPF), the classical analog of the QV.

The primary purpose of the endeavour reported here is to find a simpler approach, which attempts to avoid drawbacks and model-related issues in the approach of HRP (see Cole 1997, Cole and Rueda, 1997), by examining how an opposing flux of radiative energy and momentum should arise under natural and suitable assumptions in an accelerated frame from the viewpoint of an inertial observer and without regard to details of particle-field dynamics, i.e., independently of any dynamical models for particles. Using relativistic transformations for the electromagnetic fields, it is argued that upon acceleration a time rate of change of momentum density or momentum flux will arise out of the ZPF, and that this turns out to be directed against and linearly proportional to the acceleration. This arises after evaluation of the ZPF momentum density as it appears at a given point in an accelerated frame S, to an independent inertial laboratory observer due to transformations of the fields from the observer's inertial laboratory reference frame, I•, to another inertial frame I₁ instantaneously comoving with the object and from the viewpoint of the observer in the laboratory inertial frame I•. Absorption or scattering of this radiation by the accelerated charged particle will thus result in a force opposing the acceleration, yielding an f = ma relation for subrelativistic motions. (Vectors are symbolized throughout by boldface letters or by an arrow or a line on top of the letter,

ZERO-POINT FIELD AND HYPERBOLIC MOTION:

We assume a non-inertial frame of reference, S, accelerated in such a way that the acceleration a as seen from a particle fixed to a specific point, namely (c²/a, 0, 0), in the accelerated system, S, remains constant. Such condition leads as in Boyer (1984) and HRP to the well-known case of hyperbolic motion (see.e.g. Rindler, 1991) We again

represent the classical electromagnetic ZPF in the traditional form and assume the same three reference systems I•, I$_\tau$ and S, as in HRP and originally introduced in Boyer (1984). I• is the inertial laboratory frame. S is the accelerated frame in which the particle is placed at rest at the point (c^2/a, 0, 0). τ is the particle proper time as measured by a clock located at this same particle point (c^2/a, 0, 0) of S. I$_\tau$ is an inertial system whose (c^2/a, 0, 0) point at proper time τ exactly coincides with the particle point of S. The acceleration of this (c^2/a, 0, 0) point of S is a as measured from I$_\tau$. Hyperbolic motion is defined such that a is the same for all proper times τ as measured in the corresponding I$_\tau$ frames at a point (c^2/a, 0, 0) that in each one of these I$_\tau$ frames instantaneously comoves and coincides with the corresponding particle point, namely (c^2/a, 0, 0) of S. At proper time τ = 0, this particle point of the S system instantaneously coincides with the (c^2/a, 0, 0) point of I• and thus I• = I$_\tau$ (τ = 0). We refer to the observer's laboratory time in I• as t•, chosen such that t• = 0 at τ = 0. For simplicity we let the particle acceleration a at proper time τ take place along the x-direction so that $\vec{a}$ = a$\hat{x}$, is the same constant vector, as seen at every proper time τ in every corresponding I$_\tau$ system. The acceleration of the (c^2/a, 0, 0) point of S as seen from I• is a• = γ_τ^{-3}a. We take S as a "rigid" frame. It can be shown that as a consequence the acceleration a is not the same for the different points of S, but we are only interested in points inside a small neighborhood of the accelerated object [Rindler (1991)]. Specifically we are interested in a neighborhood of the object's central point that contains the object and within which the acceleration is everywhere essentially the same.

Because of the hyperbolic motion, the velocity $u_x(\tau) = c\beta_\tau$ in S with respect to I• , is

$$\beta_\tau = \frac{u_x(\tau)}{c} = \tanh\left(\frac{a\tau}{c}\right)$$

(1)

and then

$$\gamma_\tau = \left(1 - \beta_\tau^2\right)^{-\frac{1}{2}} = \cosh\left(\frac{a\tau}{c}\right)$$

(2)

The ZPF in the laboratory system I• is given by

$$E^{zp}\left(\vec{R}_\bullet, t_\bullet\right) = \sum_{\lambda=1}^{2} \int d^3k\, \hat{\varepsilon}(k,\lambda) H_{zp}(\omega) \cos\left[\vec{k} \cdot \vec{R}_\bullet - \omega t_\bullet - \theta(\vec{k},\lambda)\right],$$

(3a)

$$B^{zp}\left(\vec{R}_\bullet, t_\bullet\right) = \sum_{\lambda=1}^{2} \int d^3k\, \left(\hat{k} \times \hat{\varepsilon}\right) H_{zp}(\omega) \cos\left[\vec{k} \cdot \vec{R}_\bullet - \omega t_\bullet - \theta(\vec{k},\lambda)\right]$$

(3b)

R• and t• refer respectively to the space and time coordinates of the point of observation of the field in I•. At t• = 0, the point R• = (c^2/a)$\hat{x}$ of I• and the particle in S coincide. The phase term {θ(k, λ)} is a family of random variables, uniformly distributed between 0 and 2π, whose mutually independent elements are indexed by the wavevector k and the polarization index λ. Furthermore one defines,

$$H_{,p}^2(\omega) = \frac{\hbar\omega}{2\pi^2}.$$

(4)

The coordinates R• and time t• refer to the particle point of the accelerated frame S as viewed from I• We, for convenience, Lorentz-transform the fields from I• to the corresponding I$_\tau$ frame tangential to S and then, omitting for simplicity to display explicitly the λ and k dependence in the polarization vector

$$\hat{\varepsilon} = \hat{\varepsilon}(\vec{k}, \lambda),$$

we obtain

$$\bar{E}^{\,xp}(0,\tau) = \sum_{\lambda=1}^{2} \int d^3k \left\{ \hat{x}\hat{\varepsilon}_x + \hat{y}\gamma\tau\left[\hat{\varepsilon}_y - \beta_r\left(\hat{k} \times \hat{\varepsilon}\right)_z\right] + \hat{z}\gamma_r\left[\hat{\varepsilon}_z + \beta_r\left(\hat{k} \times \hat{\varepsilon}\right)_y\right] \right\} \times H_{zp}(\omega) \cdot \vec{k} \cdot \bar{R} - \omega t_* - \theta(\vec{k}, \lambda)\right]$$

(5a)

$$\bar{B}^{\,xp}(0,\tau) = \sum_{\lambda=1}^{2} \int d^3k \left\{ \hat{x}\left(\hat{k} \times \hat{\varepsilon}\right)_x + \hat{y}\gamma_r\left[\left(\hat{k} \times \hat{\varepsilon}\right)_y + \beta_r\hat{\varepsilon}_z\right] + \hat{z}\gamma_r\left[\left(\hat{k} \times \hat{\varepsilon}\right)_z - \beta_r\hat{\varepsilon}_y\right] \right\} \times H_{zp}(\omega)\cos\left[\vec{k} \cdot \bar{R} - \omega t_* - \theta(\vec{k}, \lambda)\right],$$

(5b)

where the zero in the argument of the I_τ fields, E^{xp} and B^{xp} actually means the I_τ spatial poi $\cdot\cdot$ (c^2/a, 0, 0). Here we observe that we take the fields that correspond to the ZPF as viewed from every inertial frame I_τ (whose (c^2/a, 0, 0) point coincides with the particle point (c^2/a, 0, 0) of S and instantaneously comoves with the particle at the corresponding instant of proper time τ), to also represent the ZPF viewed instantaneously and from the single point, (c^2/a, 0, 0) in S.

We can select space and time coordinates and orientation in $I_\cdot$ such that

$$\bar{R}_\bullet(\tau) \cdot \hat{x} = \frac{c^2}{a} \cosh\left(\frac{a\tau}{c}\right)$$

(6)

$$t_\bullet = \frac{c}{a} \sinh\left(\frac{a\tau}{c}\right)$$

(7)

From the equations above one obtains [1, 4]

$$\bar{E}^{\,xp}(0,\tau) = \sum_{\lambda=1}^{2} \int d^3k$$

$$\times \left\{ \hat{x}\hat{\varepsilon}_x + \hat{y}\cosh\left(\frac{a\tau}{c}\right)\left[\hat{\varepsilon}_y - \tanh\left(\frac{a\tau}{c}\right)\left(\hat{k} \times \hat{\varepsilon}\right)_z\right] + \hat{z}\cosh\left(\frac{a\tau}{c}\right)\left[\hat{\varepsilon}_z + \tanh\left(\frac{a\tau}{c}\right)\left(\hat{k} \times \hat{\varepsilon}\right)_y\right] \right\}$$

$$\times H_{zp}(\omega)\cos\left[k_x\frac{c^2}{a}\cosh\left(\frac{a\tau}{c}\right) - \frac{\omega c}{a}\sinh\left(\frac{a\tau}{c}\right) - \theta(\vec{k}, \lambda)\right]$$

(8a)

$$\vec{B}_r^{zp}(0,\tau) = \sum_{\lambda=1}^{2} \int d^3k$$

$$\times \left\{ \hat{x}\left(\hat{k} \times \hat{\varepsilon}\right)_x + \hat{y}\cosh\left(\frac{a\tau}{c}\right)\left[\left(\hat{k} \times \hat{\varepsilon}\right)_y + \tanh\left(\frac{a\tau}{c}\right)\hat{\varepsilon}_z\right] + \hat{z}\cosh\left(\frac{a\tau}{c}\right)\left[\left(\hat{k} \times \hat{\varepsilon}\right)_z - \tanh\left(\frac{a\tau}{c}\right)\hat{\varepsilon}_y\right] \right\}$$

$$\times H_{zp}(\omega)\cos\left[k_x\frac{c^2}{a}\cosh\left(\frac{a\tau}{c}\right) - \left(\frac{\omega c}{a}\right)\sinh\left(\frac{a\tau}{c}\right) - \theta(\vec{k},\lambda)\right]$$

(8b)

This is the ZPF as instantaneously viewed from the particle fixed to the point $(c^2/a, 0, 0)$ of S that is performing the hyperbolic motion.

INERTIA REACTION FORCE AND THE ZPF MOMENTUM DENSITY

First we consider the following simple fluid analogy involving as a heuristic device a constant velocity and a spatially varying density in place of the usual hyperbolic motion through a uniform vacuum medium. Let a small *geometric figure* of a fixed proper volume V_o, move uniformly with *subrelativistic* velocity v along the x-direction. The volume V_o we imagine as always immersed in a fluid that is isotropic, homogeneous and at rest, except such that its density $\rho(x)$ increases in the x-direction but is uniform in the y- and z-directions. Hence, as this small fixed volume V_o moves in the x-direction, the mass enclosed in its volume, $V_o\rho(x)$, increases. In an inertial frame at rest with respect to the geometric figure the mass inside the volume $V_o\rho(x)$, is seen to grow. Concomitantly it is realized that the volume V_o is sweeping through the fluid and that this $V_o\rho(x)$ mass grows because there is a *net influx* of mass coming into V_o in a direction opposite to the direction of the velocity v. In an analogous fashion, for the more complex situation envisaged in this paper, simultaneously with the steady growth of the ZPF momentum contained within the volume of the object discussed above, the object is sweeping through the ZPF of the I* inertial observer and for him there is a net influx of momentum density coming from the background into the object and in a direction opposite to that of the velocity of the object.

As it is the ZPF radiation background of I* in the act of being swept through by the particle which we are calculating now, we fix our attention on a fixed point of I*, say the point of the observer at $(c^2/a, 0, 0)$ of I*, that momentarily coincides with the object at the object proper time $\tau = 0$. and consider that point as referred to the inertial frame I_τ that instantaneously will coincide with the object at a future generalized object proper time $\tau > 0$. Hence we compute the I_τ-Poynting vector, but evaluated at the $(c^2/a, 0,0)$ space point of the I* inertial frame, namely in I_τ at the I_τ space-time point.

(9)

$$ct_\tau = -\frac{c^2}{a}\sinh\left(\frac{a\tau}{c}\right),$$

$$x_\tau = \frac{c^2}{a}\cosh\left(\frac{a\tau}{c}\right), y_\tau = 0, z_\tau = 0,$$

(10)

where t_τ, the time of I_τ is selected such that $t_\tau = 0$ at proper time τ when the particle comoves and coincides with the $(c^2/a, 0, 0)$ point of I_τ. This Poynting vec or we shall denote by N.* Everything however is ultimately referred to the I* inertial frame as that is the frame of the observer that looks at the object and whose ZPF background the moving object is sweeping through. In order to accomplish this we first compute

$$\left\langle \overline{E}_r^{zp}(0,\tau) \times \overline{B}_r^{zp}(0,\tau)\right\rangle_x = \left\langle E_{y*}B_{z*} - E_{z*}B_{y*}\right\rangle$$

$$= \gamma_\tau^2\left\langle\left(E_{y*} - \beta_\tau B_{z*}\right)\left(B_{z*} - \beta_\tau E_{y*}\right) - \left(E_{z*} + \beta_\tau B_{y*}\right)\left(B_{y*} + \beta_\tau E_{z*}\right)\right\rangle$$

$$= -\gamma_\tau^2\beta_\tau\left\langle E_{y*}^2 + B_{z*}^2 + E_{z*}^2 + B_{y*}^2\right\rangle + \gamma_\tau^2\left(1 + \beta_\tau^2\right)\left\langle E_{y*}B_{z*} - E_{z*}B_{y*}\right\rangle$$

$$= -\gamma_\tau^2\beta_\tau\left\langle E_{y*}^2 + B_{z*}^2 + E_{z*}^2 + B_{y*}^2\right\rangle$$

(11)

that we use in the evaluation of the Poynting vector

$$\overline{N}_*^{zp} = \frac{c}{4\pi}\left\langle\overline{E}_\tau^{zp} \times \overline{B}_\tau^{zp}\right\rangle_* = \hat{x}\frac{c}{4\pi}\langle E_\tau^{zp}(0,\tau) \times B_\tau^{zp}(0,\tau)\rangle_x$$

(12)

The integrals are now taken with respect to the I* ZPF background as that is the background that the I*-observer considers the object to be sweeping through. This is why we will denote this Poynting vector as N*^{zp}, with an asterisk subindex instead of a τ subindex, to indicate that it refers to the ZPF of I*. Observe that in eq.(11) the term proportional to the ordinary ZPF Poynting vector of I*, vanishes. The net amount of momentum of the background the particle has swept through after a time t*, as judged again from the I* frame viewpoint, is

$$\overline{p}_*^{zp} = \overline{g}_*^{zp}V_* = \frac{\overline{N}_*^{zp}}{c^2}V_* = -\hat{x}\frac{1}{c^2}\frac{c}{4\pi}\gamma_\tau^2\beta_\tau\frac{2}{3}\left\langle\overline{E}_*^2 + \overline{B}_*^2\right\rangle V_*$$

(13)

We can compute Eqs. (12) and (13) in more detail This as well as many other details or, the analysis will appear elsewhere (Rueda and Haisch, 1997). The Poynting vector that the radiation should have at the (c²/a,0,0) point of I* but referred to I* with the coordinates of eq.(11), can be shown to be

$$\overline{N}_*^{zp}(\tau) = \frac{c}{4\pi}\left\langle\overline{E}^{zp} \times \overline{B}^{zp}\right\rangle = \frac{c}{4\pi}\hat{x}\langle E_y B_z - E_z B_y\rangle = -\frac{c}{4\pi}\frac{8\pi}{3}\left[\int\frac{\hbar\omega^3 d\omega}{2\pi^2 c^3}\right]\sinh\left(\frac{2a\tau}{c}\right)\hat{x}$$

(14)

where E and B stand for E$_\tau$(0, τ) and B$_\tau$(0,τ) respectively as in the case of eq.(12) and where as in eqs.(11), (12) and (13) the integration is understood to proceed over the k-sphere of I*. The particle now is not in uniform but instead in accelerated motion. If suddenly, at proper time τ, the motion were to switch from hyperbolic back to uniform because the accelerating action disappeared, we would just need to replace in eq.(14) the constant rapidity ρ at that instant for aτ, and β$_\tau$ in eq. (1) would then become tanh (ρ/c). (But then N*^{zp} would cease to be, for all times onward, a function of τ and force expressions as eq.(17) below would vanish). Observe that we make explicit the τ dependence of this as well as of the subsequent quantities below. N*^{zp}(τ) represents energy flux, i.e., energy per unit area and per unit time in the x-direction It also implies a parallel, x-directed momentum density, i.e., field momentum per unit volume incoming towards the particle position, (c²/a, 0, 0) of S, at particle proper time τ and as estimated from the viewpoint of I*. Explicitly such momentum density is

$$\overline{g}_*^{zp}(\tau) = \frac{\overline{N}_*^{zp}(\tau)}{c^2} = -\hat{x}\frac{8\pi}{3}\frac{1}{4\pi c}\sinh\left(\frac{2a\tau}{c}\right)\int\eta(\omega)\frac{\hbar\omega^3}{2\pi^2 c^3}d\omega.$$

(15)

where we now introduce the frequency-dependent coupling coefficient, $0 \leq \eta(\omega) \leq 1$, that quantifies the fraction of absorption or scattering at each frequency. Let V_o be the proper volume of the particle, namely the volume that the particle has in the reference frame I_τ where it is instantaneously at rest at proper time τ. From the viewpoint of I_o, however, such volume is then $V_o = (1/\gamma_\tau)V_o$ because of Lorentz contraction. The amount of momentum due to the radiation inside the volume of the particle according to I_o, i.e., the radiation momentum in the volume of the particle viewed at the laboratory is

$$\overline{p}.^{\prime\prime} = V.\overline{g}.^{\prime\prime}(\tau) = \frac{V.}{\gamma_\tau}\overline{g}.^{\prime\prime}(\tau) = -\hat{x}\frac{4V_o}{3}(c\beta_\tau)\gamma_\tau\left(\frac{1}{c^2}\int \eta(\omega)\frac{\hbar\omega^3 d\omega}{2\pi^2 c^3}\right)$$

(16)

which is again eq. (13).

At proper time $\tau = 0$, the $(c^2/a, 0, 0)$ point of the laboratory inertial system I_o instantaneously coincides and comoves with the particle point of the Rindler frame S in which the particle is fixed. The observer located at $x_o = c^2/a$, $y_o = 0$, $z_o = 0$ instantaneously, at $t_o = 0$, coincides and comoves with the particle but because the latter is accelerated with constant acceleration a, the particle *according to* I_o should receive a time rate of change of incoming ZPF momentum of the form:

$$\frac{d\overline{p}.^{\prime\prime}}{dt_o} = \frac{1}{\gamma_\tau}\frac{d\overline{p}.^{\prime\prime}}{d\tau}\Big|_{\tau=o}$$

(17)

We *postulate* that such rate of change may be identified with a force from the ZPF on the particle. Such interpretation, intuitively at least, looks natural. If the particle has a proper volume V_o, the force exerted on the particle by the radiation from the ZPF as seen in I_o at $t_o = 0$ is then

$$\frac{d\overline{p}.^{\prime\prime}}{dt_o} = \overline{f}.^{\prime\prime} = -\left(\frac{4}{3}\frac{V_o}{c^2}\int \eta(\omega)\frac{\hbar\omega^3 d\omega}{2\pi^2 c^3}\right)\overline{a} = -m_i\overline{a}$$

(18)

Furthermore

$$m_i = \left(\frac{V_o}{c^2}\int \frac{\eta(\omega)\hbar\omega^3 d\omega}{2\pi^2 c^3}\right)$$

(19)

is an invariant scalar with the dimension of mass. Observe that in eq.(19) we have neglected a factor of 4/3 that should appear multiplying in front. Such factor must be neglected because a fully covariant analysis (Rueda and Haisch, 1997) shows that it disappears. The corresponding form of m_i as written (and without the 4/3 factor) is susceptible of a natural interpretation: Inertial mass is the mass of the energy of the ZPF radiation enclosed within the particle and that does actually interact with it ($\eta(\omega)$ factor in the integrand).

THE ZERO-POINT FIELD MOMENTUM CONTENT

Limitations in the space prevents us from discussing an important complementary approach to the previous one. The corresponding analysis is however similar to that above and will be displayed in Rueda and Haisch (1997). It produces instead of the time rate of $p^{\prime\prime}$ the time rate of p, the momentum content of the particle. The analysis

yields a natural interpretation. The following feature deserves special attention. After the acceleration proce.. s completed, from the point of view of an inertial observer attached to the stationary laboratory frame there appe s associated with the body in motion a net flux of momentum density in the surrounding ZPF. In other words, on calculating the ZPF momentum contained in the object as referenced to the observer's own inertial frame, the observer would conclude that a certain amount of momentum is instantaneously contained within the proper volume V_o of the moving object. This momentum is directly related to what would normally be called the physical momentum of the object. Calculated with respect to its own frame the object itself would find not net ZPF momentum contained within itself, consistent with the view that one's own momentum is necessarily always zero.

RELATIVISTIC FORCE EXPRESSION

From the definition of the momentum p^{zp} in eq.(16), from eqs.(17), (18), and Newton's third law it immediately follows that the momentum of the particle is

$$\bar{p} = m_i \, \gamma_\tau \, c \bar{\beta}_\tau$$

(20)

in exact agreement with the momentum expression for a moving particle in special relativity. The expression for the space vector component of the four-force is then

$$\bar{F}_\bullet \qquad \gamma_\tau \frac{\Phi_\bullet}{d_\bullet} \cdot \frac{\Phi_\bullet}{r \cdot}$$

(21)

and as the force is *pure* in the sense of Rindler (1991), after dropping the · subindex the correct form for the four-force immediately follows

$$\mathcal{F} = \frac{d\bar{p}}{d\tau} = \frac{d}{d\tau}(\gamma_\tau m_i c, \bar{p}) = \gamma_\tau \left(\frac{1}{c} \frac{dE}{dt}, \bar{f} \right) = \gamma_\tau \left(\bar{f} \cdot \bar{\beta}_\tau, \bar{f} \right) = \left(\bar{F} \cdot \bar{\beta}_\tau, \bar{F} \right),$$

(22)

in the ordinary way anticipated above.

CONCLUSION

As the expression for the ZPF reaction force of eq (18) depends only on the i .tantaneous value of the acceleration imposed on the accelerated object by the accelerating agent, it arguably follows that this absence of any memory effects, i.e., of any expression in the force that reveals its underlying unidirectional hyperbolic motion origin, permits to readily generalize the argument to much more general type of motions. Further relevant features of the general argument (Rueda and Haisch. 1997) not mentioned here are a fully covariant calculation, a discussion and analysis of the character of the k-space integrations and a more detailed evaluation of the Poynting cross products. These will also be presented in Rueda and Haisch (1997).

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Calculations on Electromagnetic Zero-Point Contributions to Mass and Perspectives

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The present article discusses material to be presented at a conference entitled, "Breakthrough Propulsion Physics Workshop," in August, 1997, at NASA. Three topics involving electromagnetic zero-point (ZP) radiation will be discussed here that appear to be of interest to the workshop, namely, the possible relation of electromagnetic ZP fields to inertial mass and gravity and a proposed process involving extracting energy from the vacuum. All three topics have been discussed in the literature in relatively recent years. In particular, a proposal was made [H. E. Puthoff, Phys. Rev. A 39 2333 (1989)] that the electromagnetic ZP fields are the fundamental basis for the gravitational interaction; later, a related proposal was made [B. Haisch, A. Rueda, and H. E. Puthoff, Phys. Rev. A 49, 678 (1994)] that these fields are also the origin for inertial mass. As summarized here, unfortunately, a detailed examination of the specific steps in the calculations supporting these two proposals show that several of the critical steps in the analyses have severe problems. Regarding the third topic, however, of extracting energy from the vacuum, this process does seem feasible. The main question here is whether a fresh perspective on ZP energy will enable viable energy extraction processes to be developed that are not already in existence.

I. INTRODUCTION

Three areas of research will be described here that appear to be of close interest to the present conference entitled, "Breakthrough Propulsion Physics Workshop." These three areas are: (1) the reaction force of electromagnetic zero-point (ZP) radiation on an accelerated electric dipole oscillator, (2) the asymptotic analysis of the van der Waals forces between electric dipole oscillators, and (3) the thermodynamics of physical operations involved with extracting energy from electromagnetic ZP radiation. Most of the present article will concentrate on the first topic of the reaction force from ZP radiation.

What relation do these three apparently very distinct topics have to each other and what relation do they have to "propulsion physics?" All three areas are related to proposals by others for constructing alternative physical means for space travel [1], [2]. As I have recently learned when approached about this workshop, to seriously consider interstellar travel within one's lifetime, significant breakthroughs in the use of new physical ideas and methods are required. More specifically, the types of propulsion for space travel that the scientific community is familiar with, or even the types that at least seem reasonably feasible given our present level of knowledge, such as propulsion via chemical, fission, or fusion methods, would all require far, far longer times than a typical human lifetime to travel from our solar system to the next nearest star (Alpha Centauri). Moreover, the present known methods for propulsion would all require incredibly enormous quantities of fuel, making such a trip essentially impossible for any reasonable flight time that one might want to consider.

The first two of the three topics that will be discussed here involve my investigations on proposed ideas by others who have attempted to explain gravity and inertia as arising from the effects of electromagnetic ZP radiation acting on matter [3], [4]. Other people [1] have some hopes that such a connection, if true, might enable means to be found for manipulating gravity via methods more familiar from electromagnetic work [5]. The third topic that will be discussed here on energy extraction from ZP radiation has been stated to be of interest to this workshop since there is a need to "discover fundamentally new on-board energy production methods to power propulsion devices." [6]

In this article I will cover these three topics sequentially, then at the end give some concluding remarks. Briefly, however, my outlook at this point is that for the first topic involving the reaction force from electromagnetic ZP radiation on an accelerated system, there is indeed some very interesting physics to report, and more to explore, but this mechanism does not appear to provide the fundamental explanation for inertia proposed in Ref. [4]. For the second topic, Puthoff [3] has proposed that gravity may be explained as the result of a van der Waals like mechanism between distant particles, due to a correlated jiggling motion caused by electromagnetic ZP radiation. Likewise, as with the first topic, this proposed mechanism looks doubtful to me. Finally, regarding the third topic of energy extraction from the vacuum [7], [8], [9], this concept seems quite reasonable. The question here, however, will be whether or not viewing energy extraction in this manner will prove to provide new practical energy extraction methods.

II. STOCHASTIC ELECTRODYNAMICS

Before covering these three topics, I need to mention that my work has all been addressed using the methods of a theory often called "stochastic electrodynamics," and usually abbreviated as "SED". The first two topics I will report on certainly rely on the calculational methods of this theory. while the third topic of "energy extraction" does not. Stochastic electrodynamics is a theory that treats the movement of classical charged particles via conventional classical electrodynamics, namely, via Maxwell's equations and the relativistic generalization of Newton's second law of motion. However, one additional feature is included, namely, the assumption is made that as the temperature of a thermodynamic system is reduced to zero, the thermal electromagnetic radiation present does not simply reduce to zero, but rather to what is called the "zero-point" spectrum given by: $\rho(\omega) = \frac{\hbar\omega}{2} \left(\frac{\omega^2}{\pi^2 c^3} \right)$.

The following reasoning provides one of the main motivating factors behind the theory of SED, namely, that one should not consider the equilibrium behavior of classical charged particles in isolation from the thermal equilibrium behavior of electromagnetic radiation. As classical charged particles interact with each other, they naturally accelerate and deaccelerate during their trajectories, thereby radiating electromagnetic radiation. Indeed, as two oppositely charged point charges rapidly approach each other, the radiated energy roughly rises inversely proportional to the distance between them. Hence, radiation must be a very key component of any system that might constitute a thermal equilibrium situation for classical charged particles. Indeed, because of Earnshaw's theorem [10], we know that a system of classical charged particles cannot exist in static, stable equilibrium. Thus, if an equilibrium situation for classical charged particles is at all possible, then the charges must be following a fluctuating, oscillating trajectory in space. A self consistent picture is then obtained when one realizes that the electromagnetic radiation arising from this fluctuating trajectory must effect the trajectory of other particles and must be an integral part for enabling thermal equilibrium to be obtained between particles and radiation. This concept is actually a fairly natural one for most people when they think of a system at a temperature $T > 0$; i.e , it is commonly accepted to think of a thermal fluctuating system with an average energy of the fluctuations dictated by T. Since the early 1900s, experimentally we know that fluctuations also exist even at $T = 0$. Combining this observation with the ideas about Earnshaw's theorem, and the other remarks above, leads SED proponents to believe that fluctuations between classical particles and fields are also a key feature even at $T = 0$.

A number of very interesting properties have been established for classical electromagnetic ZP radiation, including that the spectrum exhibits Lorentz invariance [11], [12] and that it satisfies the thermodynamic definition of $T = 0$ by resulting in no heat flow during reversible thermodynamic operations for several simple electrodynamic systems that have been examined [13]- [16]. What makes the theory of SED particularly interesting is that besides reexamining the age-old problem of whether equilibrium can exist for classical charged particles, which at some level might be viewed as purely an exercise of academic interest, one finds that SED actually predicts the correct quantum mechanical properties of simple electrodynamic systems. Indeed, many people working in the area of SED have hoped that SED might prove sufficiently powerful to provide a very deep understanding and microphysical basis for quantum mechanical phenomena.

Unfortunately, to date, this hope has not materialized. Agreement has been found for linear systems. However, for nonlinear systems found in nature, SED has so far been found to yield physically incorrect predictions. Whether this disagreement is the final story for SED, or whether there are inaccuracies in the basis for the calculations carried out to date, has not been fully settled yet [17]. Certainly, however, it is safe to say that only a very small minority of physicists believe that SED is the correct approach to adequately describe nature.

The natural question must then arise as to why would one use SED for the calculations reported in this article? At least three simple answers exist. First, provided one stays in the regime where only a linear system is considered, in particular a simple harmonic oscillator (SHO), then the results of these calculations should be accurate. Such is the case for the results reported here. Second, the physical concepts in SED are very clear; one doesn't run into the complications of quantum electrodynamics (QED) where it is difficult to keep straight what is physically real and what is not. In QED, such questions become increasingly more difficult when dealing with accelerated systems, such as what will be discussed here. Third, for some types of calculations the techniques of SED are considerably easier than those of QED. Indeed, a number of calculations in SED have preceded ones in QED, such as with the analysis of the behavior of simple electrodynamic systems accelerated through the vacuum (simple, but more complicated than a single particle) [18], or with regard to some van der Waals force calculations carried out at $T > 0$ and at all distances [21], [13].

For those interested, Refs. [22]- [27] provide further background on SED.

III. INTRODUCTORY REMARKS ON RELATING GRAVITY AND INERTIA TO THE VACUUM

Let us now turn to the first two of the three topics that will be discussed here. In relatively recent years, a line of research has been pursued by a few researchers [3], [4] that has prompted much of the work summarized in the present section and in the subsequent one. The research being referred to here involves the possible relationship between gravity, inertia, and ZP energy. Indeed, Puthoff [28] has proposed that "... gravity is a form of long-range van der Waals force associated with particle *Zitterbewegung* response to the zero-point fluctuations of the electromagnetic field." Puthoff's work contained calculations that he felt showed that one could obtain the Newtonian approximation to the gravitational interaction by considering the effects of the ZP fields on creating a correlated, fluctuating motion between distant particles. The pursuit of this idea was motivated by an article by Sakharov [29] that proposed the gravitational interaction is not a fundamental physical interaction at all, but rather that it results from a "... change in the action of quantum fluctuations of the vacuum if space is curved." [29]

Using somewhat analogous motivating ideas to that of Puthoff's in Ref. [3], Haisch, Rueda, and Puthoff (HRP) have proposed that inertia arises due to the average resistive force that acts on matter when it is accelerated through the vacuum. These researchers proposed, based on lengthy calculations for the behavior of a specific particle model, that the average of the "magnetic component" of the electromagnetic Lorentz force due to electromagnetic ZP radiation acting on the particle is equal to $-m_i a$, where a is the acceleration and m_i is the inertial mass. More specifically, they calculated $e\left\langle \frac{v}{c} \times B^{ZP} \right\rangle$, where the brackets mean an ensemble average, v is the velocity of an oscillating particle within the accelerating particle, e is the charge of the oscillating particle, c is the speed of light, and B^{ZP} is the classical magnetic ZP field acting on the oscillating particle.

Certainly if these proposals are correct, then this work represents very profound physical changes to physicists' conceptions about gravity and inertia. Moreover, if correct, then it seems reasonable to speculate that inertial and gravitational properties of matter might be alterable somewhat by modifying the structure of the vacuum, perhaps very much like what is done in cavity quantum electrodynamic experiments [30]. Although it is far from clear to me how these procedures might provide practical means of aid for improved propulsion schemes, which is one of the main aims of this conference, still, I do recognize that this possible explanation for inertia and gravity, if correct, would open up new possibilities for controlling our environment. The key question then would be to what extent this can be accomplished.

The authors in Refs. [3], [4] supply a number of suggestive arguments as to why ZP radiation should provide an explanation for gravity and inertia. Their calculations attempt to support these arguments. Consequently, it seems critically important to carefully check the accuracy of these calculations. After all, no matter how much one believes or does not believe in the basic physical arguments, the details of sorting through the calculations, their predictions, and whether they agree with physical observation, are ultimately what dictates the usefulness of the theory. Reference [31] examines the calculations in Ref. [4] in considerable detail, carries out some corrections, and extends them by removing some approximations. Here, the results of some of these calculations in Ref. [31] will be reported and summarized. In addition, many of the physical assumptions and limitations in Ref. [4] are examined in some detail in Ref. [32] and are briefly mentioned here.

The calculations in Ref. [4], in particular, were quite lengthy, with a number of approximations made to yield the final results that were obtained. The calculations were sufficiently complex to make it quite difficult to determine the full validity of the approximations, which is what prompted much of the work in Ref. [31]. As will be described here, the results of the detailed calculations that reexamine the work in Refs. [3] and [4] disagree with the major conclusions of these references. Consequently, the point that will be made in the concluding section here (Sec. VI) is that despite the very interesting qualitative ideas in Refs. [3] and [4], the details of the mathematics do not justify them in several critical ways. Unless the detailed calculations back up the general ideas, then we need to conclude that the gravity and inertia ideas involving ZP energy as the source, are not correct as they presently stand.

IV. REACTION FORCE OF ELECTROMAGNETIC ZP RADIATION

Reference [4] consid... . an electric dipole SHO that was uniformly accelerated through the va.. m. A specific model of a particle was considered that consisted of an overall neutral particle containing an internal oscillating point charge. This point charge was assumed to undergo stochastic oscillations in its trajectory due to the fluctuations of the ZP fields acting upon it. The SHO binding force acting on th oscillating particle essentially connected to the rest of the composite particle. The entire system was assumed to be uniformly accelerated through space, meaning that as observed in the rest frame of the equilibrium point of the composite particle (i.e., the place where the SHO force equals zero), the equilibrium point was always accelerated at a constant rate given by a.

Although one might wonder why the behavior of such a specific system might be chosen to be analyzed when we know it represents, at best, only a very approximate description for a molecule, an atom, a nucleus, or a subatomic particle, probably the best reason is that for anything much more complicated, the calculations become extremely unwieldy and unmanageable. As with many papers in physics, dating back to the early papers of such people as Einstein and Planck, often difficult calculations are done on the simplest system possible to first demonstrate the intended behavior, and are then generalized if at all possible once the pattern of the underlying physical behavior is understood. I believe this was the intent of Refs. [3] and [4] Indeed, since then, Rueda and Haisch in Ref. [33] have attempted to generalize the results in [4] to other systems in nature [34].

To calculate $e\left\langle \frac{v}{c} \times \mathbf{B}^{\mathrm{ZP}} \right\rangle$, the oscillating trajectory of the fluctuating internal particle must be known, which was obtained in Ref. [19] by essentially linearizing the Lorentz-Dirac equation that describes the motion of a classical charged particle. In this way, the velocity $\mathbf{v}$ can be expressed in terms of the proper time of the particle and in terms of the ZP fields acting to cause the fluctuating motion of the internal particle. As done in Ref. [4], if the coordinate system is set up so that the uniform acceleration occurs along the $\hat{x}$ direction and oscillations are constrained to occur in the $x - y$ plane, then the ensemble average of this magnetic component of the Lorentz force, as measured in the rest frame of the equilibrium point of the composite particle, is given by

$$F_{\mathrm{M},x} = \frac{e}{c} \left\langle \frac{dy_{\tau_e}}{dt_{\tau_e}} B_{\tau_e,z}^{\mathrm{ZP}}\left(\mathbf{X}_{\tau_e}\left(t_{\tau_e}\right), t_{\tau_e}\right) - \frac{dz_{\tau_e}}{dt_{\tau_e}} B_{\tau_e,y}^{\mathrm{ZP}}\left(\mathbf{X}_{\tau_e}\left(t_{\tau_e}\right), t_{\tau_e}\right) \right\rangle_{t_{\tau_e}=0} . \tag{1}$$

Here, τ_e represents the proper time associated with the equilibrium point of the composite particle, t_{τ_e} is the time as measured in the instantaneous inertial rest frame of this point, $\mathbf{X}_{\tau_e}$ is the position of this equilibrium point in this inertial rest frame, and y_{τ_e} and z_{τ_e} represent the y and z positions of the oscillating internal particle in this same frame. Upon expressing y_{τ_e} and z_{τ_e} in terms of the ZP fields causing the fluctuating motion and upon recognizing some symmetry properties, one obtains:

$$F_{\mathrm{M},x} = \frac{e^2}{m_0 c} \frac{(-i)}{\pi} \int_{-\infty}^{\infty} d\tau_e' J\left(\tau_e' - \tau_e\right) \left\langle E_{\tau_e',y}^{\mathrm{ZP}}\left(0,\tau_e'\right) B_{\tau_e,z}^{\mathrm{ZP}}\left(0,\tau_e\right) \right\rangle \quad , \text{ where} \tag{2}$$

$$J(\alpha) = \int_{-\infty}^{\infty} d\Omega \frac{\Omega \exp\left[i\Omega\alpha\right]}{\left[\omega_0^2 - \Omega^2 - i\Gamma\left(\Omega^3 + \Omega a^2/c^2\right)\right]} . \tag{3}$$

Here, $\Gamma = \frac{2}{3}\frac{e^2}{mc^3}$ and m is the mass of the internal oscillating particle. In Eq. (2), the quantity $\left\langle E_{\tau_e',y}^{\mathrm{ZP}}\left(0,\tau_e'\right) B_{\tau_e,z}^{\mathrm{ZP}}\left(0,\tau_e\right) \right\rangle$ represents the correlation function, or ensemble average, between two components of the electric and magnetic ZP fields at different proper times τ_e' and τ_e along the trajectory of the equilibrium point of the uniformly accelerated particle.

Equation (2) can be shown to agree with expressions in Ref. [4] before certain approximations were made there. What is particularly interesting about this expression is that if one carries out a calculation of $\left\langle E_{\tau_e',y}^{\mathrm{ZP}}\left(0,\tau_e'\right) B_{\tau_e,z}^{\mathrm{ZP}}\left(0,\tau_e\right) \right\rangle$ in SED for $\tau_e' \neq \tau_e$, then in the no-cut-off limit (i.e., meaning in the limit where the upper frequency limit of the ZP spectrum is assumed to be infinite, so that there is no upper frequency cut-off), one can show that $\left\langle E_{\tau_e',y}^{\mathrm{ZP}}\left(0,\tau_e'\right) B_{\tau_e,z}^{\mathrm{ZP}}\left(0,\tau_e\right) \right\rangle$ exactly equals zero. This result can be shown to agree exactly with the corresponding quantity in QED [35], [36].

Hence, one's initial reaction to the expression in (2) might be naturally be that the force should equal zero. Such was my initial reaction, which was one of the reasons why I strongly suspected that the results in Ref. [4] might be incorrect. Casting the equation for $F_{\mathrm{M},x}$ in terms of an integral over a correlation function is what enables one to make this observation; Eq. (2) is different, but equivalent, to the starting expressions in Ref. [4]. My suspicion was that Eq. (2) did indeed equal zero, although I also suspected that there was another term involving $e\left\langle z \cdot \nabla \mathbf{E}^{\mathrm{ZP}} \right\rangle$ that needed to be calculated that might contribute in an important manner.

However, Eq. (2) does not equal zero. Although I did not arrive at the same results that HRP did, due to a number of reasons that I will roughly explain here, neither did I obtain a zero answer. The reason for this is that one has

to be very careful when carrying out the integral in Eq. (2) over τ'_e, as the correlation function does not equal zero when $\tau'_e = \tau_e$. Instead, the correlation function is singular at this point. Consequently, one needs to use more sophisticated techniques for dealing with this singularity while integrating through it. Reference [31] describes how this was carried out. Roughly, though, it involves first evaluating the integrand in Eq. (2) when a finite upper frequency limit is assumed for the ZP spectrum. For a finite upper frequency limit, the integrand is no longer singular, so the integration can then be safely carried out. The result is that $F_{M,x}$ can be expressed as a function of the frequency cut-off, at which point one can then examine taking the no cut-off limit in the spectrum.

Several approximations made in Ref. [4] were removed in [31], including a small velocity approximation involving Eqs. (20) and (21) in Ref. [4], which can be shown to be invalid when carrying out the integral over all τ'_e in Eq. (2). Also, the exact expressions were obtained for $J(\alpha)$ in Eq. (3), from which a full expansion to any order in Γ can be made. Finally, an accurate method was found to express the correlation function [37],

$$C_{M,\sigma}\left(\tau'_e - \tau_e\right) \equiv \left\langle E^{ZP}_{\tau'_e,y}(0,\tau'_e)\, B^{ZP}_{\tau_e,z}(0,\tau_e)\right\rangle\ ,\tag{4}$$

while integrating over the product of $J\left(\tau'_e - \tau_e\right)C_{M,\sigma}\left(\tau'_e - \tau_e\right)$ in Eq. (2). These steps led to the recognition that the step in Ref. [4] of neglecting the $\tau'_e > \tau_e$ part of the integral in Eq. (2) was not correct [38].

Correcting these steps lead to the result that the average of the ZP Lorentz force, as expanded in the ZP spectrum cut-off parameter σ [37], is given by:

$$F_{M,x} = 0\cdot a\frac{\Gamma\hbar}{\pi\sigma^2} - \frac{3}{2\,c^2\Gamma}a\frac{\hbar}{\pi} + \left(\frac{1}{c^3\Gamma^2} + \frac{3\omega_0^4\Gamma^2}{c^3}\right)a\hbar\sigma + O\left(\sigma^2\right)\ .\tag{5}$$

If the $\tau'_e > \tau_e$ integral contribution in Eq. (2) was neglected, as was done in Ref. [4], then the first term above that is proportional to $1/\sigma^2$, would not have dropped out, as the $\tau'_e < \tau_e$ contribution to the integral in Eq. (2) equals $-\left(1 - 3\left(\omega_0\Gamma\right)^2\right)a\frac{\Gamma\hbar}{\pi\sigma^2}$, while the $\tau'_e > \tau_e$ contribution equals the exact negative of this quantity. This term is closely related to the result of

$$F_{M,x} = -a\frac{\Gamma\hbar}{2\pi\left(c/\omega_c\right)^2}\tag{6}$$

which HRP obtained as their final result of Eq. (109) in Ref. [4], when using their sharp cut-off model that treats the ZP field as being sharply cut off above all frequencies larger than ω_c. Clearly, then, the $\tau'_e > \tau_e$ integral contribution must be retained.

Consequently, unfortunately, despite many of the interesting and suggestive ideas in Ref. [4], at present, the detailed calculations do not support the authors' proposal in Ref. [4]. From Eq. (5), we see that the "magnetic" component of the ZP Lorentz force does cause a resistive force proportional to the acceleration, but this SED result does not become large as the cut-off in the ZP spectrum is removed (i.e., as $\sigma \to 0$); this result, although quite interesting, hardly seems able to provide a fundamental explanation to inertia. Instead, this result shows that the ZP field can cause mass corrections, a result long known from QED analyses.

My belief is that the SED calculation of the "electric" contribution to the ZP Lorentz force, namely, the contribution from $e\left\langle z\cdot\nabla E^{ZP}\right\rangle$, will prove to be more interesting, but I do not believe that the result will lead to a new fundamental explanation for inertial mass in the manner described in Ref. [4]. Calculations on this term are still in progress.

V. ASYMPTOTIC ANALYSIS OF THE CASIMIR-POLDER EQUATION

The following analysis regarding work in Ref. [3] was contained in a letter I wrote to Dr. H. Puthoff in 1993 [39]. Earlier, I had become aware of the as yet unpublished work in Ref. [4]. While investigating HRP's reasoning, I reexamined Puthoff's proposal in Ref. [3] for explaining gravity based on ZP fields [3], since the possible correctness or incorrectness of that proposal might be tightly coupled to the same outcome for HRP's proposal that the ZP fields were also responsible for explaining inertia. Unfortunately, my analysis of Ref. [3], as outlined here, did not support Puthoff's proposal on gravitation. Since that letter, K. Danley worked with Prof. A. Rueda and wrote a Master's

thesis [40] that came to the same conclusions as my letter, although he and Rueda held out hope that a relativistic analysis might yield results in line with Puthoff's original suggestion. Unfortunately, I am unaware of any evidence to either support or not support this hope, so at present I do not share this optimism.

Briefly, Puthoff's work in Ref. [3] referred to the Casimir-Polder potential between polarizable particles as an appropriate starting point for his analysis, where this potential is given by:

$$U(R) = -\alpha^2 \frac{\hbar c}{\pi} \int_0^\infty du \frac{u^4 \omega_0^4}{\left(c^2 u^2 + \omega_0^2\right)^2} \frac{e^{-2uR}}{R^2} \left[1 + \frac{2}{uR} + \frac{5}{(uR)^2} + \frac{6}{(uR)^3} + \frac{3}{(uR)^4}\right] \ . \tag{7}$$

Here, R is the distance between the two particles, and Puthoff considered the case where the two particles were SHOs with resonant frequency ω_0 and polarizability given by $\alpha = e^2/\left(m\omega_0^2\right)$. His treatment in Ref. [3] considered only the first term in brackets above [41], in which he substituted $\omega_0 = 0$ into the integrand and then supplied some arguments to support that this term would result in a $1/R$ effective potential between particles. Later, in response [42] to a criticism by Carlip [43] on the mathematical steps used in Ref. [3], he gave some additional arguments and different reasoning to still yield this $1/R$ effective potential, now emphasizing that there should be physical reasons for imposing cut-offs in the integration that enable this $1/R$ form to be obtained.

Some of the points made in Ref. [39] were that (1) one cannot simply extract the first term in Eq. 7, as all of the terms contribute on a roughly equal footing in the large distance regime, and (2) one can directly analyze Eq. (7) without imposing approximations. By making the substitution of $w = uR$ in Eq. (7), one obtains:

$$U(R) = -\alpha^2 \frac{\hbar c}{\pi} \frac{\omega_0^4}{c^4 R^3} I\left(\frac{\omega_0 R}{c}\right) \ , \text{ where} \tag{8}$$

$$I(b) \equiv \int_0^\infty dw \frac{w^4 e^{-2w}}{\left(w^2 + b^2\right)^2} \left[1 + \frac{2}{w} + \frac{5}{w^2} + \frac{6}{w^3} + \frac{3}{w^4}\right] \ . \tag{9}$$

Thus, $U(R)$ has a functional form of $1/R^3$ times an integral that depends on $\frac{\omega_0 R}{c}$, where each of the terms in the Casimir-Polder integral make an important contribution. In Eq. 9, one can also replace the upper limit of infinity by an upper cut-off, such as might be imposed if the ZP spectrum was thought to be cut off at sufficiently large frequencies. If a $1/R$ potential is to emerge for the form of $U(R)$, under whatever limiting conditions one imposes (e.g., large R, small ω_0, etc.), then $I(b)$ must result in a b^2 dependence under these conditions.

However, a full evaluation of Eq. (9) does not reveal any such dependency, even if one imposes a reasonable upper ZP spectral cut-off limit. Instead, as shown in Fig. 1, at large $b = \omega_0 R/c$, $I(b)$ is bounded by the asymptotic van der Waals expression of

$$I_r(b) \equiv \frac{23}{4} b^{-4} \ , \tag{10}$$

yielding an overall $1/R^7$ dependence for $U(R)$ in this regime. At small b, $I(b)$ is bounded by the unretarded van der Waals expression of

$$I_{ur}(b) \equiv \frac{3\pi}{4} b^{-3} \ , \tag{11}$$

yielding an overall $1/R^6$ dependence for $U(R)$ in this regime. At no point either between these extremes, or at these extremes, is there any behavior that remotely approaches a b^{+2} dependence that would be required to yield a net $1/R$ dependence for $U(R)$. An upper ZP frequency cut-off does not substantially change this analysis.

In Ref. [42], Puthoff added the additional argument that to obtain a net $1/R$ dependence in potential, an upper effective frequency limit of ω_i needed to be imposed in the integration, where $\omega_i < \omega_0$, followed by the condition that the limit of $\omega_0 \rightarrow 0$ was to be taken. In his justification for this reasoning, he used an argument by Boyer in Ref.

[44] that only the low frequency contribution of the interaction between polarizable particles sho ild be effective in yielding the long range attractive force due to correlated motion. This argument is indeed valid; however, applying this reasoning leads to the retarded van der Waals expression in Eq. (10) with its $1/R^7$ dependence, rather than to any $1/R$ dependence. If the *additional* constraints are imposed of an upper limit of ω_i in the integration, with $\omega_i < \omega_0$, as well as that the limit of $\omega_0 \to 0$ be taken, then this procedure is equivalent to saying that additional physical effects need to be imposed that are not present in the full Casimir-Polder expression. Indeed, after reading Refs. [3] and [42], one might have the impression that the Casimir-Polder expression reduces to a $1/R$ potential if one could only calculate it appropriately under the correct conditions. Instead, the Casimir-Polder expression clearly contains the retarded van der Waals expression with its $1/R^7$ dependence as a limiting case (see Fig. 1). The physical reasoning of the largest contribution to this result being due to the small frequency regime is indeed correct and is not an additional requirement that needs to b : imposed when evaluating the integral in Eq. (7). Instead, the requirements of Puthoff in Ref. [42] involving ω_i, $\omega_i < \omega_0$, and $\omega_0 \to 0$, constitute additional physical impositions that are certainly not contained withi.. '.e Casimir-Polder equation. Indeed, I am not aware of physical mechanisms that would result in these impositions. Consequently, without additional justification available, I belie· e it is necessary to conclude that Puthoff's conjecture that the gravitational attraction is due to ZP fields, is incorrect. There may be other ties between ZP fields and gravitation, such as in Sakharov's brief article [29], but this particular connection does not appear to hold.

VI. EXTRACTING ENERGY FROM THE VACUUM

Turning to the last topic of this article, Forward in 1984 first wrote about a possible means for extracting useful energy from the vacuum [7]. He described a relatively simple mechanical mechanism usiny charged conducting plates that are brought close enough together to allow the Casimir force to overcome the electrostatic repulsion between the plates, thereby enabling charge to be stored at a very high electrostatic potential energy. Indeed, some scientists have speculated that there may be enormous quantities of energy that can be extracted and harnessed from the vacuum, since the energy density of the electromagnetic ZP fields has been estimated to be incredibly large [45]. I am strongly convinced that there is little question that energy can in principle be extracted from the vacuum; Forward's example is one simple method that should clearly work. As for practical means of generating large quantities of energy, that is a separate issue I will discuss in a moment.

Two sets of questions typically arise during discussions about extracting energy from the vacuum. The first set involves the physical legitimacy of being able to extract this energy; *i.e.*, the very concept seems like it must be violating some physical law, such as conservation of energy or the second law of thermodynamics. Indeed, there are a number of subtle issues involving thermodynamic operations at or near $T = 0$, such as regarding the behavior of physical systems under thermodynamically reversible processes (*e.g.*, Casimir plates held apart and then quasistatically displaced toward each other) or irreversible ones (*e.g.*, the same plates initially held apart, the.a released so that they collide), or whether heat can be generated at $T = 0$ (no it cannot for reversible operations, but yes it can for irreversible ones), and how is energy conserved for these processes (the "vacuum" changes under thermodynamic operations, resulting in the net energy in ZP radiation plus the energy of the system being examined to always be conserved). Although subtle in some cases, at least until one clearly starts examining the issues, all of these concerns appear to be readily understandable and to not constitute violations of physical laws. References [8] and [9] go over many of these concerns in some detail. Reference [22] briefly summarizes some of the work in Refs. [13]- [16] on related thermodynamic issues concerning ZP radiation, as well as specifically addressing the issue of conservation of energy for charged particles and ZP electromagnetic fields.

The second set of questions that typically arise involve the practical issues of how one might extract large quantities of energy from the vacuum. I am aware that there are some technologists actively working on this problem, including Puthoff, who has been working with what he refers to as a charged plasma. Since from a physical standpoint I am convinced that one should be able to extract usable energy, then it seems possible that some of these experiments will be successful, although I have not as yet carried out any specific investigations. Theoretical calculations should also be possible to estimate the quantity of energy possible in specific situations, which should be helpful. In addition. it may be possible to put limits in general on the maximum amount of useful energy one can extract from the vacuum.

I think, though, that the following viewpoint should be kept cautiously in mind when considering ZP energy extraction. The theory of SED has the perspective that the stability of atoms and molecules is due in large part to the balance between "energy pick-up" from the electromagnetic ZP fields and the radiated energy from electrons in their orbits. Although SED has not been shown to hold for nonlinear systems in nature, still, this physical picture is carried over in some ways in quantum theory, where the vacuum field is formally necessary for stability of atoms, otherwise radiation reaction will cause canonical commutators like $[x, p_x]$ to decay to zero unless the fluctuating vacuum is

included. Consequently, much phenomena in nature, such as chemical reactions, can possibly be viewed, roughly, as "extractions of energy" from the vacuum, in analogy to the irreversible change of position of colliding parallel plate capacitors. After all, chemical reactions roughly rearrange average "positions" of electrons in atoms as well as atoms in molecules, and typically release electromagnetic energy in the process. Hence, in this sense, extracting energy and heat from the vacuum is not mysterious at all, but is daily observed in common phenomena such as with batteries, combustion, and other chemical reactions [46]. Even fission and fusion may be similar examples, although such operations would then necessarily involve the ZP fields associated with nuclear interactions.

I don't mean to claim that the above is true, but it may be, and one should bear this in mind when trying to construct new ideas for generating energy. If true, then the only real advantage for specific thoughts on energy extraction from the vacuum would be that the deliberate aim of directly attempting this procedure with ZP radiation might enable methods more familiar from electromagnetic work to generate inventive energy extraction methods [9], [1].

VII. CONCLUDING REMARKS

This article briefly covered aspects of the following three topics that appear to be of close interest to the present workshop, namely: (1) a proposal by IIRP [4] that electromagnetic zero-point (ZP) radiation may provide a fundamental explanation for inertia, (2) a related earlier proposal by Puthoff [3] that electromagnetic ZP radiation may also provide a fundamental explanation for gravity, and (3) the extraction of energy from the vacuum. As summarized here, and as will be discussed in much more detail elsewhere [32], [31], the calculations in [4] on the first topic have, unfortunately, been found to have some poor approximations in them that when corrected, do not yield results for the average of the "magnetic" component of Lorentz force from the electromagnetic ZP field that fit with the author's proposal for explaining the origin of inertia. In addition, there are a number of more basic issues, other than the details of the calculations, that limit the intended scope and generality of the work in Ref. [4], such as that the use of the Abraham-Lorentz-Dirac equation in arriving at the results already contains the concept of mass embedded in it; these points are discussed in some detail in Ref. [32].

Regarding the second topic, the point was made here that the Casimir-Polder integral can be explicitly evaluated [see Eqs. (8) and (9) and Fig. 1]. The approximations made in [3] and [42] are not valid for examining the asymptotic, long distance behavior of the Casimir-Polder integral. Only if additional physical constraints, not included within the basic physics embodied by the Casimir-Polder integral, are imposed, can the proposed steps made by Puthoff in Ref. [42] be justified. At present, I am unaware of any physical mechanisms that justify these constraints, so Puthoff's gravity explanation appears to be invalid.

Finally, regarding the third topic of extracting energy from the vacuum, and despite what may appear to be in violation of one's common sense, I do not presently see physical reasons that prevent the occurrence of such thermodynamic processes. References [8] and [9] provide explanations here. The real question here will be whether this knowledge will aid the creation of additional practical methods for energy extraction that we do not already know about and indeed make use of presently, such as in the chemical process of combustion. Quite possibly this additional knowledge and insight on the contribution of ZP energy to typical physical processes will be helpful in constructing new processes, but that of course remains to be seen.

As for recommendations for future work, I have several. First, a deeper physical understanding can certainly be gained by continued exploration of the issues on inertial mass contributions from ZP fields. This topic is an important part of the renormalization program in QED and is closely related to investigations by physicists in cavity quantum electrodynamics on effecting the lifetime of excited atomic states and the measured mass of particles. It is far from clear to me that such work should have any relation to advanced space propulsion schemes, but from the standpoint of useful advanced physics, this direction is certainly a good one that should be explored more fully, both theoretically and experimentally. Zero-point fields should clearly provide a contribution to inertial mass, although it seems doubtful that it can be the full explanation. After all, there are certainly other contributions to the measured mass of particles, such as due to electromagnetic binding forces in composite particles and even in models of fundamental particles [48]. The unique transformation properties of ZP fields, in particular with regard to Lorentz invariance, plus their large magnitude, are undoubtedly what enable them to make important inertial mass contributions.

Second, since ZP energy should clearly contribute to inertial mass, there is still work to be done to unravel the relationship of ZP fields and the gravitational interaction. Puthoff made an interesting proposal that does not appear to me to hold, but there is still the curious article of Sakharov [29] and other issues involving energy, mass, gravitation and ZP fields that are not yet settled. These relationships need to be examined more deeply and pinned down.

Third, further investigations should be carried out on specific examples of proposed energy extraction methods from the vacuum. In particular, detailed calculations should be carried out to pin down the legitimacy of specific proposals and to aid in setting up the best conditions for experimentation, as well as on more general issues involving the maximum energy that could be extracted in idealized thought experiments.

Zero-point fields may well be at the heart of many fundamental problems in physics, including quantum mechanical effects and fundamental understandings of thermodynamics and statistical mechanics [22 - 27]. Regarding a space program, however, here the connection is more difficult. For energy extraction, I can see where a small research effort on this approach might be worthwhile to pursue in a long-range space program, since there may be considerable energy that can be harnessed in this manner. However this statement should be tempered with the statement that such an effort is considerably less likely to succeed at achieving a technologically useful outcome than continued emphasis on more conventional energy resource approaches. As for pursuing ZP energy related methods to control inertial mass and gravity, the likelihood of those approaches succeeding in a space program seem extremely doubtful to me.

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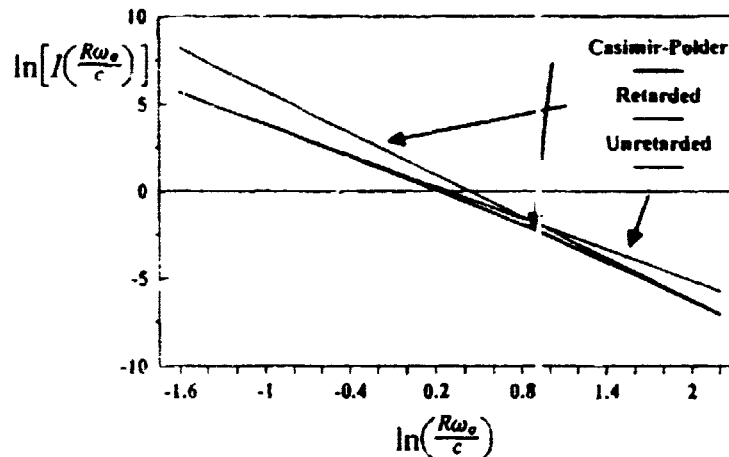
Fig. 1: $\ln(I(b))$, $\ln(I_r(b))$, and $\ln(I_{ur}(b))$ vs. $\ln(\cdot) = \ln(R\omega_0/c)$

NEXT DOCUMENT

Casimir Effects: Evidence and Implications

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So you want it simple? Well I'll make it simple. But then don't ask me to explain everything." – Titus Coleman

ABSTRACT

The physical origin of Casimir effects is discussed together with the notion of "extraction of energy from the vacuum."

CASIMIR EFFECTS

Limited space, time, and knowledge make it impossible for me to to describe all that is significant about Casimir effects. I have previously studied the subject in some detail [Milonni 1994]. Here I will summarize the most salient features and how they can be understood.

Mainstream physicists regard the world at its most basis level as a set of inteiacting quantized fields. Particles are associated with excited states of these fields. Quantized fields, much like the quantized harmonic oscillator, have fluctuations in all states, including the ground or zero–point state of no particles. Associated with that state is a zero–point energy, or actually a spectrum of zero–point energies. Casimir effects are a consequence of a change in the zero–point spectrum of a quantum field when boundary conditions are imposed (or when the topology is non–Euclidean). Brief overviews, including some history, are available [Milonni and Shih 1992; Spruch 1996].

The best known Casimir effect, often called *the* Casimir effect, is the attractive force between two parallel conducting plates:

$$F = -\frac{\pi^2 \hbar c}{240 d^4} , \tag{1}$$

where d is the distance between the plates. The force per unit area (F) is about $0.013/d^4$ dyn/cm^2, where d is in microns, giving 0.013 dyne for 1 cm plates separated by 1 μm. Two square plates, each 200 ft across and separated by 1 μm, are attracted to each other with a force of about 1 pound. It is not a large effect.

It has been of interest primarily because of the way Casimir first derived it [Casimir 1948]. In free space the number of modes per unit volume in the frequency interval $[\omega, \omega + d\omega]$ is the well known $\omega^2/(\pi^2 c^3)d\omega$, and each mode of frequency ω has a zero-point energy $(1/2)\hbar\omega$. The zero-point field energy density in the interval $[\omega, \omega + d\omega]$ is therefore $(\hbar\omega^3/2\pi^2 c^3)d\omega$.

If instead of free space we have two conducting plates, parallel and separated by d, the possible field frequencies in the space between the plates are restricted. Outside the plates there are no restrictions on the frequencies. The total field energy is therefore different from the case of free space. As in free space, the total energy over all possible frequencies is infinite. The difference U between these two infinite energies can be calculated in various ways, and it turns out that the force $F = -\nabla U$ is finite and given by Equation (1).

Sparnaay reported the first experiments to test this prediction [Spaarnay 1958, 1989]. By measuring the capacitance change of a capacitor connected to one of the plates, the displacement of a spring was determined and used to infer the force between two conducting plates with separations in the range 0.3 - 2 μm. Sparnaay's experiments are frequently cited as evidence for the Casimir force, but it should be noted that the relative errors in the measured forces were on the order of 100% due to errors $\Delta d \sim 0.3$ μm caused by hysteresis in the capacitor. Sparnaay himself was more careful, writing that "The observed attractions do not contradict Casimir's theoretical prediction."

If Casimir's prediction were wrong, a fundamental change in our understanding of quantum fields and vacuum fluctuations would be required. It is highly noteworthy, therefore, that Lamoreaux recently undertook a new, accurate measurement for d in the range 0.6 - 6 μm. In this experiment the force was inferred from the correction voltage that had to be applied to a capacitor in order to keep fixed the angle of a torsion pendulum attached to one of the Casimir plates. Excellent agreement ($\sim 5\%$) between experiment and Equation (1) was obtained without any adjustable parameters [Lamoreaux 1997].

Equation (1) follows as the limit for perfect conductors of a complicated formula derived by Lifshitz for dielectrics [Lifshitz 1956; Schwinger, DeRaad, and Milton 1978; Milonni 1994]. There is a rather large literature on Casimir forces if their interpretation is extended to dielectrics. The first successful experiments were reported in 1951 [Derjaguin, Rabinovich, and Chursev 1978; Milonni and Shih 1994].

Casimir effects also appear in the microscopic domain. The famous $1/r^6$ van der Waals interaction, for instance, goes over to a $1/r^7$ interaction when the distance r between the atoms is large compared with an absorption wavelength, a consequence of the finite speed of light [Casimir and Polder 1948]:

$$U(r) = -\frac{23\hbar c}{4\pi r^7}\alpha_A \alpha_E \; , \tag{2}$$

where α_A, α_B are the static polarizabilities of atoms A,B. This, as well as the usual "nonretarded" interaction, can be interpreted as a change in the zero-point energy of the field as a consequence of the presence of the two atoms. Similarly a large part of the Lamb shift can be interpreted as a change in the zero-point field energy due to the mere presence of a single atom, which changes the free-space modes of the field by acting as a dipole scatterer. Casimir effects can also play a role in the spectra of Rydberg atoms [Spruch 1996].

An atom near a conducting wall is attracted to the wall as a consequence of the dipole–dipole interaction with its image; the interaction energy goes as $1/d^3$, where d is the distance of the atom from the wall. But in the retarded regime of large d the interaction varies as $1/d^4$:

$$U(d) = -\frac{3\hbar c\alpha}{8\pi d^4} \; , \tag{3}$$

where α is the static polarizability of the atom [Casimir and Polder 1948]. Again we can interpret this in terms of a change in the zero–point field energy. The transition from the nonretarded to the retarted interaction has been accurately verified in beautiful experiments carried out by Hinds's group [Sukenik, Boshier Cho, Sandoghar, and Hinds 1993].

VIEWPOINTS

Vacuum fluctuations and zero–point energy have real, measurable physical consequences. However, it does not necessarily follow that there is an enormous (infinite!) field energy out there that could be put to good use if only we were more imaginative. It is important, first of all, to remember that there are other ways to interpret the effects we have just described.

The explanation of these effects in terms of zero–point field energy seems so natural that they are often invoked as proof for the reality of this zero–point energy. However, underlying these explanations is a particular and rather arbitrary choice for the ordering of field operators. Different operator orderings suggest different physical interpretations. In particular, a *normal ordering* of field annihilation and creation operators suggests that Casimir effects can be attributed entirely to *source* fields [Milonni 1994]. In fact, in a theory differing fundamentally from standard quantum .eld theory in that there are *no nontrivial vacuum fields*, Schwinger et al. derived various Casimir forces based entirely on source fields [Schwinger, DeRaad, and Milton 1978].

I cannot properly explain the vacuum and source interpretations in standard Heisenberg-picture quantum electrodynamics without resorting to straightforward but involved calculations, and it is impossible to do so here. It is also uncalled for, as I have done so many times before for problems relating to spontaneous emission, the Lamb shift, van der Waals forces, .asimir effects, and the laser linewidth [Milonni 1994]. Here I will present a simple "toy model" to make the point. The model system is a laser amplifier with (small–signal) gain coefficient g and with all N atoms per unit volume assumed to be in the excited state of the amplifying transition. The field inside the amplifier is assumed to remain weak enough that we can take g to be constant. The intensity I can grow because of stimulated emission and also because of spontaneous emission at rate R into the field mode under consideration:

$$\frac{dI}{dz} = gI + R\hbar\omega N \; , \tag{4}$$

where z is distance along the pencil–shaped amplifier. We will assume that there is no input field, so that I is generated by spontaneous emission. The appropriate solution of equation (4) for the intensity at the output end $z = L$ of the amplifier is therefore

that with $I(0) = 0$:

$$I(L) = \frac{R\hbar\omega N}{g}\left(e^{gL} - \right) . \tag{5}$$

This is the output intensity resulting from the spontaneous emission from a uniform distribution of excited atoms along z.

Now let us take a different point of view, ignoring spontaneous emission but assuming an input noise intensity I_N. In this case we write $dI/dz = gI$ with $I(0) = I_N$, so that

$$I'(L) = I_N e^{gL} , \tag{6}$$

where I' denotes the intensity calculated from this viewpoint. The claim is that the results (5) and (6) are equivalent if I_N is the noise intensity associated with the zero-point field energy $(1/2)\hbar\omega$ per mode. In other words, we can understand the output intensity either in terms of *source* fields – the spontaneous radiation from the excited atoms – or in terms of the amplification of the *vacuum* field incident at $z = 0$.

To justify this claim, we first note that the viewpoint from which Equation (6) follows takes the zero-point field to be a real, amplifiable field. This field is always present, so that I' is never zero. In fact $I' = I + I_N$, where I is the measurable intensity over and above that associated with the ever-present zero-point field. Thus Equation (6) reads $I(L) + I_N = I_N e^{gL}$, or

$$I(L) = I_N \left(e^{gL} - 1\right) . \tag{7}$$

The equivalence of Equations (5) and (6) then follows if $I_N = R\hbar\omega N/g$. To see that this is so, use the gain coefficient for bandwidth $\Delta\omega$: $g = 2\pi^2 c^2 AN/\omega^2 \Delta\omega$, where A is the Einstein A coefficient for spontaneous emission into *all* modes, and write $R = \beta A$, where β is the mode fraction factor for emission along the pencil-shaped amplifier. Then

$$\frac{R\hbar\omega N}{g} = (c\frac{1}{2}\hbar\omega)\left(\beta\frac{\omega^2}{\pi^2 c^3}\Delta\omega\right) . \tag{8}$$

Recalling again that $(\omega^2/\pi^2 c^3)\Delta\omega$ is the number of free-space modes per unit volume in the frequency interval $[\omega, \omega + \Delta\omega]$, we recognize the right-hand side of Equation (8) as the intensity over the gain bandwidth $\Delta\omega$ of a field of energy $(1/2)\hbar\omega$ per mode, this field consisting of $\beta(\omega^2/\pi^2 c^3)\Delta\omega$ modes per unit volume. In other words, $R\hbar\omega N/g$ is the noise intensity associated with the zero-point field.

This little analysis can be justified more rigorously by treating the electromagnetic field as a quantized field with boson annihilation and creation operators a and $a^\dagger$ for each mode. In the quantized-field treatment the fact that $\langle aa^\dagger\rangle = \langle a^\dagger a\rangle + 1$ leads to the relation $I' = I + I_N$ used above. Equation (5) follows from a "normal" ordering $(a^\dagger a)$ of field operators, whereas Equation (6) is derived if we work instead with "anti-normally" ordered field operators $(aa^\dagger)$.

Is it better to regard the intensity at the end of our amplifier as amplified vacuum field energy or as amplified spontaneous emission from the excited atoms? According to the formalism either interpretation is possible, and neither the source nor the vacuum-field picture is better in principle. And the same is true of Casimir effects: derivations in terms of zero-point field energy are correct and appealing, but they are not the *only* way to interpret Casimir effects, no matter what we read in the newspapers!

We can in fact explain some Casimir effects qualitatively without referring explicitly to either vacuum or source fields. Consider an atom at a distance d from a dielectric half-space made up of N identical atoms per unit volume, each with polarizability α. Assume a pairwise interaction given by Equation (2) between the atom outside the dielectric and each atom of the dielectric, so that the total interaction energy between the atom at d and the dielectric is

$$U(d) = -N\frac{23\hbar c\alpha^2}{4\pi} \int_{-\infty}^{\infty} dx \int_{-\infty}^{\infty} dy \int_{d}^{\infty} dz (x^2 + y^2 + z^2)^{-7/2} = -\frac{69\hbar c\alpha}{160\pi}\frac{1}{d^4}\frac{\epsilon - 1}{\epsilon + 2} , \quad (9)$$

where in the last step we have used the Clausius–Mosotti relation between the polarizability and the dielectric constant ϵ. In the limit $\epsilon \to \infty$ of a perfect conductor,

$$U(d) \to -\frac{69\hbar c\alpha}{160\pi d^4} , \quad (10)$$

which is within 15% of the Casimir–Polder result given by Equation (3). A similar calculation for two walls separated by d gives about 80% of the Casimir force defined by Equation (1).

In fact, if we take into account that van der Waals interactions are *not* really pairwise additive, but that the interaction between two atoms is affected by the presence of a third atom, then we can regard these Casimir effects as just macroscopic manifestations of van der Waals interactions [Milonni 1994]. And van der Waals interactions are interpretable in terms of source fields or vacuum field energy. But then again we can derive these interactions using standard perturbation theory and not worry about the interpretation, or even take a stand "against interpretation"!

TAKING ENERGY FROM THE VACUUM

There have in recent years been clever suggestions, based on Casimir effects, that it is possible to extract energy from the vacuum. The preceding discussion was intended in part as a warning against taking zero–point energy too literally. It is possible to use Casimir effects to transform electromagnetic energy into other forms, but the fanciful notion of "extraction of energy from the vacuum" can not only fascinate, but also mislead laymen or even physicists who have not had the good fortune to study Casimir effects.

A simple analogy may be useful. Consider two point charges q at points x_1 and x_2. Each produces a Coulomb field, and the field energy is $(1/8\pi) \int d^3x E^2(x)$, where $E(x)$ is the electric field at x due to both charges. The interference term in the field energy,

$$U = \int d^3x \nabla \left(\frac{1}{|x - x_1|}\right) \cdot \nabla \left(\frac{1}{|x - x_2|}\right) = -\frac{q^2}{4\pi} \int d^3x \frac{1}{|x - x_1|} \nabla^2 \frac{1}{|x - x_2|}$$

$$= q^2 \int d^3x \frac{1}{|x - x_1|} \delta^3(x - x_2) = \frac{q^2}{|x_1 - x_2|} , \quad (11)$$

is the interaction energy between the charges. The field energy associated with the self-energy of each charge is infinite, but this poses no problem in deriving U, because

to properly calculate U we must subtract from the total (infinite) energy the (infinite) energy of the field when the charges are infinitely far apart. As in the case of the Casimir interaction calculated from the perspective of zero-point field energy, the difference of the two infinite energies yields a finite interaction energy. And as in the Casimir calculation, the interaction energy can be regarded as the change in the field energy due to the existence of the bodies whose interaction energy we are calculating.

To carry the analogy further, we can imagine electrostatic generators to extract energy from the Coulomb field. Such devices, of course, already exist! They might be said to extract energy from the infinite energy of the Coulomb field. However, a more down-to-earth explanation would start from the fact that charged particles exert forces on one another. Similarly, the proposed "Casimir machines" could in my opinion be more sensibly described starting from the fact that polarizable bodies exert van der Waals forces on one other.

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NEXT
DOCUMENT

THE NEW THEORY OF GRAVITY AND
THE 5th TEST

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ABSTRACT

Gravity is an interactive N-body phenomenon whereas Einstein's general theory of relativity in general leads to only noninteractive solutions of Schwarzschild type. Thus general theory of relativity cannot produce legitimately the N-body interactive effects such as the planetary perturbations in the solar system. One such effect is the N-body perturbative advance of planetary perihelia which in the case of Mercury is 532" per century (1194" for Earth, 1559" for Mars, so on). We call the presence of these N-body effects *the 5th test* of gravitational theory and consider it a *crucial* test. A new theory modifying Einstein's field equations by adding the gravitational field stress-energy to the matter stress-energy passes the 5th test.

It is known that the only possible modification of general relativity that leads to the four classical tests, namely, 1) the red-shift, 2) light-bending, 3) the perihelion precession, and 4) the time-delay, is [1]

$$1/2 \; G_\mu{}^\nu = T_\mu{}^\nu + \lambda t_\mu{}^\nu$$

here $G_\mu{}^\nu$ is the Einstein-Hilbert tensor, $T_\mu{}^\nu$ is the matter tensor, $t_\mu{}^\nu$ is gravitational field stress-energy tensor,

$$t_\mu{}^\nu = -\partial_\mu\phi\,\partial^\nu\phi + (1/2)\,\delta_\mu{}^\nu\partial^\lambda\phi\partial_\lambda\phi$$

in the Newtonian limit, and λ is an arbitrary parameter. (Here we shall not need the more general form of $t_\mu{}^\nu$.)

It is also known that the value $\lambda = 0$ corresponds to General Relativity, and $\lambda = 1$ to what we call "The New Theory of Gravitation"

$$\lambda = 0 \qquad \text{General relativity}$$

$$\lambda = 1 \qquad \text{The new theory}$$

and that a **5th** test is needed to remove the "final arbitrariness" (of λ) in the field equations. [2] Note that if matter is in the form of particles (matter concentrations), then masses are given by $T_\mu{}^\nu = \sigma u_\mu u^\nu$, $\sqrt{-g}\sigma = \Sigma_A m_A\delta(x - x_A)$ where $\sqrt{-g}$ is the Jacobian, $\Delta\phi = \Sigma_A m_A\delta(x - x_A)$.

An essential distinction between the two theories is that for $\lambda = 0$ (General Relativity) one has no <u>N-body interactive</u> (force) solutions contrary to the Newtonian correspondence, whereas for $\lambda = 1$ (The New Theory) one has N-body interactive solutions satisfying the Newtonian correspondence (the slow motion limit). This comes about as follows: If one demands that one shall have N-body solutions with Newtonian correspondence, there arises, in the expression of the Einstein-Hilbert tensor, the condition (obstruction) [3]

$$(\lambda - 1)(\phi\phi_{ik} - 3\phi_i\phi_k + \delta_{ik}\phi_r\phi^r - \delta_{ik}\phi\phi_r) = 0$$

where (italic) indices on ϕ's are partial derivatives. If $\lambda = 1$, the obstruction is removed and we have the N-body solutions. If $\lambda = 0$ the second paranthesis must vanish but it can be shown explicitly (for example, by a symbolic manipulation computer) that the second paranthesis contains the cross terms $m_j m_k$ as a factor and they are all removed by the condition. Consequently, there are no cross terms, hence thre are no interactive solutions if $\lambda = 0$. On the other hand, if $\lambda = 1$, the N-body solutions in question are found to be of the form: [4]

$$g_{00} = e^{-2\phi}, \qquad -g_{ik} = \delta_{ik} e^{2\phi}$$

$$\phi = \Sigma_A m_A / |x - x_A|$$

and are here called the "interactive N-body solutions." From this solution one finds the corresponding N-body Hamiltonian

$$H = \Sigma_A [e^{-\phi} [\sqrt{(m^2 + e^{-2\phi} p^2)}]_A \cong \Sigma_A p^2_A / 2m_A - \Sigma_A m_A (\phi + 3\phi^2)_A + K$$

from which the second order N-body equations of motion

$$m_p d^2 x_A / dt^2 \cong m_p \Sigma_A (1 + 6\phi/c^2) m_A (x - x_A) / |x - x_A|^3$$

can be obtained and all the numbers in Table 1 and Table 2 can be calculated where m_p is the mass of the moving planet which here drops out. Note that the analog of the Newtonian force can also be obtained to this order as $\partial_v (\sqrt{-g} t_\mu{}^v)$ but we need the Hamiltonian to connect to the rate of momentum change or acceleration d^2x/dt^2.

Note that in the $\lambda = 0$ theory a 1-body solution of the usual Schwarzschild type (the central body solution) is allowed by the condition. A 1-body solution can, *at most*, lead to a test-body theory where the four classical tests mentioned above can be derived (though not fully legitimately) by putting the test bodies (if planets are considered as unphysical test-bodies) by hand. But this violates the N-body symmetry of the Newtonian theory since one of the bodies is in the solution, the others are not. (In fact according to the condition the Newtonian correspondence is violated even in the sense that if ϕ is a solution, then ϕ + C is not a solution to the field equations. The latter has serious consequences as Pauli expressed in an other context.) [5]

In the Tables I below and in the formula that follow the N-body interactive nature of the planetary perturbations are clearly indicated. Table II gives further evidence of the universal N-body interactive

nature of gravity. A 1-body solution cannot interact with anything as there is nothing else with which to interact. Nevertheless, a test body calculation gives (though illegitimately) similar results to the case of a small body moving in the field of a very massive body. For that reason test-body theories are widely used for convenience. One must keep firmly in mind, however, that test-body theories can never give N-body perturbative effect.

TABLE I

Planet : Perturbative Contribution to Mercury's perihelion advance

Planet	Contribution
Venus	277.86
Earth	90.04
Mars	2.54
Jupiter	153.58
Saturn	7.30
Uranus	0.14
Neptune	0.04
Pluto	–
TOTAL	531.50

Table 1 can be calculated from the new theory. In lowest order a reasonable approximation of the total is obtainable as [7]

$$\dot{\omega} = (3/2)\pi \, K \, M^{-1}m_\mu \Sigma_p m_p/[(r_p - a)r_p(r_p + a)]$$

where M is the mass of the Sun, m_μ mass of Mercury, m_p are those of perturbing planets, r_p are their distances from the Sun, K is a constant depending on units and a is a semiempirical parameter. The important point is that the perturbing planets contribute according to their (active) masses in the solution. If these were test bodies, their active masses would be zero and all the planetary-perturbative parts would be zero.

Furthermore, the test bodies cannot interact wi⁻' each other (they are not of interactive Newtonian type since they are not in the solution) hence the planetary-perturbative parts of the advance of planetary perihelia cannot be obtained from a test-body theory. (Summation signs over test bodies would be missing.) These can, however, be obtained from the new theory. This calculation is carried out in the case of planet Mercury and fo. d to be as shown in Table I. In Table II the N-body perturbative advances of perihelia for other planets are also shown just to appreciate how pervasive and important these N-body effects are. The observational presence of these N-body perturbative effects which are predicted by the new theory, and not by general relativity, is a *crucial* test. In view of the other four "classical" tests it is here called "the 5th test" of the curved space-time theory of gravity. [6]

TABLE II

Planet	Perturbative Part	Relativistic Part	Observed Total
Mercury	531.59	42.98	574.57
Venus	– 117.42	9.62	– 108.80
Earth	1194.44	3.84	1198.28
Mars	1559.43	1.35	1560.78
Jupiter	839.87	0.06	839.93
Saturn	– 1948.90	0.01	– 1948.89
Uranus	1312.56	-	1312.56
Neptune	– 844.43	-	– 844.43
Pluto	– 132.25	-	– 132.25

Planetary perturbations are a most important part of celestial mechanics. So essential that from their presence and their precise magnitudes the planet Uranus, and Neptune, were discovered (predicted) on paper before their discovery by observations. Let us ask the crucial question: "Are these planetary perturbations and, in

particular, the planetary perturbative advances of the perihelia of the planets obtainable from Einstein's theory of general relativity?" Or putting it rather bluntly, "Could the planets Uranus and Neptune be so discovered (predicted) on paper if the only theory of gravity available at the time were general relativity?"

The answer to this question is an emphatic no! We are compelled to say that general relativity is only a test-body theory (one body in the solution, all other bodies being test particles put by hand) and that it cannot meet the demands of the 5th test which requires N real bodies with mutual interactions. We have seen above that such N-body solutions are possible only when $\lambda = 1$, hence the 5th test leading to this value of λ may be considered the "experimentum crucis" of the curved spacetime theory of gravitation.

The only (though only psychological) barrier to this conclusion is the belief that the Einstein-Infeld-Hoffmann papers of 1938-39 obtained the Newtonian limit from their N-body expansion method. But the truth is that they implicitly assumed the N-body potentials without proof. A careful study of a summary given by Bergmann [8] clearly shows this. With Eqs. (15.12) on page 239 in his well-known book the equations are satisfied in first order (right-hand side put to zero in vacuum) but with Eqs. (15.25) on page 234 they are not satisfied in second order. Yet as stated on page, 232 to obtain the equations of motion one has to satisfy the equations in both first and second order. Thus it appears that the EIH metric is not a solution to Einstein's equations in second order and this can, in principle, be checked by a computer program.

Since for the Newtonian limit on page 238 one needs to keep only the $\phi_0{}^0 = \phi$ component [3] from the beginning, one can ignore all the other potentials. Then it is clear from our previous discussion that in order to have N-body solutions of the Newtonian type one has to equate the

right-hand side of Eqs. (15.25) on page 234 to

$$(1/2) \ G_\mu{}^\nu \ = \ T_\mu{}^\nu \ + \ t_\mu{}^\nu$$

that is, $(1/2) \ G_\mu{}^\nu \ = \ t_\mu{}^\nu$ in source-free space. In other words, Einstein-Infeld-Hoffman method will produce the Newtonian limit with appropriate N-body solutions if the underlying theory were the new theory with $\lambda = 1$. But with $\lambda = 0$ the implicitly assumed N-body solutions do not materialize, hence the N-body Newtonian theory is not recovered. The introduction of $1/c^2$ factors in the metric components does not help in the evaluation of the field equations because the Christoffel symbols are of the nature of logarithmic derivatives of the metric components, hence they drop out of the calculations. All calculations mentioned in this paper can easily be verified by any of the modern computer programs. [9] The problem of pseudo tensors arising from the use of ordinary partial derivatives of the background metric is common to all curved spacetime theories. This problem is now solved by using background-covariant derivatives and checked out for all time-independent metrics we have studied. [10] The process is general and of course applies also to general relativity.

We would like to take this opportunity to also answer some criticisms of the new theory. These are mainly of two categories: 1) In the first category the authors attack our theory by trying to show that it is wrong mathematically or else physically. In this category are S. Antochi [11] and C. W. Misner. [12] Antochi's claim that the theory still has a pseudo-tensor problem is not valid because that problem is resolved as mentioned above. On the other hand Misner's claim that Yilmaz' theory cancels Newton is totally unfounded. It is already answered by showing that one of his premises is false. [13] Beside, our metric has the requisite N-body solutions satisfying the Newtonian limit, to required order, so how can it cancel Newton? 2) In the second category the authors think that we are attacking general relativity (Actually, of course, we are not attacking general relativity – we are only exhibiting the structure of the two theories on the basis of two mathematical identities so that we may be able to modify general relativity correctly.) and defend it so that by implication our analyses appear unjustified. To understand this category one must understand under what assumptions

the equations of motion are obtained in the two theories. 1) In the new theory the Bianchi identity gives

$$\partial_v(\sqrt{-g}\sigma u_\mu u^v)/\sqrt{-g} - 1/2\sigma \, \partial_\mu g_{\alpha\beta}u^\alpha u^\beta + D_v t_\mu^{\ v} = 0$$

The first term is zero $\partial_v(\sqrt{-g}\sigma u_\mu u^v) = 0$ by Freud's identity, hence we have

$$1/2\sigma \, \partial_\mu g_{\alpha\beta}u^\alpha u^\beta = D_v t_\mu^{\ v}$$

which, for a given the form of $g_{\mu v}$, determines the form of $t_\mu^{\ v}$ (up to a zero divergence). The equations of motion fellow from the Lagrangian to be [3]

$$\sigma \, du_\mu/ds = 1/2\partial_\mu g_{\alpha\beta} \, (\sigma \, u^\alpha u^\beta + t^{\alpha\beta})$$

In the slow motion limit $\partial_\mu g_{\alpha\beta} \, t^{\alpha\beta} \to 0$, hence we essentially recover the geodesic equations of motion as a limit.

2) In general relativity the $t_\mu^{\ v}$ is assumed to be zero (an unnecesary restriction since, as have seen above, Freud Id. plus Bianchi Id. determine the $t_\mu^{\ v}$ for any given $g_{\alpha\beta}$), hence under the Freud and Bianchi identities one has the restricttion

$$1/2\sigma \, \partial_\mu g_{\alpha\beta}u^\alpha u^\beta = 0$$

This is bad because the expression is the righ-hand side of the geodesic equations of motion and is zero! In general relativity one tries to fix up this problem as follows: From the Bianchi identity one first has

$$\partial_v(\sqrt{-g}\sigma u_\mu u^v)/\sqrt{-g} - 1/2\sigma \, \partial_\mu g_{\alpha\beta}u^\alpha u^\beta = 0$$

Then, by differentiation of the first term one writes

$$(\sqrt{-g})^{-1} \partial_v(\sqrt{-g}\sigma u^v) \, u_\mu + \sigma \, du_\mu/ds - 1/2\sigma \, \partial_\mu g_{\alpha\beta}u^\alpha u^\beta = 0$$

(via $u^v\partial_v x_\mu = du_\mu/ds$) Now in addition to the Freud identity one sets

$$\partial_v(\sqrt{-g}\sigma u^v) = 0,$$

hence one gets

$$\sigma \, du_\mu/ds = 1/2\sigma \, \partial_\mu g_{\alpha\beta} u^\alpha u^\beta$$

which gives the impression that the geodesic equations of motion follow from the field equations. However, in view of the Freud identity the condition $\partial_\nu(\sqrt{-g}\sigma u^\nu) = 0$, implies $\sigma du_\mu/ds = 0$, hence what really follows is $0 = 0$.

But suppose one does not know about the Freud identity or one forgets to take it into account. Then one would tend to take the result ($\sigma \, du_\mu/ds = 1/2\sigma \, \partial_\mu g_{\alpha\beta} u^\alpha u^\beta$) seriously as if legitimate. Since it is formally similar to the new theory's equation of motion it will appear to give similar results. Hence our papers can be made to appear to have criticized general relativity unjustly. Brill,[14] Cooperstock-Vollick [15] and Fackerell [16] articles are of this category. In virtually all such articles the conclusions drawn are not justified because they are based on implicit assumptions voiding Freud's identity at least once, (sometimes twice). Since this is not stated explicitly the writer, as well as the reader is impressed by sophisticated manipulation of formulae. Cooperstock and Brill implicitly assume such an equation of motion believing that it will lead to a gravitational force. Then add an electrostatic force to balance. Of course, there will be no balance since the gravitational part is zero. Such a balance will be achieved in the new theory as can be seen from our remarks at the earlier part of this discussion. Freud Identity is an integral part of any spacetime theory of gravity and its omission will lead to inconsistencies in the form of overdetermination, hence nullification of the formulae. As It turns out, in these articles the Freud identity is not even mentioned. It is hoped that this discussion be carefully read by these authors and due apologies made for their misunderstanding and not so civilized language in some of their writings.

SUMMARY

A) The first four tests are compatible with arbitrary λ in

$$1/2 \, G_\mu{}^\nu = T_\mu{}^\nu + \lambda t_\mu{}^\nu .$$

B) The 5th test is compatible only with the value $\lambda = 1$, hence

$$1/2 \, G_\mu{}^\nu = T_\mu{}^\nu + t_\mu{}^\nu .$$

Thus, the field equations at the Newtonian limit are completely determined by experiment. Any generalization must therefore reduce to this case in order to be viable in its Newtonian limit.

Let us remember now what Einstein himself said:

My equation is like a house with two wings. The left-hand side is made of fine marble, but the right-hand side of perishable wood.

A. Einstein

NOTES AND REFERENCES

1) B. O. J. Tupper, Nu. Cim. **19B**, 135 (1974). Note that Tupper used only the first three classical tests but it turns out that fourth test is also covered by his procedure.

2) B. O. J. Tupper, Lett. Nu. Cim. **10**, No 4, 627 (1974). It is in this short paper that Tupper made his important statement: "Since λ appears only in a second-order term, a suitable second-order experiment will be required to remove the final arbitrariness in the field equations." Our λ is defined as 1/2 of his.

3) H. Yilmaz, Nu. Cim. **107B**, No 4, 941 (1992). (Isotropic coordinates are used for convenince.) In the new theory the field equations do not determine the equations of motion. Eqs. of motion are obtained from a separate (x) variation or equivalently from the Hamiltonian. In the slow motion limit they are the geodesic equations of motion.

4) H. Yilmaz, Phys. .Rev. 111, 1417, (1958). Thus the N-body solutions were known as early as 1958 from our original paper but their connection to planetary perturbation were not realized until much later. The author realized this connection first in 1983 while reading a Scientific American article by I. Bernard Cohen.

5) W. Pauli. "The Theory of Relativity", p. 192, Dover (1958). Note that Pauli criticized G. Mie's theory on this ground. We see here that general relativity has the same problem. (The new theory does not.)

6) C. A. Hein, "Perihelion Advance of Mercury" (Unpublished) In this paper it is the first time that a "seamless" calculation from one single line element (our solution) both the Newtonian and the relativistic are calculated. In general relativity one can calculate the relativistic part from a test-particle theory but the planetary perturbative part is calculated from the Newtonian theory and "patched" onto the former.

7) D. Park,"Classical Dynamics and Its Quantum Analogues", Springer-Verlag, p. 249, (1990).

8) P. G. Bergmann, "Intr. to the Theory of Relativity", Dover, (1976).

9) Extensive calculations are made by A. P. Doohovscoy, Ching Yun Ren, Kirk Burrow, Kennet Aschan, in collaboration with H. Yilmaz and Carroll O. Alley with MACSYMA, Maple, Math. Tensor and Mathematica. A minute amount is explicitly reproduced in Ref. 3. Anybody familiar with suitable programs can verify all of our results.

10) H. Yilmaz, "Toward a Comprehensible Physical Theory", Kluwer Acad. Publishers, S. Jeffers et al. (eds), pp. 503-525 (1997).

Note: There is a group of theorists called "Grand Challenge Alliance" trying to find N-body black hole solutions in the $\lambda = 0$ theory.

11) Antochi, S., Nu. Cim. 110B, N. 9, 1025 (1996).

12) Misner, C. W., "Yilmaz Cancels Newton," (unpublished) Can be obtained from Internet Los Alamos Preprint Archive.

13) Alley, Aschan and Yilmaz, "Refutation of Misner's Claim, Yilmaz Cancels Newton, (unpublished) Can be obtained from Internet Los Alamos Preprint Archive. Note: Both this paper and Misner's are submitted to Il Nu. Cim. quite a time ago The journal so far cannot make up its mind.

14) Brill, D. (To be submitted to a Festschrift volume (1997).

15) Cooperstock, F.L.and Vollick,D.N., Nu. Cim.111B, N.2,265 (1996).

16) Fackerell, E. D., To be published in the proceedings of one of the Marcel Grossmann Meetings. It can also be obtained from the Internet Los Alamos Preprint Archive. (More accurate references will be provided as they become available to the author.)
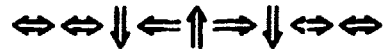
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NEXT DOCUMENT

Hyper–Fast Interstellar Travel
via a Modification of Spacetime Geometry

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ABSTRACT:

We analyze difficulties with proposals for hyper–fast interstellar travel via modifying the spacetime geometry, using as illustrations the Alcubierre warp drive and the Krasnikov tube. As it is easy to see, no violations of local causality or any other known physical principles are involved as far as motion of spacecrafts is concerned. However, the generatior and support of the appropriate spacetime geometry configurations does create problems, the most significant of which are a violation of the weak energy condition, a violation of local causality, and a violation of the global causality protection. The violation of the chronology protection is the most serious of them as it opens a possibility of time travel. We trace the origin of the difficulties to the classical nature of the gravity field. This strongly indicates that hyper–fast interstellar travel should be transferred to the realm of a fully quantized gravitational theory. We outline an approach to further the research in this direction.

INTRODUCTION:

It is commonly accepted that for an interstellar travel to become of a practical interest and importance one should acquire a capability to complete such a travel within a reasonable interval of time by the clocks of both the traveler and the community remaining on the Earth. In most cases it is the total time of the round trip that one is concerned but, under special circumstances. it might be also the one way time of arrival at a destination.

The troubles with the time of an interstellar travel emerge as the result of an interplay between two major contributing factors, (1) the necessity to coyer very large distances to reach even the nearest stars, and (2) the limitation on the maximal speed of a spacecraft imposed by relativity. This speed must be smaller than the speed of light. Equivalently, the world line of the spacecraft must pass inside the local light cone in a neighborhood of each point of this world line.

In Minkowski spacetime (the case of special relativity) the construction of the light cone is global and the distance between the Earth and the star of destination in the frame of reference of the Earth's observer is fixed. Under these conditions the only means to reduce the travel time is to increase the speed of the spacecraft within the limit determined by the null cone. The nature of the limitation on the minimal time of travel in this case is best illustrated by the spacetime diagram (Fig. 1). Points S and R on the world line of the Earth's observer are the events of the start and return of the interstellar expedition, while point A on the world line of the star is the event of the expedition arrival at its destination. The world line of the spacecraft SAR. and with it the the expedition duration for the traveler, can be made as short as desirable by choosing pieces SA and AR sufficiently close to the null cones (moving at a speed sufficiently close to the speed of light with respect to the Earth). Meanwhile, the distance between A and R along the world line AR of the Earth (the duration of the expedition as perceived by Earth's observers) obviously cannot be made less than $2d$. where d is the distance between the Earth and the star of destination in the frame of the Earth.

General relativity opens, at least seemingly, opportunities to circumvent this difficulty. As in the case of special relativity, the speed of the spacecraft is limited by the speed of light, i. e. the world line of the spacecraft should pass inside of the local light cone at each point of the world line. However, the metric and topology of spacetime is not fixed, and presumably can be manipulated. The construction of the null cone is not global in this new setting. The spacetime geometry, and with it the tilt and the opening of the local light cones can be manipulated in a controlled fashion. Such a manipulation allows in some cases to reduce the distance to be covered by the spacecraft, which reduces the time of arrival at the destination as well as the round trip time. In other cases it allows to transform the spacelike separations into the timelike separations, which does not reduce the time of arrival but reduces the round trip time.

It is easy to write down an expression for a spacetime metric that satisfies the basic chronometric requirements of a feasible interstellar flight (cf. the next section for some details and references). Whether such a metric can be generated, supported and controlled in the real physical world without violating the most basic laws of physics, is a different and, perhaps, the most troublesome issue. Whatever the final answer might be, any attempt to analyze the emerging situation demands an expansion of the domain of application of the laws of physics far beyond the conditions for which they were formulated originally.

1. A straightforward computation of the Einstein tensor shows that in all cases gravitational fields corresponding to desirable metrics demand "exotic" matter to be at least a part of their source. Such "exotic" matter violates various commonly accepted energy conditions, including the weak energy condition, which means that it is supposed to have negative energy density. Although the negative energy density is not ruled out by quantum field theory, understanding of its coupling to the gravitational field is incomplete and it shows up sooner than one might expect.

2. In many cases (a good example is the Alcubierre warp drive spacetime) the domain of modified geometry is causally disconnected. This means that the appropriate configuration of the gravitational field cannot be generated, sustained, or controlled as a result of any geometrodynamic evolution unless one has at his disposal tachyonic matter, or some kind of a device capable of emulating tachyonic effects.

3. All known configurations of modified spacetime geometry involved in a hyper–fast travel, when considered in conjunction with the principle of general covariance, invariably lead to a capability of building a time travel machine. Basic theorems characterizing the causal structure of spacetime [Geroch & Horowitz, 1979] tell one that, as a consequence, such spacetime geometry cannot be a result of any geometrodynamic evolution unless there are some means to contribute to the spacetime structure externally (spacetime singularities, appropriate boundary conditions, tachyonic effects, quantum effects, topological effects, etc.).

The recent literature presents quite a few attempts to asses compatibility of the idea of modified spacetime geometry as a means of hyper–fast travel with basic concepts of physics (we will provide a more detailed account and references in subsequent sections). Unfortunately, most of this literature has a tendency to rely on standard theoretical constructions without any modifications or with minimal modifications, frequently without clear understanding of their relations to observations. The results are all too predictable. This approach leads one rather fast and in a relatively trivial fashion to ruling out virtually all particular geometry modification proposals on the ground of their nonphysical nature via seemingly plausible arguments. The arguments are relying heavily on rather involved computations and contain numerous assumptions necessary for their tractability. Some of these assumptions are questionable, others leave one with the impression that they might be circumvented via more sophisticated designs. In brief, the trouble with this direction of thought is that it does not provide an understanding of the common mechanism of the failure.

The arguments of more general nature, less computationally demanding, and appealing to more basic and dependable arguments are scattered in the literature, but have not been systematically used for more balanced assessment of the problems and prospects of the field. In this paper we attempt to do so having as goals (1) to determine the restrictions imposed on modifications of spacetime geometry, (2) to determine the nature and the origin of these restrictions, (3) to formulate the conditions on the mechanism that might circumvent the restriction, and (4) to evaluate possible realizations of such mechanism.

SPACETIME GEOMETRY MODIFICATION AND HYPER–FAST INTERSTELLAR TRAVEL:

There are numerous examples of spacetimes with tilted null cones (where the travel distance is reduced), such as Godel Universe [Godel, 1949], cosmic strings spacetimes [Deser, 't Hooft, 1984], traversable wormhole [Morris & Thorne. 1988], and the recently suggested warp drive spacetime [Alcubierre, 1994]. Although all of these examples are useful for improving our understanding of the related issues, in the context of an interstellar travel achieved by technological means only traversable wormholes and the warp spacetime are of a possible interest as they involve only local modifications of spacetime geometry and topology. The transformation of the spacelike separations into the timelike ones, thus reducing the round trip time, is illustrated by what is frequently called the Krasnikov tube [Krasnikov, 1995; Everett, Roman. 1997]. We are going to use for illustrating the idea of hyper–fast interstellar travel via spacetime geometry modification the two most recent proposals — Alcubierre warp drive and the Krasnikov tube. They utilize two different features of modified spacetime null cones. Other proposals work in a way similar to one of these two and pose the same kind of difficulties in their realization.

Alcubierre Warp Drive Spacetime:

Alcubierre warp drive spacetime is the best studied example of modifying spacetime geometry for the purpose of hyper–fast interstellar travel. The basic idea of the Alcubierre warp drive is to modify the spacetime geometry to the one expressed by the metric (dimensions y and z are omitted as they are irrelevant for an explanation of the basic effect)

$$ds^2 = -dt^2 + (dx - v_s\, f(r_s)\, dt)^2$$

where $r_s = |x - x_s|$, $v_s(t) = dx_s(t)/dt$; and $x_s(t)$ f are arbitrary smooth functions such that $x_s(0) = 0$, $x_s(T) = d$, $f(\xi) = 1$ for $0 \leq \xi < R - \epsilon$, $f(\xi) = 0$ for $\xi \geq R$, while ϵ, T and R are arbitrary positive parameters. If $v_s(t) \equiv 0$ this metric reduces to the Minkowski metric, in which case $(v_s f \equiv 0)$ the null cone at all points of spacetime is determined by the left and the right future directed null vectors

$$\mathbf{l} = \partial_t - \partial_x, \qquad \mathbf{r} = \partial_t + \partial_z$$

In the warp drive spacetime, where $v_s f$ changes from point to point of spacetime, the left and the right future directed null vectors are given by

$$\mathbf{l} = \partial_t + (v_s f - 1)\partial_x, \qquad \mathbf{r} = \partial_t + (v_s f + 1)\partial_z$$

The change of the future null cone is shown pictorially in Fig. 2. One can observe that as $v_s f$ grows the null cone tilts to the right while the opening of the cone narrows down in such a way that some curves that used to be spacelike in Minkowski geometry become timelike and vice versa.

Fig. 3 represents spacetime geometry determined by the warp drive metric which is pictured in t-x coordinates by the world tube of radius R and thickness ϵ with axis given by $x_s(t)$. The spacetime geometry outside the tube is Minkowski geometry. Inside the tube the geometry is also flat but the light cones are tilted with respect to the outside cones. The wall of the tube represents the curved domain of spacetime.

Suppose now that $x_s(t)$ represents the world line of a spacecraft with a device on board that enables it to modify spacetime geometry to that given by the warp drive metric. The spacecraft is then surrounded by the bubble (warp bubble) with the wall containing curved spacetime and moving at a coordinate speed $v_s(t)$. The case $v_s > 1$ would be nonphysical in the original geometry of spacetime for a spaceship constructed of standard matter as its world line would be passing outside the null cone (superluminal motion). However, as it is easy to see in Fig. 3, the ship's warp bubble tilts the null cones inside of it in such a way that the world line of the ship becomes timelike and physically acceptable for any $v_s(t)$, including superluminal. It is clear that the proper time of any Earth's observer coincides with the coordinate time $\tau_e = t$ as the Earth is outside the warp bubble at all times. The expression for the warp drive metric implies that the proper time of the ship also coincides with t. To summarize, the elapsed time of the trip coincides with the coordinate

time by the clocks of both Earth and the ship. If the coordinate distance to the star of destination is d then the time of arrival at the destination is

$$\tau_e = \tau_s = \frac{d}{v_s}$$

where v_s is not restricted by the speed of light and can be made as large as it is desirable. This means that the time of arrival at the destination can be made arbitrary short by both the clock of the Earth and the clock of the ship.

We put off temporarily a discussion of difficulties present in the Alcubierre warp drive proposal. Instead, we introduce a different idea which seems to avoid some of them.

Krasnikov Tube:

A modification of spacetime geometry known as Krasnikov tube is, perhaps, the least studied of all proposals. Although it shares some of the difficulties (among them the most serious) with other ideas along the same directions, it avoids some of them. In any case, it is different enough to deserve a brief introduction.

Krasnikov tube idea is based on modifying spacetime geometry to the one determined by the metric

$$ds^2 = -(dt - dx) \, (dt + k(t, x)dx)$$

where $k = 1 - (2 - \delta)\theta_\epsilon(t - x)\,[\theta_\epsilon(x) - \theta_\epsilon(x + \epsilon - d)]$, and θ_ϵ is a smooth monotonic function, such that $\theta_\epsilon(\xi) = 1$ when $\xi > \epsilon$ and $\theta_\epsilon(\xi) = 0$ when $\xi < 0$, while δ and $\epsilon < d$ are arbitrary small positive parameters. Obviously, in the case $k \equiv 1$ (or, equivalently, $\delta \equiv 2$) the Krasnikov tube metric reduces to the Minkowski metric. The interesting case, however, is that of δ being a small positive number.

The future null cone of such geometry is changing from point to point and is determined at a point by the left and the right future null vectors

$$l = k\,\partial_t - \partial_x, \qquad r = \partial_t + \partial_x$$

The change of the future null cone as k is changing from 1 to $-1 + \delta$ is depicted in Fig. 4 (the cone tilts to the left and opens wider). One can observe that when $k < 0$ the vector l shows in the direction of decreasing value of t.

The Krasnikov tube metric subdivides spacetime in three regions (cf. Fig. 5). The first one is the outside region $\{x < 0\} \cup \{x > d\} \cup \{x > t\}$. The metric in it is the Minkowski metric ($k = 1$). Future light cones in the region are determined by null vectors $l_O = \partial_t - \partial_x$ and $r_O = \partial_t + \partial_x$. The second region is shaded in Fig. 5. Spacetme is curved in it. The third region $\{x < t - \epsilon\} \cap \{\epsilon < x < d - \epsilon\}$ is flat ($k = \delta - 1$). The future light cones in it are determined by null vectors $l_I = -(1 - \delta)\partial_t - \partial_x$ and $r_I = \partial_t + \partial_x$. The cones are open wider than in the outside region to such an extent that along some future directed timelike curves coordinate t is decreasing (the curves go back in coordinate time).

A hyper-fast interstellar travel utilizing the Krasnikov tube is best illustrated by spacetime diagram (Fig. 5). The spacecraft is moving from Earth to the destination star along the timelike world line SA in the outside region. The arrival time by the clock of the spacecraft can be made small if the line SA is close to the null cone (i. e. the speed of the ship with respect to Earth is close to the speed of light). The time of arrival by the Earth clock (pictured by SA' cannot be made smaller than d and is very large. However, the ship carries on board a device that changes the spacetime metric during its flight to the destination forming the Krasnikov tube metric. On the way back the ship is moving along the world line AR which is future directed in the modified metric but carries the ship back in coordinate time (which coincides with the proper time of the Earth). Thus it becomes possible to complete the round trip for a short interval of time by both ship's and Earth's clocks.

DIFFICULTIES OF MODIFYING THE SPACETIME GEOMETRY:

It is clear that hyper-fast interstellar travel utilizing modified spacetime geometry does not involve any violations of local causality or any other known physical principles as far as motion of spacecrafts is concerned. However, the generation and support of modified spacetime geometries (such as the Alcubierre warp bubble and the Krasnikov tube) does create problems, the most significant of which are a violation of the weak energy condition and a violation of the causality protection.

Exotic Matter:

A straightforward computation of Einstein tensor and the energy-momentum tensor for Alcubierre and Krasnikov metrics shows that the regions of curved spacetime in both cases are filled with matter. In the case of the Alcubierre warp bubble the matter is supposed to have the negative energy density everywhere in the wall of the bubble (of the external radius R and thickness ϵ) [Alcubierre, 1994; Pfenning & Ford, 1997]. In the case of the Krasnikov tube the expression for the energy-momentum density is more complicated and its evaluation is possible only for a particular choice of the function k [Everett & Roman, 1997]. However, any reasonable choice of this function (smooth and monotonically decreasing in of the wall from 1 on the outside to $-1 + \delta$ on the inside, yields qualitatively the same picture. The energy density must be negative near the inner side of the wall and positive on the outer side of it. In any case, the source of the gravity field modifying the spacetime geometry in a desirable fashion always contains, at least partially, matter with a negative energy density, which is often called exotic matter. In other words, the weak energy condition is violated.

Violation of the weak energy condition is ordinarily considered inadmissible in the classical theory, and with good reasons. In brief, existence of negative masses produces effects that do not contradict basic laws of physics but never have been observed in reality. However, quantum fields are commonly thought to be capable of violating the weak energy condition. The violation of the weak energy condition is restricted by the quantum inequality [Ford & Roman, 1996]. The inequality implies that the larger is the average negative energy over a sampling interval of time the shorter must be the duration of this interval. Application of the inequality in conditions generated by the modified geometries has been recently used to estimate the amount of negative energy required to produce the modifications such as the Alcubierre warp drive [Pfenning & Ford, 1997], the Krasnikov tube [Everett & Roman, 1997], and Morris-Thorne traversable wormholes [Ford & Roman, 1996]. The results are discouraging and similar in all the cases, as they yield absolutely nonphysical orders of magnitude for the energy. To illustrate the situation it is enough to say that to make a Krasnikov tube 1 meter long and 1 meter wide the energy required is of the order of 10^{16} galactic masses.

The significance of these results should not be overestimated. They are based on the quantum inequality the validity of which has been established originally in flat spacetimes, and later in the quantum field theory on a curved background. This means that they neglect the back reaction of quantum matter fields on the gravity field (treated classically). There are examples of modified spacetime geometry where the quantum inequality is violated. Among them are "critical" wormholes [Krasnikov, 1994; Yurtsever, 1991] and Misner with massless scalar field in the conformal vacuum state [Krasnikov, 1996]. The point, however, is that relevance of the estimates is dubious in the context of spacetime geometry modifications. Essentially, restrictions are applicable only to exotic matter that does not modify spacetime geometry.

In order to make relevant estimates it is necessary to use a theory taking into account full coupling between the gravitational field and matter fields. The standard procedure of coupling quantum fields to gravity through the regularized expectation value of the energy-momentum tensor is unlikely to provide dependable results for exotic quantum matter. What one really needs is a procedure of coupling the quantum gravity field with quantum matter fields. Unfortunately, such a procedure has not been developed in general case. Our proposal would be to develop it for the cases of particular modified spacetime geometries.

Violations of causality and chronology protection:

The idea of hyper-fast travel via spacetime geometry modification encounters obstacles of a more serious nature. The first one can be observed in the Alcubierre warp drive if the gravity field is assumed to be

generated, supported and controlled from the ship. It is easy t) see (Fig. 3) that the the world line of the front of the bubble passes everywhere outside of local null cones (moving at a superluminal speed) if $v_s > 1$. The depth of the layer moving superluminally is determined by the condition $v_s f < 1$. The energy density of matter filling this layer is nonzero. This means that the layer eit ier should consist of tachyonic matter, or be replenished all the time from the ship which also requires tachyons. This conclusion is usually taken harder than it should be. Nontrivial and positive part of it is that if there were tachyons the ship that itself consists of nontachyonic matter could be moved superluminally. Besides, absence of tachyons (i.e. fields violating local causality) does not mean by itself that a local object cannot act on events off its causal future. In particular, the metric itself can, in some cases, act as a tachyon field [Krasnikov, 1995]. Simpler yet, one can place automatic devices along the route well before the ti ne of the expedition and program them to emulate a desirable tachyonic effect. The natural name for such an arrangement could be the jump gate. It is easy to see that none of these issues show up in Krasnikov tube, which is the main reason why it has been introduced.

The second and the most serious obstacle is that all known configurations of modified spacetime geometry involved in a hyper-fast travel make it possible to build geometries with timelike closed curves (time travel). Fig. 6 shows how it can be done with Alcubierre warp drive and Krasnikov tube. According to basic theorems characterizing the causal structure of spacetime [Geroch & Horowitz, 1979] such spacetime geometry cannot be a result of any geometrodynamic evolution (chronology protection violation). The situation could change if there were some means to contribute to the spacetime structure externally (spacetime singularities, appropriate boundary conditions, tachyonic effects, quantum e fects, topological effects, etc.), which would amount to an evolution with the initial conditions changing during the evolution.

This is an exciting and unresolved problem in general relativity [Krasnikov, 1996]. We do not go into details here because we do not feel at this time that the time travel should survive in the final account. The important point is that in the classical theory any attempt to introduce varying conditions resulting in globally superluminal phenomena unavoidably leads to time travel. The reason for that is general covariance of the theory, in particular its slicing independence. This featu e does not survive in quantum gravity. The general covariance is broken. The Schrödinger equation and cor straints are attached to one slicing [Kheyfets & Miller, 1996], the slicing being determined, roughly speaking, by quantum "ether". The varying conditions and related superluminal effects in expectation values are caused by this quantum gravitational vacuum and take place only in this slicing. This means that superluminal phenomena might survive while the time travel does not. All of this is possible only in a truly quantum gravitational system differing in essential way from the one with the state functional expressed by a Gaussian centered at a classical solution [Kheyfets & Miller, 1995].

CONCLUSION:

Our review and analysis of the current state of the theory concerning hyper-fast interstellar travel via modifications of spacetime geometry based on general relativity leads us to the following conclusions:

1. No violations of local causality or any other known physical principles are involved for as far as hyper-fast motion of spacecrafts in spacetimes with modified geomet ies is concerned.

2. Generation, sustaining and control of gravitational fields modifying spacetime geometry presents several problems.

   a) A necessity to use as sources of gravity fields matter with negative energy density.

   Up to day analysis of this problem, including the quantitative estimates, cannot be considered as satisfactory. It essentially neglects the back reaction of quantum matter fields on the gravity field and downplays possible gravitational effects. Better understanding of coupling between quantum matter fields and the gravity field is needed to improv the situation. It is our opinion that analysis of the problem in quantum gravity might be crucial.

   b) Violation of local causality in some modified spacetime configurations.

   Some modified spacetimes (cf. Alcubierre warp drive) require tachyonic effects for their generation, sustaining and control. The issue has been investigated only partially. Better understanding of

tachyon-like effects produced by gravity fields is necessary. It is conceivable that such effects, especially when they are of quantum origin, will not lead to contradictions with observations.

c) Chronology protection violation.

All spacetime geometry modifications, when considered within classical general relativity, allow to design spacetimes containing closed timelike curves (time travel). The fact that such spacetimes cannot be produced as a result of causal geometrodynamic evolution, in our (as well as some other authors) opinion still does not rule them out as there are means to interfere with this evolution (one of the simplest ideas is the jump gate). The source of the time travel effect invariably associated with hyper fast travel is the general covariance of the classical theory of gravity. Only quantum gravity. where the general covariance is broken for essentially quantum states, there is a hope to have hyper fast travel without time travel.

It appears that only quantum gravity is in principle capable to give a key to a possibility of hyper fast travel free of the difficulties encountered in classical general relativity. Accordingly, we suggest to undertake an investigation in quantum gravity having the following goals:

1. To design quantum gravitational configurations resulting in modification of an expectation value spacetime geometry suitable for hyper-fast interstellar travel yet excluding time travel;

2. To investigate the configuration of the source of the gravity field necessary to generate, support and control such a modified geometry.

3. To investigate coupling between quantum gravity and quantum matter fields having as a goal to estimate possible contribution of gravitational effects towards forming modified geometries.

4. In particular, to investigate a possible contribution of quantum gravitational effect to tachyon like phenomena and to the effects similar in their nature to these produced by the negative energy density matter.

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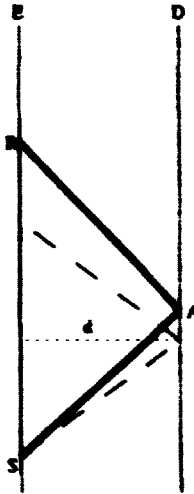
Fig. 1. Interstellar travel in Minkowski spacetime.

$v_s f = 0$ $v_s f = 1$ $v_s f = 2$
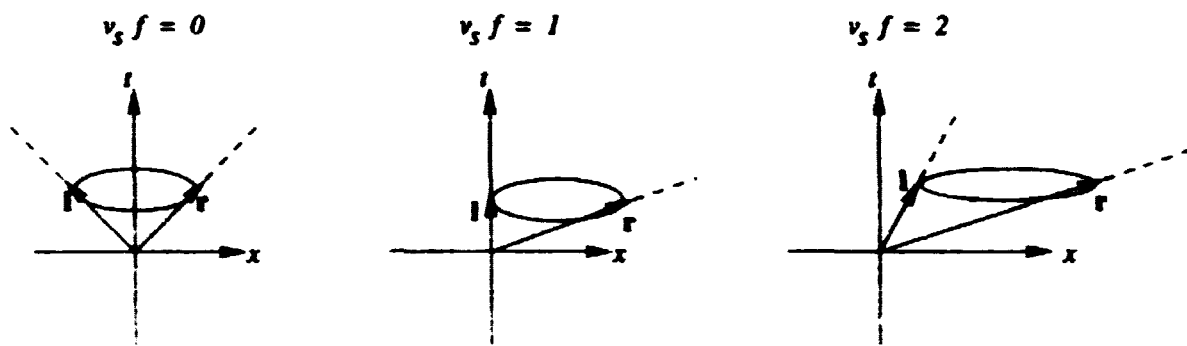
Fig. 2. Light cones in Alcubierre warp drive spacetime for different values of $v_s f$.
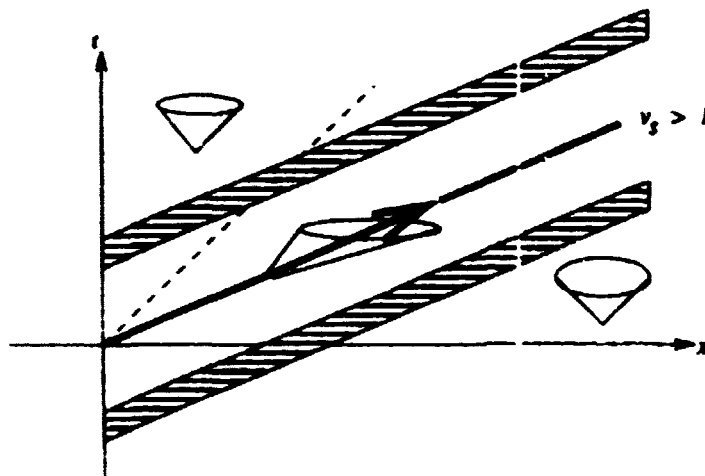
Fig. 3. A hyper-fast ("superluminal") Alcubierre warp bubble.
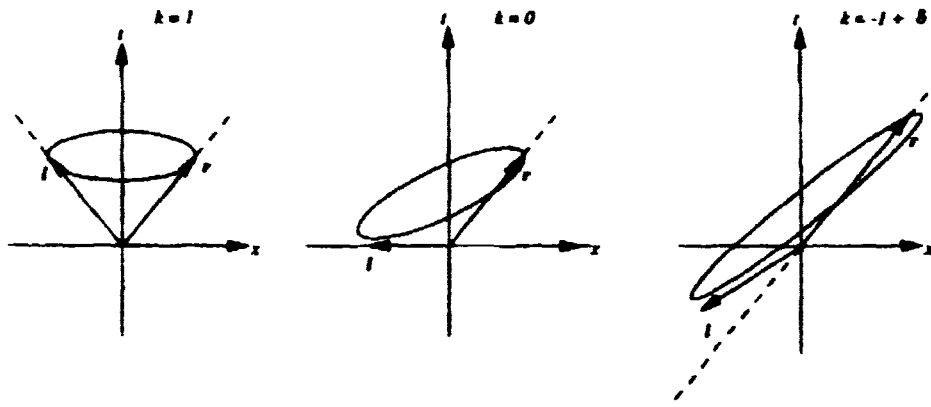
Fig. 4. Light cones in Krasnikov tube spacetime for different values of   k.
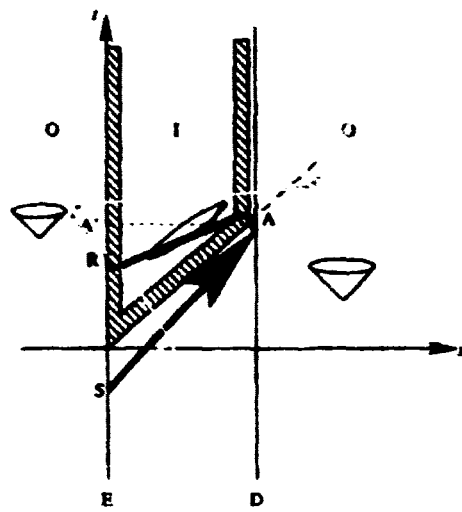
Fig. 5. Hyper-fast interstellar travel in Krasnikov tube spacetime.
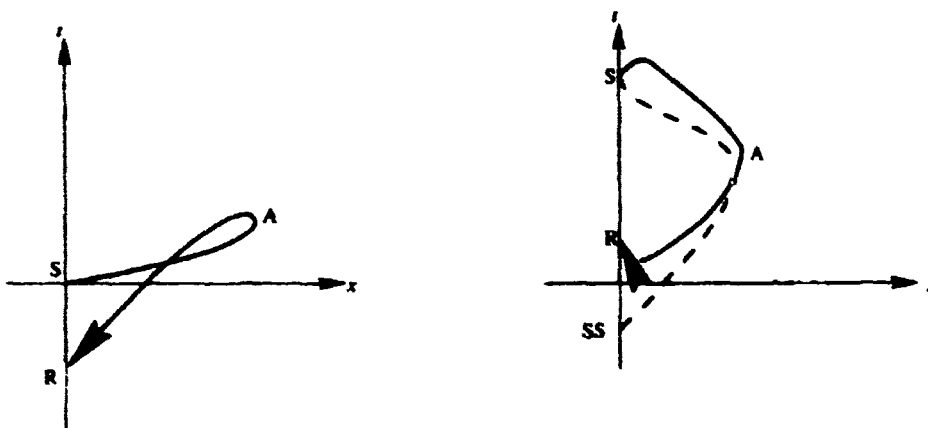
Fig. 6. Timelike closed curves SAR (time travel) generated by Aicubierre warp drive (on the right) and by Krasnikov tube (on the right). SS-S represents the world line of the ship creating the Krasnikov tube.

NEXT DOCUMENT

Ultrarelatvistic Rockets And The Ultimate Future of the Universe

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ABSTRACT:

Traversing cosmological scale distances will require ultrarelativistic rockets, i.e., rockets for which $\gamma = (1-v^2/c^2)^{-1/2} \gg 1$. I outline the theory of high γ rockets, showing that (1) the expansion of the universe can be used to slow the rocket, thus drastically reducing the initial mass ratio: (2) proton-antiproton annihilation is the favored rocket propellent. (I develop the theory of rockets with such propellent); (3) the Standard Model of particle physics allows baryon number conservation to be violated, making it easier to manufacture antiprotons; (4) payloads will probably weigh less than a kilogram, because virtual humans will be the only humans ever to engage in interstellar travel; (5) constraints imposed by the universe's ultimate future must be taken into account in any analysis of interstellar travel. I show that these ultimate future constraints imply the top quark mass is 185 ± 20 GeV and the Higgs boson mass is 220 ± 20 GeV.

I. INTRODUCTION:

At this conference we've seen many proposals for

(1) Propellantless Propulsion

(2) Faster-Than Light Interstellar Travel

I proved a number of Theorems in the late 1970's (Tipler (1976, 1977a, 1977b, 1978a, 1978b) showing that faster-than-light travel is impossible unless we have a violation of the Timelike/Null Convergence Condition ($R_{\mu\nu}U^\mu U^\nu \geq 0$, where $R_{\mu\nu}$ is the Ricci tensor and U^μ is a timelike or null vector respectively), or a violation of the Averaged Null Convergence Condition (ANCC):

$$\int_{-\infty}^{+\infty} R_{\mu\nu}U^\mu U^\nu \geq 0 \tag{1.1}$$

integration over complete null geodesics. The most recent evidence (Ford & Roman, 1996, 1997) strongly suggest that the ANCC holds even if the Casimir Effect causes a violation of the other two conditions. BUT — suppose the evidence is misleading. Suppose that we CAN build a propellantless spaceship or a faster-than light (FTL) drive.

WHY BOTHER?

That is, think *carefully* about the implications of these proposed devices. I want to challenge the TACIT assumptions of this conference.

In Section II, I shall show that an antimatter rocket can effectively move a spaceship as close to the light cone as could a propellantless engine. As regards a FTL drive, it is well known (e.g. Tipler 1974) that such a device is equivalent to a time machine. This means that if such a device is possible, then superbeings from the universe's future can travel to us now, and restrict our actions to ensure their survival. In Section III, I shall outline the physics of the Ultimate Future, and show it will not be in the superbeings' interest to allow us to use FTL drives.

II. ULTRARELATIVISTIC ROCKETS:

A relativistic spacecraft is one whose cruising speed is comparable to the velocity of light c. For "short" interstellar distances, there is really no point in going faster than $0.9c$, because at such a speed the transit time relative to the universal rest frame is 90% of the minimum transit time, whereas going faster than than $0.9c$ is extremely costly in terms of energy. For "large" interstellar distances a spacecraft needs a high initial speed in order to avoid being slowed down during transit by the expansion of the universe. I shall summarize the basic theory of spacecraft traveling at relativistic speeds; see (Tipler 1994b, 1996) for details.

The General Theory of Relativistic Rockets

If the mass of the payload is M_p and the mass of the entire rocket is initially M_i, then the mass ratio is $r \equiv M_i/M_p$. Defining $\beta \equiv v/c$, $\gamma \equiv (1 - \beta^2)^{-\frac{1}{2}}$, we recall that the total energy E of the spacecraft is given by $E = \gamma m c^2$, where m is the rest mass of the spacecraft. In this paper, all masses will be rest masses. All modern textbooks in relativity written by professional relativists, use the term "mass" to refer only to rest mass, because this is the only concept of mass that is independent of the reference frame.

It will be essential to introduce a less familiar concept, that of the rapidity ω defined by

$$\cosh \omega \equiv \gamma \equiv \frac{1}{\sqrt{1 - \beta^2}} = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{2.1}$$

$$\sinh \omega \equiv \frac{\beta}{\sqrt{1 - \beta^2}} = \frac{\frac{v}{c}}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{2.2}$$

and so $\tanh \omega = \beta = \frac{v}{c}$.

The reason for introducing the rapidity is that rapidities, unlike velocities, add linearly. That is, we have $\omega_E = \omega_r + \omega_q$, since $\tanh(\omega_r + \omega_q) = \frac{\tanh \omega_r + \tanh \omega_q}{1 + \tanh \omega_r \tanh \omega_q}$ is both the standard velocity addition formula and an identity of hyperbolic functions.

To compute the mass ratio, suppose a rocket having initial mass $\tilde{M}$ moves forward by expelling a burst of gas with infinitesimal mass Δm at exhaust velocity v_s (as measured in the rocket's instantaneous rest frame), leaving the rocket with mass M and infinitesimal forward velocity dv. Then $d(\frac{v}{c}) = d\beta = \tanh(d\omega)$.

Conservation of energy in this situation is given by

$$\Delta m c^2 \cosh \omega_s + M c^2 \cosh(d\omega) = \tilde{M} c^2 \tag{2.3}$$

and the conservation of momentum by

$$-\Delta m c \sinh \omega_s + M c \sinh(d\omega) = 0 \tag{2.4}$$

Since $d\omega$ is infinitesimal, we have $\cosh(d\omega) \approx 1$, and $\sinh(d\omega) \approx d\omega$; putting in these approximations and dividing the momentum equation (2.4) by the energy equation (2.3) gives

$$\frac{\sinh \omega_s}{\cosh \omega_s} = \tanh \omega_s = \frac{v_s}{c} = \frac{M d\omega}{\tilde{M} - M} \tag{2.5}$$

But the change in the rocket rest mass is $dM = M - \tilde{M}$, so

$$d\omega = -\frac{v_s}{c} \frac{dM}{M} = -\beta_s \frac{dM}{M} \tag{2.6}$$

Now rapidities add linearly, so (2.6) can be integrated to give

$$\omega = \beta_s \ln \left(\frac{M_i}{M_p} \right) \tag{2.7}$$

which implies

$$\tanh \omega = \frac{v}{c} = \tanh \ln \left(\frac{M}{M_p} \right)^{\beta_s} \tag{2.8}$$

where v is the final velocity of the rocket in the rest frame of the Earth. After a little algebra, this expression gives

$$\frac{M_i}{M_p} = \left[\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}\right]^{\frac{v_e}{2v_e}} = \left[\frac{c + v}{c - v}\right]^{\frac{c}{2v_e}} \tag{2.9}$$

Since $\frac{v}{c} = \sqrt{1 - \frac{1}{\gamma^2}}$, then if $\gamma \gg 1$, we have $\frac{v}{c} \approx 1 - \frac{1}{2\gamma^2}$, so the mass ratio is approximately

$$\frac{M_i}{M_p} \approx (2\gamma)^{\frac{c}{v_e}} \tag{2.10}$$

For photon rockets ($v_e = c$), this means that, in the ultrarelativistic limit ($\gamma \gg 1$), the ratio of the initial total energy of the rocket, including the fuel, to the final total energy of the payload is just

$$\frac{M_i c^2}{\gamma M_p c^2} = \frac{2\gamma}{\gamma} = 2$$

Photon rockets are thus a quite efficient means of obtaining a high γ: the total initial mass-energy needed to accelerate the rocket to the final velocity v is only twice the final total energy the payload has in the rest frame of the Earth. However, once the rocket's velocity has reached $0.9c$, it becomes extremely costly to decrease significantly the travel time as measured in the universal rest frame. When $v = 0.9c$, we have $\gamma = 2.3$, whereas $v = 0.99$ corresponds to $\gamma = 7.1$; the total rocket energy must be increased by a factor of 3 in order to decrease the transit time by only 10%. This is expensive, since for photon rockets the mass ratio is 4.4 for a velocity of $0.9c$ but 14.1 for a velocity of $0.99c$.

Since any spacecraft acceleration mechanism will require at least $E = (\gamma - 1)mc^2$ of energy to be imparted to the spacecraft, the photon rocket is within a factor of 2 of the most efficient acceleration mechanism.

Using the Expansion of the Universe to Slow a Rocket

A high γ spacecraft will be useful only if the spacecraft is going so far that the expansion of the universe becomes significant — as would be the case, for example, if one wished to go to the opposite side of the universe. In such a situation, the spacecraft would appear to be going slower and slower relative to the galaxies farther and farther away, since these galaxies are moving faster and faster away from us, by Hubble's law. The FRW metric is

$$ds^2 = -dt^2 + R^2(t)[d\chi^2 + \Sigma^2(\chi)(d\theta^2 + \sin^2\theta d\phi^2)] \tag{2.11}$$

Since this spacetime is spatially homogeneous and isotropic, a geodesic initially moving entirely in the the radial (χ) direction remains without velocity in either the θ or the ϕ directions. Thus a radial geodesic moves in the 2-dimensional space defined by the metric $ds^2 = -dt^2 + R^2(t)d\chi^2$. Since the metric components do not contain χ explicitly, this means that the momentum in the χ direction, p_χ, is a constant of the motion. But $p_\chi = g_{\chi\chi}p^\chi = g_{\chi\chi}d\chi/d\lambda$, where λ is the affine parameter if the particle we are following is a photon, and is equal to the particle's proper time per unit rest mass along the particle's trajectory if the particle is timelike (as it would be if it is a spacecraft).

If we compute the momentum in the radial direction in the local Lorentz rest frame of observers at rest in the FRW coordinates — such observers have constant χ, θ, ϕ, and they are the observers at rest with respect to the cosmological background radiation — we get (letting p^χ_{Local} be this momentum):

$$p^\chi_{Local} \equiv p^{\hat\chi} \equiv \langle \omega^{\hat\chi}, p \rangle = \langle g^{1/2}_{\chi\chi}d\chi, p \rangle = g^{1/2}_{\chi\chi}p^\chi = g^{1/2}_{\chi\chi}\frac{d\chi}{d\lambda}$$

where $\omega^{\hat\chi}$ is a local orthonormal basis 1-form, and p is the 4-momentum vector. But since $g_{\chi\chi}d\chi/d\lambda$ is a conserved quantity, and since $g_{\chi\chi} = R^2(t)$, we have shown that $R(t)p^\chi_{Local}(t)$ is a constant, independent of cosmic time. Thus

$$\frac{p^\chi_{Local}(t_{now})}{p^\chi_{Local}(t)} = \frac{\gamma_{now}v_{now}}{\gamma(t)v(t)} = \frac{R(t)}{R(t_{now})} \tag{2.12}$$

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where $p^\lambda_{Local}(t_{now}) = \gamma_{now} m v_{now}$ is the relativistic momentum the spacecraft has in the rest frame of the stellar system which launches it, and $R(t_{now})$ is the scale factor of the universe the day the spacecraft is launched.

The crucial thing to note about equation (2.12) is that it says we can in effect use the expansion of the universe itself to slow down the spacecraft; we need not carry along any fuel to accomplish this. This is extremely important for high gamma spacecraft, because if all the velocity of transit had to be killed, the initial mass ratio given above would have to be *squared*. If the spacecraft is to reach the antipodal point at a time when the universe is 3×10^5 its present size, we would need an initial $\gamma_{now} = 5 \times 10^5$ for a photon rocket if the travel is to be relativistic the whole trip. (Having $\gamma(t_{max}) = 2$ is a sufficient condition for the entire trip to be relativistic, where t_{max} is the time of maximum expansion.) If we had to use the rocket to slow down from $\gamma = 5 \times 10^5$, we would have to have an initial mass ratio of 1×10^{12}. Instead, only $(3.7)(2)(5 \times 10^5) = 3.7 \times 10^6$ is necessary. (The extra factor of 3.7 is required to slow the payload from $\gamma = 2$ down to $\gamma = 1$.)

The Theory of Proton-Antiproton Rockets

However, a realistic relativistic rocket would probably not be a photon rocket, because the only known method of converting mass entirely into energy involves matter-antimatter annihilation. Thus the rocket fuel has to consist of half matter and half antimatter. The reaction $e^+ + e^- \rightarrow 2\gamma$ gives only photons, but there is no known method of storing large amounts of positrons, except as part of anti-atoms. So most of the antimatter mass would be antiprotons, which does not annihilate directly into two photons. Proton-antiproton annihilation generally proceeds (Cassenti 1988) by decay into pions:

$$p + \bar{p} \rightarrow m\pi^0 + n(\pi^+ + \pi^-)$$

where $m \approx n \approx 1.60$. None of the pions are stable, and the neutral pion usually decays via the reaction $\pi^0 \rightarrow 2\gamma$. The gamma rays from the neutral pions are lost, carrying away energy, but the charged pions will travel about 20 meters before they decay, and thus can provide thrust by having their trajectories bent by magentic fields so that they go out the rocket exhaust. The neutral pions carry away on the average zero net momentum in the rocket's instantaneous rest frame.

If some of the energy in the annihilation is lost, then equations (2.3) and (2.4) have to be modified. If a fraction $\eta \Delta mc^2$ of the propellent rest mass gets rapidity ω_s, and another fraction $\delta \Delta mc^2$ just disappears in the reaction, then equations (2.3) and (2.4) respectively become

$$\eta \Delta mc^2 \cosh \omega_s + \delta \Delta mc^2 + Mc^2 \cosh(d\omega) = \tilde{M}c^2 \tag{2.13}$$

$$-\eta \Delta mc \sinh \omega_s + Mc \sinh(d\omega) = 0 \tag{2.14}$$

Proceeding as in the derivation of equation (2.5), we get

$$\frac{\eta \sinh \omega_s}{\eta \cosh \omega_s + \delta} = \frac{M d\omega}{\tilde{M} - M} = -\frac{M d\omega}{dM} \tag{2.15}$$

where I have inserted the change in the rocket rest mass, $dM = M - \tilde{M}$. Integrating equation (2.15) gives

$$\omega = \left[\frac{\sinh \omega_s}{\cosh \omega_s + \frac{\delta}{\eta}} \right] \ln \left(\frac{M_i}{M_p} \right) \tag{2.16}$$

where now v_s is the velocity of the charged pions in the $p - \bar{p}$ annihilation reaction. Solving equation (2.16) for the mass ratio yields

$$\frac{M_i}{M_p} = \left[\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}} \right]^{\frac{c}{2v_s}[1 + \frac{\delta}{\eta \gamma_s}]} \tag{2.17}$$

where $\gamma_s = \cosh \omega_s$.

But by conservation of energy we have

$$\eta\gamma_i = \delta$$

which reduces equation (2 17) to

$$\frac{M_i}{M_p} = \left[\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}\right]^{\frac{c}{\eta}} \tag{2.18}$$

For $\gamma \gg 1$, we have

$$\frac{M_i}{M_p} \approx (2\gamma)^{\frac{2c}{\eta}} \tag{2.19}$$

instead of equation (2.10). Equation (2.19) differs from equation (2.10) by an extra factor of 2 in the exponent.

Conservation of energy gives $2 \times 938 - 4.8 \times 139$ MeV divided more or less evenly among 4.8 pions, so each charged pion has a kinetic energy of 252 MeV. The ratio of kinetic energy to rest mass is $\gamma - 1$, so each pion has $\frac{v_i}{c} = 0.935$. Equation (2.19) thus becomes

$$\frac{M_i}{M_p} \approx (2\gamma)^{2.14} \tag{2.20}$$

With the initial $\gamma_{now} = 5 \times 10^5$ required to reach the antipodal point by the time of maximum expansion, we would need an initial mass ratio of 1×10^{14}. (Remember that an extra factor of 17 is required, because the rocket must be used to reduce $\gamma(t_{max}) = 2$ down to $\gamma = 1$.)

Now the term "payload" in the mass ratio includes not only the payload proper, but also the fuel tanks and the rocket engines. The key to reducing both the mass of the payload proper and the masses of the tanks and engines is nanotechnology (Drexler 1992). I have argued elsewhere (Tipler 1994b, Section N) that the mass of the payload proper need be no greater than 100 grams. If we use molecular-size universal constructors to reshape the rocket and the engines as it accelerates, then in principle, the tanks and the motors can be made out of fuel; the tanks and motors will then make zero contribution to the payload mass. If this is done, then a matter-antimatter annihilation rocket capable of traveling, at relativistic velocities the whole way, from the Earth to the other side of the universe by the time of maximum expansion, would have a mass of ten billion metric tons.

Using the Standard Model to Reduce the Energy Cost of Making Antimatter

The current cost of five billion tons of antimatter is enormous. A large fraction of this enormous cost is due to the baryon and lepton number conservation law, which requires that a proton be created along with each antiproton. This means that at least half of the energy must go into creating useless protons. The same conservation law restricts nuclear energy to less than 1% efficiency: less than 1 % of the rest mass of nuclei can be converted into energy, whereas if the law did not hold, possibly all the mass could be converted into energy.

However, in 1976, Gerard t'Hooft showed that the law can be violated in the Standard Model of particle physics. The predicted violation is tiny, and has never been observed, but if the Standard Model is correct — and all experiments indicate that it is — then this violation must occur. A number of physicists (Tipler, 1994b, Section N) since 1976 have discovered ways in which the effect can be enhanced, but our mathematics is too primitive to analyze the details of the effect in the absence of experiments.

Why Virtual Humans will be the Only Humans Ever to Engage in Interstellar Travel

Recall that nanotechnology allows us to code one bit per atom in the 100 gram payload, so the memory of the payload would sufficient to hold the simulations of as many as 10^4 individual human equivalent personalities, at 10^{20} bits per personality. This is the population size of a fair sized town, as large as the population of "space arks" that have been proposed in the past for interstellar colonization. Sending simulations — virtual

human equivalent personalities — rather than real world pe ple has another advantage besides reducing the mass ratio of the spacecraft: one can obtain the effect of relativistic time dilation without the necessity of high γ by simply slowing down the rate at which the sp ecraft computer runs the simulation of the 10^4 human equivalent personalities on board. One needs the large γ in the trip to the universal antipode in order to get there by the maximum expansion time, not to reduce the time experienced on board the spacecraft.

A third advantage of using virtual human equivalent personalities rather than real world humans is that it solves the problem of radiation shielding. Protons in the interstellar medium have the same γ in the spacecraft's rest frame as the spacecraft has in the medium s rest frame, and the resulting intense radiation from the protons in the interstellar medium has often been cited as proving the impossiblity of high γ spacecraft. One indeed needs thick shielding: 2 meters thickness of aluminum is required to stop 1 GeV protons (γ = 2). However, if the spacecraft has a cross-sectional area of $1mm^2$, then only 5 grams of aluminum is required.

A fourth advantage of virtual humans in a virtual environment over real humans is that the virtual humans will experience the simulated acceleration of the virtual environment rather than the real acceleration of the rocket. If a rocket accelerates at 155 gravities, real humans would be converted into jelly, while virtual humans on the same rocket would experience their choice of accelerations: the usual 1 gravity or less. Since there is no difference between an emulation and the machine emulated, I predict that no real human will ever traverse interstellar space. Humans will eventually go to the stars, but they will go as emulations; they will go as virtual machines, not as real machines.

III. THE ULTIMATE FUTURE OF THE UNIVERSE:

I shall show that the mutual consistency of all the laws of physics in the Ultimate Future imply: (1) the universe must be closed, with S^3 spatial topology; (2) the universe will expand to a maximum size, then collapse to a final singularity; (3) the universe must be near y homogeneous and flat, with $\Delta T/T < 6 \times 10^{-5}$ and $4 \times 10^{-6} < \Omega_0 - 1 < 4 \times 10^{-4}$, where T, ΔT, and Ω_0 are the temperature and temperature variation of the Cosmic Background Radiation (CBR), and the density parameter resepctively; and finally the top quark and Higgs boson masses must be 185 ± 20 GeV and 220 ± 20 GeV respectively.

I shall then show that the ultimate future implied by the laws of physics is unlikely unless life expands to engulf the entire universe, and to control it, forcing event horizons to disappear. A spacetime without event horizons is called an Omega Point universe, and the theory of such a universe the Omega Point Theory. I shall show that this universe-engulfing behaviour of life is equivalent to the constructability of a "universal" computer, a computer that can emulate any other computer. Finally, I shall show life can survive in the far future only if FTL drives are never used. I shall only outline the proofs of these claims here. A full demonstration would require a book, which I've written: *The Physics of Immortality* (Tipler, 1994b).

Hawking has shown that if black holes (BHs) completely evaporate — which they will if the universe expands forever — then some information inside the BH will be lost, since event horizon can end only in singularities. This loss of information will necessarily cause unitarity to be violated. (I can show, but do not have the space to do so here, that this violation of unitarity cannot be circumvented by invoking quantum "hair" or the standard d-brane mechanisms.) But unitarity is a fundamental physical law. Hence, if astrophysical BHs exist — which they do — then the universe cannot expand forever. This means, if gravity is always attractive, that the universe must topologically be S^3 spatially, a universe which expands to a maximum size, and then recontracts to a final singularity (Barrow et al 1985, 1986).

The entropy of the universe is bounded below by the entropy in the CBR. By the Second Law of Thermodynamics, this entropy cannot decrease. But the Bekenstein Bound (See Tipler (1994b) for an analysis of this Bound; it's basically the Heisenberg Uncertainty Principle in relativistic guise) says if there are event horizions present:

$$Entropy < Information\ in\ Universe < \frac{\pi R^2}{L_{Planck}^2 \ln 2} \tag{3.1}$$

where R is the scale factor of the universe, and L_{Planck} is the Planck length (10^{-33} cm.). We have a contradiction with the Second Law if there are event horizons. since $R \to 0$ in the contracting phase of

the universe. (The CBR entropy contradicts (3.1) when the CBR temperature reaches 10^4 GeV in the contracting phase.) However, if there are no event horizons present, then the Bekenstein Bound is not (3.1) but

$$Entropy < Information\ in\ Universe < \frac{2\pi ER}{\hbar c \ln 2} \tag{3.2}$$

where E is the total non-gravitational energy in the universe. It can be shown that if life (and/or computers) has engulfed the universe, then the available energy in the contracting phase increases as R^{-3}, so the righthand side of (3.2) diverges to infinity as $R \to 0$, thereby avoiding Second Law violation.

So life must become ubiquitous near the final singularity, and event horizions must disappear if the laws of physics are to remain consistent. But — it is well-known that S^3 homogeneous solutions of Einstein's equations without event horizons are of measure zero in the space of all solutions. It is exceedingly implausible that the entire universe could be evolving toward a measure zero state, so if such were to occur it would mean that some essential physics was being left out.

A universe with no event horizions is measure zero, however, only if the actions of life/computers are left out of the analysis. But if life is present, its effect on a large physical system cannot be ignored. Consider the Earth's atmosphere. If we ignored the effect of life, we would infer that it would have to consist of 95% carbon dioxide, the same as the atmospheres of Venus and Mars. Life has completely changed Earth's atmosphere: carbon dioxide has been removed by green plants and they have introduced free oxygen. The oxygen is sustained by the continual action of plants. So it will be with the universe as a whole. Life in the far future will expand and engulf the universe, and eliminate event horizions, something life must do if it is to survive. Further, life must be present in the ultimate future for the mutual consistency of the physical laws. As I show below, taking life into account makes the elimination of horizons necessarily present in the space of all physically reasonable solutions of Einstein's equations. In such a space of solutions, those solutions without event horizons are of normalized measure one, not measure zero.

In the preceeding discussion, I have identified life with computers. Let me now justify this, and rederive the Omega Point Theory from a computer science postulate (Tipler 1986): A UNIVERSAL COMPUTER CAN BE CONSTRUCTED.

The reason for believing a Universal Computer is not only fundamental in computer complexity theory, but its constuctability is also possible physically comes from the Feynman/Deutsch view of physical processes (Deutsch 1997), according to which computations and physical processes are in one-to-one correspondence: not only are all computations physical processes (obviously!) but conversely, all physical processes are really computations. In particular, the evolution of the universe is just a gigantic computation! Life also must be a form of computation, one in which the information is preserved by natural selection. The Oxford University zoologist Richard Dawkins (1976, 1987) has independently defended this computer definition of life. This view of physics — regarding computer science and physics as being in 1-1 correspondence — has lead Feynman and Deutsch to invent the quantum computer, which justifies the view experimentally.

The ultimate limit to computation is therefore a fundamental physical law, the fundemantal limit on the complexity of physical processes. Computer science has already determined the most natural limit to the complexity of a computer, namely a universal computer.

Recall some key facts about universal computers. First, by the Church-Turing Thesis (see Deutsch 1997 for a discussion of this thesis), all universal computers are equivalent (not surprising, since by definition a universal computer is one which can emulate all other computers.) I shall need two theorems about universal computers: (1) they all have an infinite memory, and (2) each bit of this memory is always accessible to the central processor. See Minsky (1967) for the proofs of these theorems. These theorems have the following three implications for cosmology if a universal computer can be constructed:

(A) computation must continue in the universe until the end of time, since for all events p and q in a deterministic spacetime, $J^+(p) \cap J^-(q)$ is compact, where $J^\pm(q)$ is respectively the causal future $(+)$ and causal past $(-)$ of the event q (Hawking & Ellis 1973). A compact set *cannot* contain an infinite computer memory.

(B) the computer must process an infinity of bits between now and the end of time 'since the computer is infinite), and

(C) the computer must store a diverging amount of causally connected bits of information as end of time is approached (causally, since each bit of the memory must be always accessible).

A universal computer cannot be constructed in an open (or inflationary) universe because all structures decay, and such universes expand too fast to use available energy to re-construct them (Tipler 1992). A universal computer cannot be constructed in a flat universe because there would not be enough energy available to send an infinity of signals back and forth across the universe an infinity of times (which must happen if all bits are to always be causally accessible). Thus we PREDICT that the universe must be closed. Recall that each bit of information *irreversibly* processed requires expending kT of free energy. By Implication (B), we must have

$$Total\ Information\ Processd = \int_{now}^{end\,of\,time} \frac{dE/dt}{kT}\,dt = +\infty \qquad (3.3)$$

The energy density ρ available in an appropriate asymmetric collapse of the universe increases $\sim R^{-6}$, the total available energy as $\sim \rho R^3 \sim R^{-3}$ (as I stated above) the temperature increases as $\sim R^{-1}$, and $R \sim t^{1/3}$, where t is the proper time until the final singularity is reached at $t = 0$. Thus in a closed universe, there is MORE THAN ENOUGH ENERGY to process an infinity of bits.

PROVIDED event horizions disappear, so computer operations can be carried out over the entire universe. Note that the disappearance of event horizions also guarantees that each bit stored in memory is always available for further processing. The absence of event horizon: means that in Penrose's c-boundary construction (Hawking & Ellis 1973; Tipler 1994b), the future c-boundary consists of a single point: call it the *Omega Point*, and this theory of the universe's Ultimate Future *The Omega Point Theory*.

Since the temperature of the universe is going to infinity as the final state is approached (recall $T \sim 1/R$), information must be stored in some other form than the chemica bonds now used. In general, information is stably stored if it is coded in energy levels with energy greater than kT. Such storage can be accomplished if we store info as standing waves with the universe itself as the bounding box, since the collapse of the universe would itself increase the energy of the waves as $E \sim 1/R$. Transferring the information from its present matrix of chemical bonds to standing waves is easiest if universe slows its collapse before the temperature reaches the chemical bond energy of $\sim 1/100$ eV. The Standard Model of particle physics minimally coupled to gravity says such a slowing force must exist, and *may* be of sufficient magnitude to work. The slowing effect is *maximized* and hence the likelihood of successful info transfer is maximized if (PREDICTION [Tipler 1994a,b]):

mass of top quark $= 185 \pm 20$ GeV, and mass of Higgs boson $= 220 \pm 20$ GeV

Computers will not be able to eliminate event horizions if all matter condenses into giant BHs before the matter can be reached by ultrarelativistic rockets. The only way this can be prevented is for irregularities to not have grown too large before other parts of the universe are reached by such rockets. Projecting this back on the CBR gives (PREDICTION): $\Delta T/T < 6 \times 10^{-5}$.

Setting up the conversion from information storage in present-day chemical bonds to universe-sized standing waves requires that computers/life have already engulfed the universe, and further, have been in causal contact before the standing waves are set up. It can be shown (Tipler 1994b) that this requires, in addition to approximate homogeneity at that far future time, (PREDICTION): $4 \times 10^{-6} < \Omega_0 - 1 < 4 \times 10^{-4}$.

The energy from asymmetric collapse of the universe does not become available until after the recollapse of the universe has begun. Until then, the conversion of matter into energy will be the primary source of energy. The causal structure of the universe actually prevents this matter-energy from being used too fast: in a matter-dominated universe, the universal antipodal point cannot be reached by $v < c$ rockets until after the time of maximal expansion. But a FTL drive would permit life to use resources too fast, and thus far future life would intervene to stop the use of FTL drives. With the above Ω_0, virtual humans would arrive at antipode 10^{18} years from now (when $R(t)/R(t_{now}) = 3 \times 10^5$), and our Sun would have long since left

the Main Sequence However, if Earth and the other planets in the universe are downloaded in computers before they are destroyed, virtual humans can eventually return to (emulated) Earth and/or all other planets at any time they choose. In short, every virtual human can personally see everything in the present day universe there is to see. FTL spaceships are unnecessary!

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NEXT DOCUMENT

Possible Evidence of Anomalous Energy Effects in
H/D-Loaded Solids—Low Energy Nuclear Reactions (LENRs)

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ABSTRACT

A growing body of experimental evidence is cited showing that low-energy nuclear reactions (LENRs) can occur under select conditions in solid lattices loaded with hydrogenous atoms. There appear to be various reaction regimes leading to different nuclear products. If this phenomenon continues to be verified, a radically different theory for the interaction and the subsequent reaction must be developed. None of the presently proposed theories have been adequately benchmarked. One key difficulty remains--the irreproducibility of experiments, possibly due to yet to be identified variability of the solid state structure involved. To illustrate the LENR effect, recent experiments at the University of Illinois are discussed, where a large number of new elements are observed in thin films of various metals such as Ni undergoing electrolysis. A semi-empirical theory to interpret these results is also outlined. If LENRs are verified, this will lead to a breakthrough in nuclear physics understanding and also to a number of important potential applications, such as space power units.

INTRODUCTION

The phenomena of anomalous heating effects in deuterated metals gained worldwide attention through the famous S. Pons and M. Fleishman (PF) announcement of "cold fusion" in 1989. [1] Shortly after that, discrepancies in their report were uncovered. Due to that and to difficulties in reproducing the experiment, the scientific community became skeptical. When the DOE ERAB committee commissioned to evaluate the situation released a negative report, skepticism accelerated. Despite this, a number of scientists worldwide have continued dedicated but low-key studies of such effects, and there have been numerous reports of positive results. Thus, in a recent review article, E. Storms [2] cites over one-hundred positive experiments of various types reported by well-known laboratories around the world. While even these experiments are still plagued by nonreproducibility, the fact that this many definitive experiments have been reported provides rather convincing evidence that anomalous heating and/or nuclear effects can occur in a variety of materials loaded with high concentrations of hydrogen or deuterium. Most recently, a number of these experiments have identified nuclear reaction products that are attributed to hydrogen or deuterium interactions with the metal electrode, rather than the D-D-type fusion studied by PF [3-6]. Consequently, workers have renamed this field as "Low Energy Nuclear Reactions (LENRs)." This work has used a variety of configurations and a variety of loading techniques giving reaction products ranging from Helium-4, Tritium, to an array of heavy elements. Various theories have been advanced to explain these results, but they are usually restricted to a class of reaction products. In this paper, we will first briefly review some of the LENR experiments and theories reported by others and then concentrate on experiments by the author at the University of Illinois. [4,5]

LENR CHARACTERISTICS

As indicated in Figure 1, the PF D-D-type reactions when observed experimentally, have shown characteristics that are quite different from normal hot fusion D-D reactions [1]

■		hot fusion	"P-F" type
■	<u>D-D</u>	> 2 keV	≤ 1 eV
■	T + p	50%	<0.1%
■	He-3 + n	50%	<10*-6%
■	He-4 + gamma	< 10*-3%	99+%
■			<u>"NEW" LENRs</u>
■	p+metal	——	fps
■	hydrinos	——	x-rays

■ <u>Conclusion</u>: "New" LENRs are distinctly different from P-F D-D type and both differ from normal hot fusion reactions.

Figure 1. LENR Characteristics vs "Standard" Reactions

The original PF concept is that if the compound He-4 nucleus formed by the D-D reaction is in a lattice, its excitation energy might transfer in a coherent transfer mode to the lattice structure. This would yield heat and helium as the main outputs instead of tritium and neutrons that normally occur by the fast decay of excited He-4. [7] The most recent LENR-type experiments have reported yet amazingly different major products ranging from tritium production to an array of isotopes with masses below and above the mass o' the reacting metal. [3-6] Other experiments appear to funnel energy into X-rays through a collapse of grou id-state hydrogen into a lower energy level leading to so-called hydrinos. [8]

These LENR reactions have been produced by a variety of techniques ranging from the more traditional electrolytic technique on to electrical discharges in gases, electric arcs in water, high-pressure gas loading, and biological action. In view of this wide range of conditions, theoreticians are faced with a chal enge in defining a common driving force of the reaction. One thought is that all of these phenomena basically involve nonequilibrium flows in the crystalline structure, but other investigators argue that the reactions themselves are so different that they may involve entirely different mechanisms.

Examples of the wide variety of experimental conditions and the variety of reaction products observed are outlined in Figure 2. [1]

■ Electrolysis -- PF, IMRA, SRI, CETI, etc.
  • D₁O, Pd; fused salt...... heat, He-4, ..
  • H2O, Ni, Pd, ... heat, fps
■ Plasma discharge — Karabut,Dufour,Claytor
  • D2. Pd, .. — tritium, fps
■ Proton conductor --- Mizuno, Oriani, Biberian
  • Sr(Ce,..)O₃. AlLaO₃ -- heat, (fps)
■ Ultrasonic, Gas loading --- EQ,P antelli,Fiat
  • metals — heat, rad., fps

Figure 2 Examples of LENR Experiments

Questions can be raised, but many of these reported results appear to definitively demonstrate that LENRs do occur. For example, T. Claytor's experiments at Los Alamos [9], employing a plasma discharge loading method, have achieved tritium levels that are orders of magnitude greater than background. Nuclear reactions appear to be the only way that tritium could be created in these experiments. The man issue that remains is reproducibility—tritium production occurs only in about 15% of the many experiments performed. This problem, a characteristic of most of the work in this field, is generally attributed to differences in crystalline structure of the solid being loaded. To date, however, a definitive identification of the cause has not been made. Suggestive experiments by Srinivasin in India [10] exposed electrodes after a run to X-ray film and found a speckled pattern of bright spots. This observation and related experiments by others suggest that the lattice contains a scattered pattern of nuclear-active-sites. [1] but exactly what defines such a site and how to create one remains unknown.

KEY PHYSICS ISSUES

Assuming that, based on this data, LENRs occur, a number of key new physics issues must be tackled to understand the phenomenon. Basically, any theory must explain two key issues: how penetration of the Coulombic barrier between high reactants can occur, and then how a "nontraditional" reaction occurs. Some of the many theories that have been advanced to explain these issues are listed in Figure 3. [1,11] The majority of the theories involve in some manner a coherent wave structure in the crystalline host material. Others attribute the effect to formation of new particles such as hadrons or polyneutrons.

- *Chubb and Chubb* - ion band theory, wave overlap - critical crystal size - He4; *Bush* - resonant wave interactions

- *Preparata* - QED, coherent fields combine, x-rays

- *Bazhutov, McKibben* - hadrons, fractional chg pts

- *Miley & Hora* - SEL at thin film interfaces

- *Hagelstein* - energy transfer via phonon laser

- *Fischer* - polyneutron - BCS condensate, nuclear rx

- *Mills, Dufour* - fractional energy levels in H

- *Kucherov* - phonon energy transfer to metals

- *Miley - RIFEX* - combines SEL and BSC condensate

- Issue - *despite major differences, non fully accepted due to lack of benchmark.*

Figure 3. Some Theories

Despite the major differences among these theories, none have gained general acceptance. The reason is that there has not been an accepted benchmarking of the theories against experimental data. This is partly due to the problems of nonreproducibility of the experiments, and also to the inability to define a definitive benchmark experiment. Some progress is being made, e.g., initial steps towards benchmarking RIFEX theory with thin-film data are noted later, but much more work is needed to complete this effort and to evaluate other possible theories.

SIGNIFICANCE

While the field of LENR remains somewhat ill-defined due to the issues noted above, it is clear that if LENRs are fully demonstrated in a reproducible manner, research will rapidly expand, and extremely important scientific and practical applications can be expected. The physics necessary to explain LENRs is so radically different from

traditional nuclear reaction physics that it offers a whole new field of study, which has the potential of new breakthroughs. The field is quite interdisciplinary bringing together physics, chemistry, and materials science. Consequently, all three scientific areas stand to benefit from the new insights gained from this research. The conclusion of this research could lead to an extremely important new nuclear energy source, which would have far-ranging implications for both terrestrial and space. Other extremely important applications could involve isotope production and radioactive waste management. Additional applications are likely to emerge as more is learned about this remarkable phenomenon.

RECENT REACTION PRODUCT MEASUREMENTS AT THE UNIVERSITY OF ILLINOIS

G. Miley et al. recently reported [4 5] a series of unique measurements that employed various metallic (Ni, Pd, Ag, Ti,..) thin films (500 Å) coated on millimeter-sized plastic beads. These beads served as the cathode in a flowing, packed-bed electrolytic cell. One molar Li_2SO_4 in light water was used, w th the objective of studying proton-induced metal reactions. Runs were carried out over a three-week period with a 0.1 W input and a measured output of 0.1-5 W. Analysis of the beads was done before and after the experiments using high precision techniques including NAA, SIMS, EDX, and ICP-MS. A wide range of new elements were found in the metallic films following the runs. These "reaction products" had mass numbers ranging well below and above the base metal mass number. In several runs, very high yields of reaction products were obtained, the key products comprising approximately 40 atm % of metallic film following the run. The increase in mass of eight key elements appearing in the thin films (Al, Ag, Cr, Fe, Cu, V, Co, Zn) was measured by NAA in the film, electrolyte, and cell components before and after a run. As illustrated in Figure 4, most elements increased in mass by an amount that was an order of magnitude or more greater than all of the corresponding impurity present in the cell electrolyte, the major source of impurities. Further, there was no evidence of a plating out, i.e., significant reduction of impurities in the electrolyte after a run. Further, the "new" element concentrations peaked in the film volume rather than at the film-electrolyte interface.

SOME NAA ELEMENT RESULTS FOR RUN #8, NI FILM

	Increase, mg Per 10^3 beads	mg, 100 ml electrolyte	Ratio*
Ag	1.5	3×10^{-3}	500
Cu	1.1	8×10^{-2}	10

*mg increase/mg electrolyte

Deviation from natural abundance, NAA on 1) bead sample.

Ag-107	+ 3.9% ± 1.2	Ag-109	- 4.3% : 1.3
Cu- 63 :	+ 3.6% ± 1.6	Cu- 65 :	- 8.1% :: 3.6

Figure 4. Large Yield of RPs in Fi m.

As also shown in Figure 4, these elements typically exhibited a small but significant deviation from natural abundance. All of the facts provide strong evidence for production of these elements by nuclear reactions. A number of additional isotopes, up to seventy in some runs, were observed by SIMS to increase. However, this measurement uses a localized region on the bead and suffers from possible line overlaps, introducing added uncertainties compared to the NAA results. Further details of the experiments and the coated beads are provided in [4,5].

While these results were unique in that the combination of thin films and analytic techniques allowed a reasonably accurate measurement of the reaction product concentrations, several prior studies had reported a similar array of products. [6] The latter studies, however, typically used thick electrodes and the products were found micrometers beneath the surface in a thin zone, roughly a thickness of the present thin films. Due to the "dilution" of the products by the base metal, absolute concentrations are difficult to obtain in such experiments, so the main focus was on non-natural isotope ratios.

The key characteristic of the reaction products found in the thin-film measurements as well as the earlier solid electrode studies cited, is a grouping of high-yield elements in roughly four "zones" of mass number. This pattern is clearly seen in Figure 5.
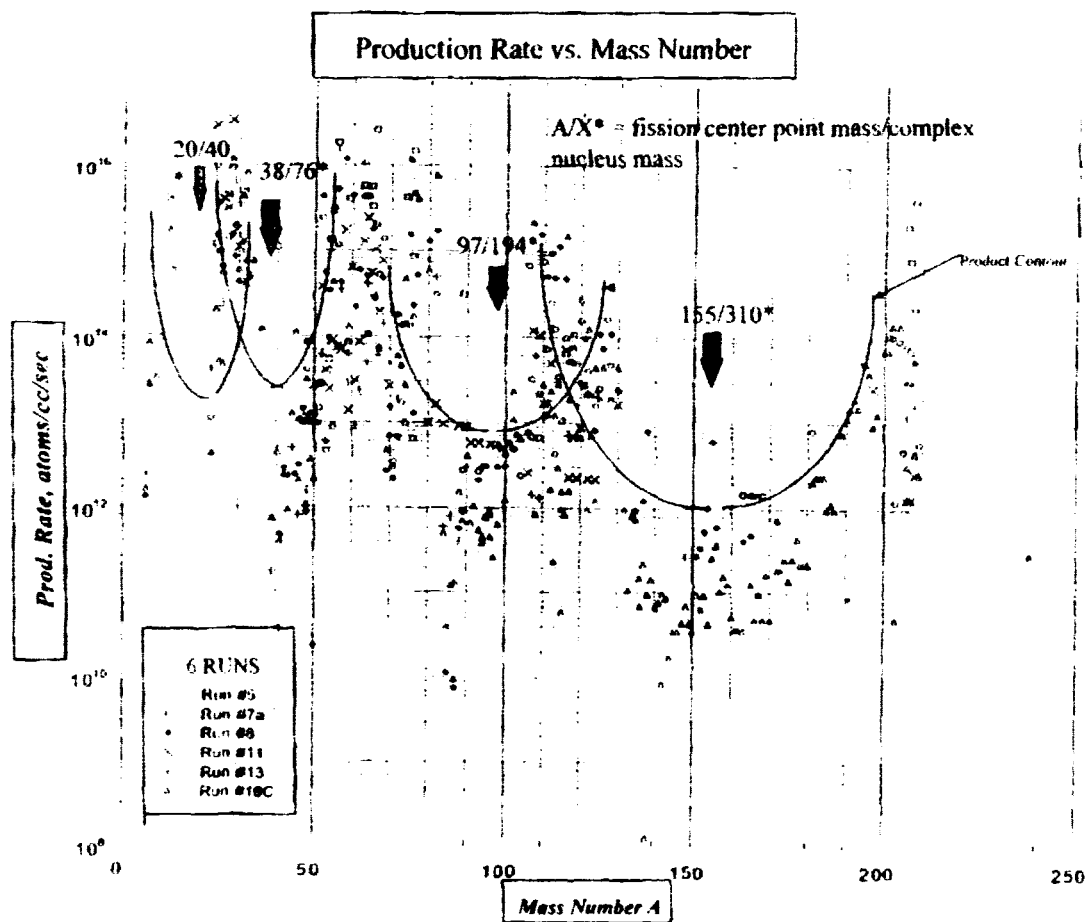
Figure 5. Reaction Rate vs Mass Number

Additional key experimental observations that appear to be characteristic of these reactions include a lack of high-energy radiation, the production of nearly stable elements, the observation of low-energy X-ray or beta radiation for beads following a run, and non-natural isotope ratios. Further, since reaction products have been observed consistently in twenty runs using various metal films at the University of Illinois, the thin-film configuration appears to be an effective method to "initiate" reactions. Also, unlike solid electrode experiments that appear to have local active regions, sometimes giving volcanic-like spots on the electrode surface, the thin films appear to react more uniformly. While the film surface is roughened during a run, no significant local artifacts have been observed from SEM studies. With these characteristics in mind, the author is working on a semi-empirical theory: RIFEX (Reaction in a film-excited compleX) and this theory is briefly described next.

RIFEX THEORY

The RIFEX model is based on the observation that the yield pattern in Figure 5 resembles a fission spectrum with valleys of low yield lying at A = 20, 38, 97, and 155. This suggests that the corresponding compounding nuclei, lying at A = 40, 76, 194, and 310 fission to produce the pattern of light and heavy products on each side of the valleys. These compound nuclei, termed complexes, designated X^*, are theorized to be created through BCS pairing of neutrons and protons. (This concept has some aspects similar to other theories that evoke compound nuclei to explain LENR effects, e.g., see [11-14].)The corresponding liquid drop model predicts that the observed complexes are marginally unstable to fission. The initial complex immediately breaks up into several lower mass complexes, which then undergo fission into an array of products. The fission fragmentation for this pairing and the corresponding reduced excess energy is predicted to yield near-stable elements, in agreement with the experiment. The overall reactions involved are summarized in Figure 6, where reactions involving Ni and Pd, corresponding to data from runs in Figure 5, are shown along with various possible reactants (thin-film materials). The reactants
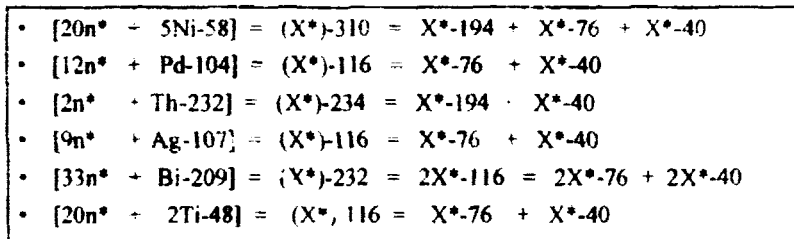
- $[20n^* + 5Ni-58] = (X^*)-310 = X^*-194 + X^*-76 + X^*-40$
- $[12n^* + Pd-104] = (X^*)-116 = X^*-76 + X^*-40$
- $[2n^* + Th-232] = (X^*)-234 = X^*-194 \cdot X^*-40$
- $[9n^* + Ag-107] = (X^*)-116 = X^*-76 + X^*-40$
- $[33n^* + Bi-209] = (X^*)-232 = 2X^*-116 = 2X^*-76 + 2X^*-40$
- $[20n^* + 2Ti-48] = (X^*, 116 = X^*-76 + X^*-40$

Figure 6. Illustrative Complex Nuclei Pathways

generally "funnel" into the lowest mass quasi-stable complex available, in these cases $X^* = 116, 232$ and 310. This in turn determines the "breakup" states. Again, a consistency with the experiment is observed because Ni (runs 8, 18c, Fig. 5) gives high yields in all four mass number regions; whereas, Pd has the highest yields at the two lower mass number regions. This is consistent with the predicted breakup of the respective postulated complex nuclei in Figure 6. The predicted preference to form lower mass number complexes for reactions with Th, Ag, Bi, and Ti is also in general agreement with data for these materials reported by N. Gokul [15] and by J. Patterson [16].

The penetration of the Coulombic barrier and subsequent formation of the complex nuclei in this model rely upon a combination of the swimming electron layer (SEL) theory for thin films, and subsequent coherent oscillation of the lattice nuclei, ultimately leading to the multibody reaction complex illustrated. While these events proceed sequentially, the overall result is the combination of a large number of virtual neutrons, n^*, with the base metal nuclei, as shown in brackets in Figure 6. The formation of the virtual neutrons follows from an electron-proton capture process such as proposed by Stoppini [17].

The RIFEX model is also in rough agreement with the overall energy balance observed experimentally. A comparison can be made by taking the sum of the products of all of the reaction products and their binding energies and subtracting the similar sum for the reactants. When this is done for Ni-based material, using the reaction product yields from Figure 5 and the proton-Ni ratio from Figure 6 to compute the reactants (assuming nucleon conservation), a power level of 0.9 W is predicted, vs 0.1-0.5 W recorded experimentally. A similar calculation for Pd yields a somewhat higher power output, again consistent with the experiments. Some of the reaction energy is also carried off by neutrinos created during electron capture, but this fraction is relatively small in most cases.

In summary, while the RIFEX model predicts some of the important trends observed in reaction product experiments, it assumes various features such as SEL penetration, coherent oscillation collapse, and nucleon pairing which are radical departures from conventional nuclear physics. Thus it or other contending theories, need much more study before a fully acceptable theory is possible. RIFEX is presented here, however, to illustrate the type of radical "new physics" that would be required to explain the observed phenomena. Other theories that also predict some features of these experiments include Kucherov's "slow excitation model" [13] and a recent unpublished modification of Fisher's original "polyneutron model" [12], and Prepara a's QED model. [11] In each case, radical departures from traditional physics are involved which require verification. There are other important differences

among the theories, e.g., Fisher's model does not involve complexes or fission, but relies on polyneutron propagation reactions to build up high mass elements.

CONCLUSION

Mounting data supports the reality of low-energy nuclear reactions in solid-state lattices loaded with hydrogenous gases under a variety of conditions. The situation is complicated, however, by the possibility that several different reaction regimes exist: e.g., D-D reactions in PF cells, hydrinos in Mills cells, tritium in Claytor's cells, and an array of fission products in the Miley-Patterson cells (cf. Figs. 1,2). One challenge is to find some commonality between the initiating and reaction mechanisms, which can tie together the seemingly disparate results. Before confidence can be gained in the area of LENRs and theories can be sorted out by benchmarking, it remains necessary to develop an experiment that provides good reproducibility. The thin-film experiments described here appear to be a step in this direction, but confirmation of this will depend on demonstrations of reproducibility by a number of independent laboratories. Should the existence of LENRs be verified, as anticipated in this paper, the implications are immense, both scientifically and practically. For example, the power densities reported in present cells are quite high, such that a simple volumetric scaling could be used to quickly develop 10-100 kW power units. In addition, there is no obvious fundamental block to going to yet much higher power levels, but new designs would be required to handle the extreme heat loads involved.

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NEXT DOCUMENT

The Replication of an Experiment Which Produced Anomalous Excess Energy

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ABSTRACT:

New propulsion methods for interstellar spaceflight will most probably require new on-board energy production methods deriving energy from presently unknown sources.

An experiment conducted by the author in 1981 with a very simple device showed a measured energy output significantly greater than the measured energy input. The origin of the excess energy was and still is unknown. The purposes of this paper are to describe that experiment and to urge that it be replicated. If the anomalous excess energy is seen again, then this experiment might reveal its source and show how it can be enhanced. This may lead to a previously unknown source of energy that could be harnessed to drive the propulsion methods that can take mankind to the stars.

INTRODUCTION:

In recent years, there have been a number of claims, in both scientific journals as well as patents, of devices or processes that produce anomalous energy effects, sometimes including an energy output greater than the known energy input. These include anomalous excess heat produced under special conditions in some solids (Patterson, J., 1997), electrical discharges through water (Graneau, P., 1985), organized electron clusters (Shoulders, K., 1991), and others (King, M., 1992).

In 1981, this author was part of a team that conducted an experiment with a very simple device in which the measured energy output from this device was significantly more than the measured energy input. Estimated experimental errors were relatively small; the anomaly appeared to be real and not readily explainable. This experiment has apparently never been published. Whatever the origin of the excess energy, this experiment should be replicated and the phenomenon explored further and enhanced, if possible.

Specifically, a source of radiant heat energy being used for other tests consisted of a piece of carbon (graphite) heated (in air) to white hot incandescence with dc electricity. The electrical power heating the carbon and radiant heat flux emitted by the carbon were carefully measured, and data were recorded by a computer. The mass of the carbon, before and after heating, was also measured. Even taking into account the relatively slight amount of heat caused by the combustion of the carbon, the output power at equilibrium was approximately 152% as large as the input power.

THE ORIGINAL EXPERIMENT:

Unfortunately, only some pieces of the data from this intriguing experiment still exist. These are:

The experimental apparatus (refer to Figure 1) consisted of the elements listed below.

- A rectangular piece of graphite (purity unknown), which had dimensions (the part that was heated to incandescence) of approximately 8.9 cm long, 1.6 cm wide, and 0.24 cm thick.
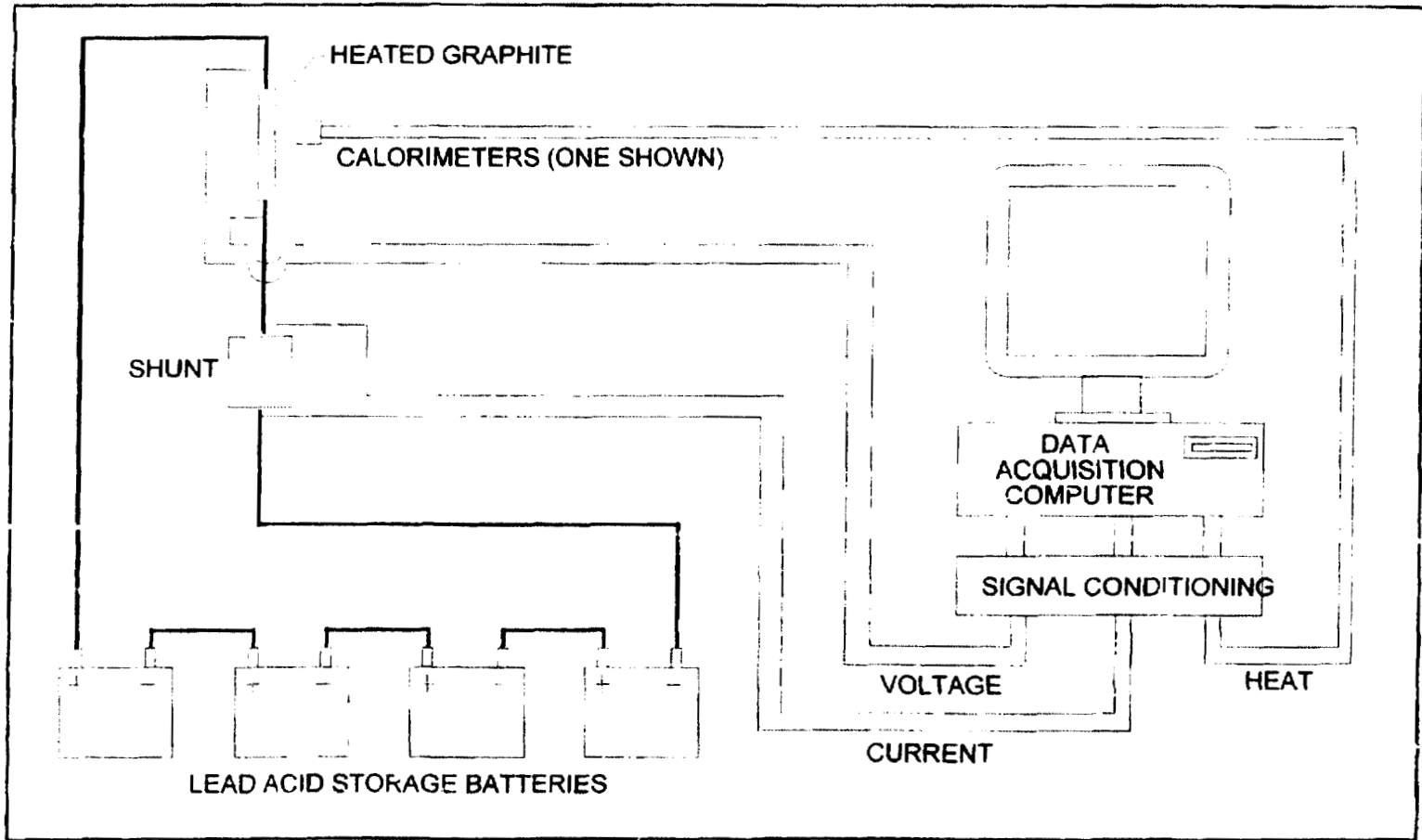
HEATED GRAPHITE

CALORIMETERS (ONE SHOWN)

SHUNT

DATA
ACQUISITION
COMPUTER

SIGNAL CONDITIONING

VOLTAGE

HEAT

CURRENT

LEAD ACID STORAGE BATTERIES

Figure 1. An experiment that produced anomalous excess energy

- The electrical power source, consisting of four truck-type 12-volt lead-acid storage batteries connected in series. Each battery was fully charged to a voltage of approximately 12.8 volts.

- A calibrated voltmeter to measure the voltage across the graphite and a calibrated shunt to measure the electrical current through the graphite.

- A water-cooled, calibrated calorimeter used to measure the heat flux radiated by the incandescent graphite. This instrument was used within its rated range and had a calibration traceable to the National Institute of Standards and Testing (NIST). The calorimeter was positioned approximately 0.4 cm from one of the large faces of the graphite, approximately 2.5 cm from an end of the graphite, and on the longest centerline of the large face. Other details of the calorimeter are no longer available.

- A heavy-duty switch consisting of several car-starting solenoids connected in parallel, used to complete the circuit through the graphite.

- A separate timing circuit that energized the solenoids thereby allowing current flow through the graphite for a predetermined length of time, which was typically 10 seconds.

- Heavy-duty cables that connected the batteries, graphite, current-measuring shunt, and heavy-duty switch in a series circuit.

- A computer and associated equipment to record the data.

- A laboratory balance used to measure the mass of the graphite both before and after a test run to determine the mass loss of the graphite due to combustion.

The data measured for a run (with typical values taken during a steady-state portion of that run in parentheses) were:

- voltage drop across the graphite: (33.61 volts);
- current flowing through the graphite: (502 amperes);
- heat flux radiated from the graphite. (759 watts per cm^2 area times the incandescent area of 32.75 cm^2, which equals a total radiated output o. 24 86 kilowatts);
- graphite mass loss due to combustion in air: (0.235 grams); and
- run duration: (10 seconds).

In addition to the radiated heat output, a significant amount of heat was conducted from the graphite through the water-cooled metal clamps that were holding the graphite and providing current contacts. The flow rate and temperature rise of this cooling water allowed the power conducted away in this manner to be calculated. There was also a small convective heating of adjacent air, which was calculated by a method described in a heat transfer textbook (Incropera and DeWitt, 1990).

The energy (actually power) balance for one particular run was as follows:

- radiated output power: 24.86 kilowatts;
- conducted output power: 1.74 kilowatts;
- convected output power: 0.14 kilowatts;
- electrical input power: 16.87 kilowatts; and
- chemical (combustion) input power: 0.76 kilowatts. (This assumes the carbon burned to yield carbon dioxide, which would give the most power.)

The calculated ratio of output power divided by input power was then:

$$\frac{Output\ Pwr}{Input\ Pwr} = \frac{(24.86\ kW + 1.74\ kW + 0.14\ kW)}{(16.87\ kW + 0.76\ kW)} = \frac{26.74\ kW}{17.63\ kW} = 1.52 = 152\%$$

Others at this same laboratory had previously conducted essentially tie same experiment except that the incandescent heat source was a 0.635-cm-diameter graphite rod and the calorimeter was placed further away from this rod. On several occasions, the investigators had measured a radiated heat output power that when divided by the electrical input power gave a ratio of more than 200%. (They did not measure conducted nor convected output powers nor the mass loss of graphite due to combustion.)

THE DESIGN OF THE PROPOSED EXPERIMENT:

It is proposed the present experiment be conducted in the same manner as the original. If fundamental parameters were changed, the excess energy (if it is real) may not appear and the reason would not be learned. However, this still allows improvements to be made in areas such as instrumentation. The electrical power source should again be four track-type 12-volt lead-acid storage batteries connected in series.

The dc electrical power (watts) delivered to the incandescent graphite is the product of the voltage drop (volts) and current flow (amperes) through the graphite. Voltage drop and current flow data are recorded in the data acquisition computer. The radiant energy emitted by the graphite is measured with a calorimeter with output that is an electrical signal, which is also recorded in the computer.

Primary experimental data, recorded in a computer (at selected time intervals, e.g., every 0.1 second) by using the appropriate software and signal conditioning, will consist of:

- voltage drop across the graphite;
- voltage drop across the calibrated shunt (from which current flow through the graphite is calculated); and
- the electrical signal from the calorimeter (which allows the radiant heat flux emitted from the graphite to be calculated).

The ends of the graphite are physically held by copper clamps, which also serve as electrical current connections. It is necessary that these clamps be water-cooled, or they will melt.

Additional experimental data will consist of:

- volume flow rate and temperature increase of the cooling water to the graphite current connection clamps, which allow conducted heat output power to be calculated; and
- mass of the graphite before and after heating and run duration, which allow combustion input power to be calculated.

The output power convected away by air is relatively small, but this can be calculated (Incropera and DeWitt, 1990).

THE DIFFICULTY OF MEASURING RADIANT HEAT ENERGY:

Nearly all the energy output from the graphite will be radiated heat, and it is recognized that its accurate measurement is not as straightforward as the measurement of the other parameters, e.g., voltage, temperature, and mass. For example, one problem can be caused by heat reflecting back to an emitting surface, causing a different emitting surface to emit more heat. To be sure radiated heat will be measured as accurately as possible, it is

proposed that part of the planning process for this experiment will include a trip to a laboratory known for the accurate measurement of radiated heat. which could perhaps be a section of NIST. This trip is included in the estimated costs.

SAFETY CONSIDERATIONS:

- Ignitable surfaces must be kept several feet away from the incandescent graphite.

- Hydrogen must be vented properly when the lead-acid storage batteries are recharged.

- The four batteries connected in series will provide approximately 50-volts potential, which requires common sense precautions in its use.

ESTIMATED COSTS:

The estimated costs of equipment and labor for conducting this proposed experiment are given in the table below.

Materials, Equipment, and Hardware	$1,500.00
Instrumentation and software	$2,850.00
Travel	$4,000.00
Labor (600 hours for planning, procurement, fabrication, calibration, and testing)	$30,000.00
TOTAL	**$38,350.00**

The above costs assume that fabrication and assembly of experimental components could be completed and enough test runs conducted to determine if the anomalous energy, measured in the original experiment, is real or not. If the anomalous energy were seen again, the cost of additional testing would be mainly for labor. These costs also assume the testing facility is already available, and they do not include suggested improvements referred to in the next section.

SUGGESTED IMPROVEMENTS:

If the anomalous excess energy is seen again, the following are ways the experiment may be enhanced to explore this phenomenon further.

- The chemical reactions (combustion) of the graphite could be eliminated by enclosing it in an inert gas (e.g., argon) or in a vacuum. This also allows for more continuous operation, providing the power source has enough capacity.

- Rather than using a radiant flux calorimeter, the incandescent graphite could be enclosed inside a calorimeter.

- Different purity grades of graphite could be tested. If the anomalous effect is caused by impurities in the graphite, then the graphite should be intentionally "doped" with various elements (one at a time) to learn which ones are responsible. This could lead to a major enhancement. If anomalous excess energy appears only when the graphite is doped with a specific element (or elements), then this could be evidence for the occurrence of anomalous excess heat produced under special conditions in some solids. Whether the graphite is doped or not, it should be chemically analyzed before and after heating. If anomalous excess energy was emitted by

extremely pure graphite and the graphite had the same purity after heating, then perhaps some other source of energy, such as "zero point energy", is being tapped.

CONCLUSIONS:

In conclusion, the search for an unknown source of energy should begin with anomalies already known. The experiment proposed here is fundamentally very simple and has already been partially replicated; however, it should be replicated again. If the anomalous excess energy is seen again and it can be determined that it is real and is not due to experimental errors, the fundamental simplicity of this experiment may allow the phenomenon to be significantly enhanced. This phenomenon might then be developed nto a fuel-less energy source of a sufficient size to drive interstellar space vehicles.

ACKNOWLEDGMENTS:

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NEXT DOCUMENT

Special Relativity with Complex Speeds

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ABSTRACT:

The speed of light is a barrier that prevents subluminal craft from reaching superluminal speeds. However, if speed becomes complex, we can go "around" the light speed singularity the way a car faced with an insurmountable road block might leave the road to go around the barrier.[1] The treatment is a mathematical device. In theory, it makes possible much higher speeds without severe energy demands or other drastic relativistic effects. In practice, challenges exist in the model, the most obvious being that no known physical interpretation exists for complex speed. However, precedent does exist for physical meaning derived from complex numbers. Drawing analogies between such theories and the complex speed formulation can offer insight into the physical interpretation and may suggest experiments that will further the goal of breakthrough propulsion physics for interstellar travel.

INTRODUCTION:

The speed of light, c, is a barrier that prevents subluminal objects from reaching superluminal speeds. If we make speed complex, we can go around c in a manner analogous to a car faced with an insurmountable road block leaving the road to go around the barrier.[1] The theory itself is simple, but the challenges it presents are anything but bland, the most obvious being that no known physical interpretation exists for complex speed. However, precedent does exist for physical meaning derived from complex numbers. Drawing analogies between such theories and the complex speed formulation offer insight into the physical interpretation and may suggest experiments that will further the goal of breakthrough propulsion physics for interstellar travel. Sec. 2 of this paper summarizes the physics involved, Sec. 3 presents the complex speed formalism, and Sec 4 considers analogies that offer physical insight and suggest paths to verification

SUPERLUMINAL PHYSICS:

A large and growing body of research exists on superluminal physics,[2]-[13] and many reviews and bibliographies have been compiled.[14]-[17] The paper that introduced many modern ideas on the subject is the article by Bilaniuk, Deshpande and Sudarshan.[2] Feinberg introduced the word tachyon, from the Greek word *tachys* meaning "swift."[3] Two words are offered for subluminal particles, "bradyon" from the Greek word for "slow" and "tardyon" from the obvious derivation.[14, 16, 17] To avoid the similarity between tachyon and tardyon, I follow Recami and use bradyon. Following Bilaniuk and Sudarshan, I use "luxon" for particles with luminal speed.[16]

Properties

Special relativity predicts that the transition from sublight to superluminal speeds is impossible because an object traveling at light speed has finite mass relative to slower reference frames. However, the theory doesn't actually rule out superluminal processes. Assuming it holds in a superluminal universe, it can be used to predict the behavior of tachyons, which have c as their *lower* speed limit. This suggests three classes of objects: bradyons (Class I particles) that travel at subluminal speeds; luxons (Class II) that have no mass and travel at light speed; and tachyons (Class III) that travel at superluminal speeds.

Tachyons and bradyons show significant differences in their predicted behavior. Suppose a space ship can travel at any speed u, where $|u| < c$. Two observers keep track of it, one in reference frame S and the other in S'. The frames share a common x axis. S' moves at speed v relative to S, where $|v| < c$; and u is measured relative to S. If the observer in S records the ship as traveling distance Δx in time Δt, the Lorentz transformations give the intervals in S' as[17]

$$\Delta x' = \gamma \Delta x (1 - \frac{v}{u}) \qquad \Delta t' = \gamma \Delta t (1 - \frac{uv}{c^2}) \qquad (1)$$

where $\beta = u/c$ and $\gamma = 1/\sqrt{1-\beta^2}$. Depending on the values u and v, the distance interval $\Delta x'$ can have the same or the opposite sign as Δx. However, $|uv| < c^2$ for all u and v, so $\Delta t'$ always has the same sign as Δt. An observer may record a ship moving in either the $+x$ or $-x$ direction, but every observer agrees the ship goes forward in time.

At superluminal speeds, $|u| > c$, and time and space interchange character. Assuming the observers are still subluminal, $|u| > |v|$ and $\Delta x'$ always has the same sign as Δx, but $\Delta t'$ may have either the same or the opposite sign as Δt. All observers agree on the ship's direction in space but *not* in time. This gives rise to the so-called causality problem.

The transformations also predict that if we observe a particle moving into the past, we measure its energy, $E = Mc^2$, as negative. Here the mass $M = m_0\gamma$, where m_0 is the rest mass.[18] Let E and Δt be energy and time intervals in frame S, say for a particle with speed u that travels Δx. If E' and $\Delta t'$ are the energy and time intervals in S', then[17]

$$\frac{E'}{E} = \frac{\Delta t'}{\Delta t} = \left(1 - \frac{v^2}{c^2}\right)\left(1 - \frac{uv}{c^2}\right). \tag{2}$$

When $uv > c^2$, both E' and $\Delta t'$ change sign relative to their values in S. Eq. 2 is inconsistent with the known stability of the universe because matter is unstable against the emission of particles with $E < 0$.[3, 17]

Reinterpretation provides one way to resolve the problem; a tachyon with negative energy going into the past can be reinterpreted as an anti-tachyon with positive energy going into the future, from its destination to its point of origin.[2, 16] Suppose particle P_a emits a tachyon with energy $E > 0$ that travels until particle P_b absorbs it. Observers who measure its energy as negative would record its absorption before its emission. Reinterpretation suggests they see the time-reversed process: P_b emits an anti-tachyon with $E > 0$ that travels into the future until P_a absorbs it. Not all observers agree on the events, but the laws of physics as we know them remain valid.[19]

Reinterpretation is the temporal analogy of a familiar phenomenon. Consider two subluminal cars. Person P_a drives his car at speed v_a and person P_b drives hers at v_b. We watch from the sidewalk and observe $0 < v_a < v_b << c$, so car a goes by us in the same direction car b. However, driver P_b sees car a moving backward. That P_b sees a going backward and we see a going forward creates no paradox because all the observations are consistent among themselves, related through the Galilean transformations. Everyone agrees, for example, that P_a and P_b arrive at their destination even though not all observers see it happen in the same way.

Now say P_a is the pilot of a superluminal ship and P_b is a rocket scientist taking data from an observatory. P_a always sees himself moving forward in time because he is at rest relative to his ship. However, suppose P_b records him traveling pastward. Can she observe P_a go back in time and prevent his own birth? In analogy with the spatial example above, the pilot's observations must be consistent with those of everyone else. He experiences his life in a timeline that *for him* always goes into the future. If an event stopped his birth, it would have already happened in his timeline, which it didn't. The events of his life as observed from all reference frames, including his own, must be consistent. This doesn't mean P_a can never appear in his own past, only that he can't change what he has already experienced.

One might be tempted to call this is predetermination. I would argue that the human will is too complicated to fit into our current models of the universe. But even if all events are predetermined, for most of them we have no way to know in that determination. In essence our decisions remain indistinguishable from free will.

So what does P_b actually see when P_a goes into the past?

Imagine P_a initially travels into the future relative to observer P_b. His ship reaches x_1 at time t_1, as measured in his frame. At x_1, his ship takes on a speed such that P_b observes it going pastward until it reaches x_2 at time t_2. It then takes on a speed such that P_b records its motion as futureward while it continues to x_3. Then P_b first *sees* the ship at x'_2, where the prime indicates the measurement is in her frame. P_a on the other hand observes himself continuously traveling forward in time from x_1 to x_3. In other words P_a records $t_1 < t_2$ and P_b records $t'_1 > t'_2$.

The extension of reinterpretation into a macroscopic realm has problems associated with it, as discussed below, but does give an interpretation for the scenario described above. At x'_2 and t'_2, the observer sees two ships create by pair-production, one matter and the other antimatter (this requires enough mass in the vicinity to ensure conservation laws are satisfied). The matter ship travels to x'_3. The antimatter ship goes from x'_2 to x'_1 along a time-reversed path compared to what pilot P_a experiences himself as he goes from x_1 to x_2. Meanwhile, P_b sees a *third* ship approach x'_1, almost a twin to the matter ship now going from x'_2 to x'_3 (the ships aren't identical because they are at different points along the trajectory). At x'_1 and t'_1, the antimatter and matter ships meet and annihilate, producing an equivalent amount of energy, mass, and charge as that used to create the antimatter and matter ships at x'_2. Although the different observers see dramatically different events, the processes are all consistent. Both P_a and P_b see the same result: the ship arrives at its destination.

Of course, the macroscopic nature of this scenario makes it rather messy, one of the main problems being annihilation between matter and antimatter (see Ref. [1] for a brief discussion). In addition, relativity predicts superluminal objects have imaginary mass. With $\beta > 1$,

$$M = \frac{\mp i m_0}{\sqrt{\beta^2 - 1}}.$$
$$(3)$$

The $+i m_0$ is dropped in most treatments and I will do likewise—but only for now

The theory of superluminal reference frames provides a way to circumvent the imaginary nature of tachyons.[4]- [7] A tachyon with $\beta > 1$ relative to subluminal frames acts like a bradyon with $1/\beta < 1$ relative to superluminal frames, and tachyons obey the same physical laws in superluminal frames that bradyons obey in subluminal frames. Combined with reinterpretation, this suggests the antiparticles we observe are actually their associated particles, but traveling backward in time.

Alternatively we could postulate an imaginary rest mass m_0:

$$m_0 = i\mu \quad \text{when} \quad |\beta| > 1,$$
$$(4)$$

where μ is real. Imaginary m_0 doesn't contradict known physics because as far as we know tachyons never go slower than light, so "rest" mass has no meaning for them. Substitution of Eq. 4 into the $-i m_0$ root of Eq. 3 gives $M = \mu/\sqrt{\beta^2 - 1}$, which makes $E = Mc^2$ real. Time dilation and length contraction can be treated in a similar manner.[1]

Nothing in the Lorentz equations sets an upper limit on how fast tachyons can go. At speeds greater than $|\beta| = \sqrt{2}c$, time contracts, length dilates, and the magnitude of the mass decreases below $|m_0|$. If we are on a ship that accelerates to $|\beta| = \infty$, the observer records that our ship has no mass, that it experiences infinite length dilation, and that an infinite amount of time passes for us while none passes for her. Such objects are called "transcendent."[2] Bilaniuk and Sudarshan make the intriguing suggestion that the infinite length dilation for a transcendent particle is analogous to a particle at rest having infinite position uncertainty.[16] This follows from the Heisenberg uncertainty principle: the product of the uncertainties in position and momentum, or energy and time, must be finite. A particle at rest has zero momentum uncertainty, so its position uncertainty is infinite. The interchange of space and time at superluminal speeds suggests that if the spatial uncertainty is infinite for a transcendent tachyon, then energy rather than momentum may be known exactly.[21]

If our ship travels at speed β, it has momentum $p = Mv$. So $E = m_0 c^2 \gamma$ and $p = m_0 c \beta \gamma$. The limit $|\beta| \to \infty$ gives $E \to 0$ and $|p| \to \mu c$. This contrasts to the subluminal universe, where an object can have zero momentum but never zero energy. So bradyons have "zero-point energy" ($E = m_0 c^2$) and tachyons have "infinite-point momentum"($|p| = \mu c$). Just as $\beta = 0$ is not invariant for bradyons, but depends on reference frame, so $|\beta| \to \infty$ for tachyons depends on frame.

GOING AROUND THE TREE:

The singularity due to the $\sqrt{1 - \beta^2}$ in the denominator of γ is easily circumvented by making speed complex;

$$\beta = \beta_r + i\beta_i$$
$$(5)$$

For simplicity, I consider motion only in one dimension. Fig. 1 shows coordinates for an arbitrary complex speed β;

$$\beta_+ = 1 + \beta = r_+ \exp(i\theta_+)$$
$$\beta_- = 1 - \beta = r_- \exp(i\theta_-),$$
$$(6)$$

where $r_\pm$ and $\theta_\pm$ are the polar coordinates of $\beta_\pm$:

$$r_\pm = \sqrt{(1 \pm \beta_r)^2 + \beta_i^2} \qquad \theta_\pm = \pm \tan^{-1}\left[\frac{\beta_i}{1 \pm \beta_r}\right].$$
$$(7)$$

With these definitions, $\beta_+\beta_- = 1 - \beta^2 = r_+ r_- \exp[i(\theta_+ + \theta_-)]$. For points in the upper-half-plane in Fig. 1) (such as P), $\theta_+ > 0$ and $\theta_- < 0$. For points in the lower-half-plane, $\theta_- > 0$ and $\theta_+ < 0$. In either case

$$M = \frac{m_0}{\sqrt{r_- r_+}} \exp[-i(\theta_- + \theta_+)/2]$$
$$(8)$$

$$E = \frac{m_0 c^2}{\sqrt{r_- r_+}} \exp[-i(\theta_- + \theta_+)/2].$$
$$(9)$$

Eq. 9 is not single-valued: $E(\theta_+ + \theta_-) \neq E(\theta_+ + \theta_- + 2\pi)$. To make the energy a function, we restrict its phase to an interval where it is single-valued. The function in such an interval is a branch of E and the singular points $\beta = \pm 1$ are branch points. A branch cut originates at a branch point, can't be crossed, and is drawn to define the interval of $\theta_+ + \theta_-$ where E is single-valued.[20] Fig. 2 shows three possible cuts for the energy in Eq. 9, each of which has a physical interpretation.
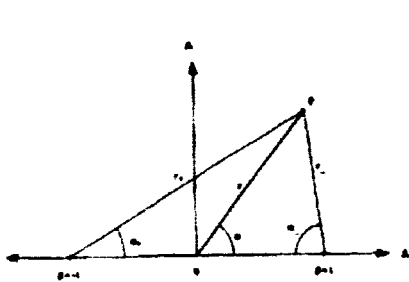

Fig. 1. Coordinates of point P in the complex speed plane. The horizontal axis specifies the real part of β and the vertical axis specifies its imaginary part, where β is the relative complex speed. For points in the upper half-plane (as shown above), $\theta_+ > 0$ and $\theta_- < 0$. For points in the lower half-plane, $\theta_+ > 0$ and $\theta_- < 0$. For the case illustrated, $\theta_+ = 45°$ and $\theta_- = -60°$. The negative sign on θ_- can be motivated by drawing a vector from the angle to the point $\beta = -1 - \beta$. The angle made by that vector with the positive axis is θ_-, which by geometry is the same angle shown as θ_- in the triangle.
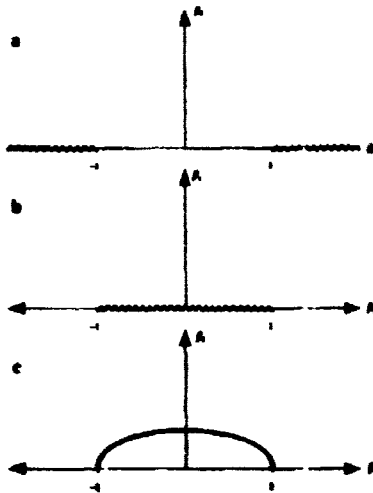
Fig. 2. Branch cuts in the complex β plane, shown as expanding in (a) bradyons (class I particles), (b) tachyons (class II particles), "neutral" class "0" particles. In each plot, the horizontal axis specifies the real part of β and the vertical axis specifies the imaginary part.
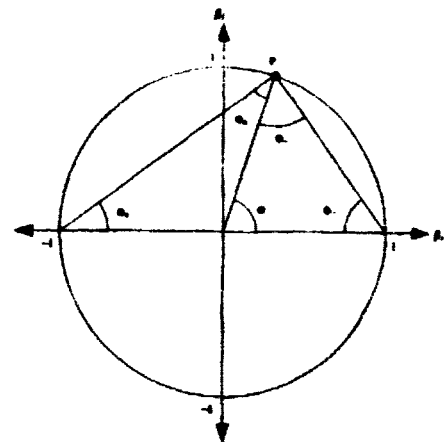
Fig. 3. The circle gives all values of β in the complex plane that have $|\beta| = 1$. It crosses the real axis at the points $\beta = -1$ and $\beta = 1$. At any point P on the circle, the magnitude of a particle's speed equals the speed of light. The angle $\theta_+ = 90°$.

Bradyons

The branch cuts shown in Fig. 2a lie on the real β axis, one stretching from $-1 \rightarrow -\infty$ and the other from $1 \rightarrow \infty$. This configuration blocks the real axis for all $|\beta| > 1$, so only $|\beta| < 1$ is allowed for real speeds and $\theta_+ = \theta_- = 0$. The energy on the real axis is thus

$$E = \frac{m_0 c^2}{\sqrt{1 - \beta_r^2}},$$ (10)

which is the usual form for E. In the universe represented by Fig. 2a, no object with real speed can ever have $|\beta| > 1$. This arrangement of branch cuts thus corresponds, along the real axis, to the universe of bradyons.

However, suppose our ship's speed corresponds to P in Fig. 1: $\beta(P) = r\exp(i\theta)$. If $\theta \neq 0$, what will the observer measure for our energy? It seems reasonable to expect she will record either A) its magnitude or B) its real part. For the time being, assume m_0 is real. Using method A on the energy gives

$$|E| = \frac{m_0 c^2}{\sqrt{r_+ r_-}},$$ (11)

whereas with method B a modulating factor appears:

$$E_r = \cos[(\theta_- + \theta_+)/2] \frac{m_0 c^2}{\sqrt{r_- r_+}}.$$ (12)

Here E_r is the real part of E. Methods A and B yield identical results for real subluminal speeds and agree with known physics. When $|\beta| \rightarrow \infty$, $E \rightarrow 0$ in both methods, as expected for a transcendent particle. However, elsewhere the equations give different results. The method A energy has no phase angle dependence, whereas the method B depends on the phase $|\theta_- + \theta_+|$. When the phase angle equals π, then $E_r = 0$ and B predicts the observed energy is zero for real superluminal speeds.

Similarly, method A predicts nonzero momentum will be observed for real $|\beta| > c$, whereas B predicts it vanishes. The branch cuts in Fig. 2a block that portion of complex speed space, but it becomes available if we deform the cuts off the real axis. Method B thus seems to suggest that when our speed is real and superluminal, we cease to exist. Although the observer happily contemplates this as an end to her observation problems, she soon realizes that B only predicts the real parts of E and p cease to exist. It says nothing about their imaginary parts. Further insight requires consideration of other speeds.

Luxons

Luminal particles, or luxons, travel at light speed. They have $m_0 = 0$; at $|\beta| = 1$ the mass M is $0/0$, which is undefined and may yield a finite number. For $\beta \neq 0$, such particles cease to exist because $M = 0$. How do we define a luxon in the complex speed plane? Consider $|\beta| = \sqrt{\beta_r^2 + \beta_i^2} = 1$. Fig 3 shows these speeds produce a circle of radius one centered at the origin and intersecting the real axis at branch points $\beta = \pm 1$. On this circle, the equations encounter no singularities off the real axis. Does this suggest luxons with mass? With $\beta_r^2 + \beta_i^2 = 1$.

$$M = \frac{m_0}{\sqrt{2|\beta_i|}} \exp[-i(\theta_- + \theta_+)/2].$$

(13)

Methods A and B thus predict

$$|M| = \frac{m_0}{\sqrt{2|\beta_i|}} \quad \text{and} \quad M_r = \cos((\theta_- + \theta_+)/2)\,\frac{m_0}{\sqrt{2|\beta_i|}},$$

(14)

where $M = M_r + iM_i$. In either method, if $m_0 \neq 0$, the observed mass goes to ∞ as $\beta_i \to 0$. To ensure M remains finite at $\beta = \pm 1$, we can make $m_0 = 0$ for all speeds on the circle. Then $M = 0$ except at $\beta = \pm 1$. This doesn't require an object with mass never have $|\beta| = 1$, only that it always satisfy $\beta_i \neq 0$. Conversely, adding an imaginary part to the speed of a massless luxon makes γ finite, so $M = 0$ and the particle ceases to exist. For these reasons, I use the term luxon only for massless particles with $\beta = \pm 1$.

Tachyons

Consider Fig. 2b, where the branch cut stretches from $-1 \to +1$. Now no points can be taken on the real axis for $|\beta| < 1$, so particles with real speed must *always* be superluminal. Fig. 2b thus represents, on the real axis, a universe of tachyons.

For real speeds, Eq. 8 gives $M = im_0/\sqrt{r_+r_-}$ if $\beta > 1$ and $M = -im_0/\sqrt{r_+r_-}$ if $\beta < -1$ (in the interval $0 \leq \theta \leq \pi$ that defines the upper-half-plane). This is consistent with the Eq. 3, where $\gamma = \mp i/\sqrt{\beta_2 - 1}$. Extending the idea of imaginary rest mass to the complex plane gives

$$m_0 = \mu \exp[i(\theta_+ + \theta_-)/2] \quad \text{and} \quad E = \frac{\mu c^2}{\sqrt{r_- r_+}}.$$

(15)

where μ is real. Along the real superluminal axis this is the same result obtained with Eq. 4. However, along the real axis, Eq 15 gives $m_0 = -i\mu$ if $\beta > 1$ and $m_0 = i\mu$ if $\beta < -1$. Hence, we no longer need to discard a root of M in Eq. 3; the phase of m_0 accounts for both. Eq. 15 is physically pleasing because it suggests that as speed changes, m_0 rotates smoothly through the complex plane rather than making a discontinuous jump from a real to imaginary value. Similar arguments can be made for time dilation and length contraction.[1]

In either Fig. 2a or 2b it is impossible to draw a curve that lies on both subluminal and superluminal sections of the real axis. In other words, if our ship has real sublight speed we can't get into the superluminal universe with real speed and vice versa; if we leave the road to go around the road block, we can't return to it after we pass the barrier.

However, other ways exist to draw the branch cuts.

Massons

If we think of complex β space as curved into a sphere, Figs. 2a and 2b are actually different configurations of the same branch cut. Envision two pins stuck in a ball such that only a few degrees of arc separate them. The ball's surface corresponds to all β space and the pins to $\beta = \pm 1$. A rubber band stretched between the pins represents the branch cuts. If we pull the band around the ball the long way from pin to pin, we have Fig. 2a. The curving of complex β space allows ∞ and $-\infty$ to "meet" on the far side of the ball, so the two cuts join into one. To obtain Fig. 2b, we move the band so it stretches the short distance between the pins.

However, with a bit of glue we can attach the band to the ball in many other ways. An infinite number of configurations exist. The only requirement is that we anchor the branch cut at $\beta = \pm 1$. Fig. 2c shows a third possibility. Now all real speeds are available except $\beta = \pm 1$, which means our ships can start at real sublight speeds and accelerate, via complex space, to real superluminal speeds. This suggests the possibility of a "Class 0" particle that can go at any speed, real or complex, *except* $\beta = \pm 1$. Class 0 would contain all particles with mass, suggesting the name massons.

A well chosen β_d can keep $|M|$ from experiencing a large increase as a ship "passes" c. As a result, fuel consumption need not be high. In addition, we can avoid other relativistic effects, such as time dilation, and so make journeys within a reasonable time-frame.

PHYSICAL ANALOGIES:

What do imaginary components of physical properties mean? Precedent does exist for the imaginary part of a complex function having physical meaning. I consider two analogies: the refractive index for damped dispersion and quantum wave amplitudes. Precedent also exists for using analogies to postulate new physics; Schrödinger, for example, developed his contributions to quantum mechanics by studying the wave equation for light.

Relativistic "Absorption"

The theory of damped optical dispersion has a complex formulation. The real part of n, the refractive index of light, gives the speed of light in a material. Its imaginary part provides a measure of how much the material absorbs light. Consider a molecule in an isotropic dielectric medium subject to EM field $E = E_0 \sin \omega t$, with N electrons per unit volume, electron mass m, and charge e. To a first approximation, the system acts like a mechanical oscillator driven by a sinusoidal force with frequency ω. The refractive index for a rarified medium, $n(\omega)$, is then[23]

$$n^2(\omega) = 1 + \frac{Ne^2}{\epsilon_0 m}\left[\frac{1}{\omega_0^2 - \omega^2}\right] . \tag{16}$$

Here ω_0 is the resonance frequency of the oscillator (assuming it has only one). We define a unitless dispersion frequency $\beta_d = \omega/\omega_0$ and a "dispersion" γ_d

$$\gamma_d = \sqrt{\frac{\omega_0^2 \epsilon_0 m}{N e^2}(n^2 - .)} . \tag{17}$$

Eq. 16 can then be written as

$$\gamma_d = \frac{1}{\sqrt{1 - \beta_d^2}} , \tag{18}$$

which has the same form as the relativistic γ, with ω and ω_0 playing analogous roles in dispersion to v and c in special relativity.

However, classical dispersion theory neglects absorption. Energy losses due to absorption cause the oscillating atom to behave like a damped oscillator, with damping force $f = mG(dR/dt)$, where G is a constant and dR/dt is the time derivative of the displacement R experienced by the electron cloud. With absorption, n becomes[24]

$$n^2(\omega) = 1 + \frac{Ne^2}{\epsilon_0 m}\left[\frac{1}{(\omega_0^2 - \omega^2) - iG\omega}\right] \tag{19}$$

Combining Eqs. 19 and 17 yields

$$\gamma_d = \frac{1}{\sqrt{1 - \beta_d^2 - iG\beta_d/\omega_0}} . \tag{20}$$

With $\beta = \beta_r + i\beta_i$, the complex γ becomes.

$$\gamma = \frac{1}{\sqrt{1 - \beta_r^2 + \beta_i^2 - 2i\,\beta_r\beta_i}} \tag{21}$$

In dispersion theory, the resonance occurs at $\omega = \pm\omega_0$, which can be rewritten as $\beta_d = \pm 1$ (only the $+\omega_0$ root has known physical meaning). When absorption is ignored, $\gamma_d \to \infty$ at the resonance frequency. With absorption, the real part of γ_d goes to zero at $\beta_d = \pm 1$.

The relativistic $\gamma \to \infty$ at $\beta = \pm 1$. With β complex, the real part of γ equals zero on the hyperbola $\beta_r^2 - \beta_i^2 = 1$, which includes $\beta_r = \pm 1$. Assuming β_r and β_i can be positive or negative, both branches of the hyperbola have meaning. If we take as the relativistic analog of the dispersion resonance the points where the real part of $\gamma = 0$ (this includes the singularities in γ), then an object with β on the hyperbola "absorbed" out of real space! This is consistent with m_0 being zero for luminal particles. As $\beta_i \to 0$, the relativistic resonance goes to ± 1, consistent with known physics.

The equations for γ and γ_d suggest the analogies:

dispersion		relativity
$1 - \beta_r^2 + \beta_i^2$	$\longleftrightarrow$	$1 - \beta_d^2$
$2\beta_i\beta_r$	$\longleftrightarrow$	$G\beta_d/\omega_0$

Comparison of v/c with ω/ω_0 suggests β_r compares with β_d. Note that the $\beta_r \longleftrightarrow \beta_d$ doesn't require $\beta_i = 0$; rather, it indicates a constant in the dispersion model compares with a variable in the relativistic model. This leads to $\beta_i \longleftrightarrow G/(2\omega_0)$, which comes from applying $\beta_r \longleftrightarrow \beta_d$ to the second analogy relationship. In other words, β_i "damps" the energy in a manner analogous to the way absorption damps oscillation of the electron cloud.

Suppose we consider a small region around c where $\beta_i = \delta/(2c)$, where $\delta \ll c$. Physically this corresponds to a "tight" pass around c. The imaginary speed then satisfies $\beta_i^2 \ll \beta_i$, so

$$\gamma \approx \frac{1}{\sqrt{1 - \beta_r^2 - \frac{\delta}{c}\beta_r}} \tag{22}$$

which has the same form as Eq. 20 and allows the direct comparison $\delta \longleftrightarrow G$. Thus, near the light speed "resonance," the complex formalism even more strongly suggests an absorption process.

When a molecule has more than one resonance, a sum over ω_{0j} appears in Eq. 19 (j runs over all resonance frequencies). This raises the intriguing suggestion that $\pm c$ may be only the first of many singularities on the real speed axis.[26]

Quantum Wave Amplitudes

In quantum theory, all information about a system is contained in ψ, the wavefunction found by solving the Schrödinger equation (SE), $H\psi = E\psi$, where H is the Hamiltonian and E the eigenvalue. Its solutions can be imaginary; the measurable quantity is the real energy E. Consider a particle in a one-dimensional box of length L on the x axis.[22] With m its mass, its SE is $\hbar^2/(2m)\psi'' = E\psi$. Only certain values of E are allowed, giving a spectrum of discrete energies; $\cdot \quad = \pi^2\hbar^2/(2mL^2)$, where $n = 0, 1, 2, \ldots$. The wavefunction $\psi_n = C_{n+}\exp[in\pi x/L] + C_{n-}\exp[-in\pi x/L]$, where coefficients C_{n+} and C_{n-} derive from boundary conditions, such as $\psi = 0$ at the edges of the box. The average value of any physical quantity F can be found from its expectation value $< F >$;

$$< F > = \int_{allspace} \psi^* F \psi \, dx , \tag{23}$$

ψ^* being the complex conjugate of ψ. The Hermiticity of H ensures that if F represents a real observable quantity, such as momentum or position, then $< F >$ is real.

An analogy between quantum theory and special relativity suggests we measure properties for massons with nonzero β_i using some sort of expectation value. This is consistent with method A. If antiparticles are tachyons observed in our universe, then perhaps the energies, momenta, and other properties we measure for them are actually expectation values for superluminal particles.

Now consider quantum scattering theory. The Greens function that describes the propagation of a scattered particle has singularities similar to those in the complex speed formulation of special relativity. The particle energy E is extended into the complex plane: $E = E_{rr} - i(1/2)\Gamma$. In the Breit-Wigner formulation, the probability of a transition taking place from initial state 1 to final state 2 derives from the cross-section σ_{12}, which is the squared magnitude of a transition amplitude.[25]

$$\sigma_{12} \propto \frac{\frac{1}{4}\Gamma}{(E - E_r)^2 + \frac{1}{4}\Gamma^2} + \text{higher order terms} \tag{24}$$

The quantity Γ is the lifetime of the metastable resonance. Near the resonance energy E_{res}, the system forms a metastable bound state. The resonance is a pole embedded in the energy continuum much the way the speed of light is a pole embedded in the speed continuum of β. In scattering, multiple resonances states can occur, so an analogy between scattering and complex relativity suggests more resonances might occur at $|\beta| > 1$, again raising the possibility that c is only the first in a discrete spectrum. The similarities among scattering, complex relativity, and "relativistic absorption" suggest further investigation of the resonance scattering analogy. This is the direction of current research.

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Complex energy has an interpretation in scattering theory; perhaps complex relativistic quantities have comparable interpretations in relativistic theory. Scattering phenomena are easy to observe, so if the analogy holds up, it may offer plausible interpretations for the imaginary properties of superlum nal objects and insight into how we might observe tachyons. Finding tachyons would be a first step in determining how to access superluminal space ourselves.

In the years since this work was begun,[27] a growing body of research on superluminal effects in quantum tunneling has appeared.[8]-[12] A tunneling system has negative kinetic energy, which implies imaginary speed. If tunneling does turn out to involve superluminal effects, it may help verify the complex speed formalism of special relativity.

CONCLUSIONS:

The "laws" of physics represent models that describe the universe to the best of our knowledge. A lack of evidence is not in itself proof of impossibility. In the past, leaps in understanding have been accompanied by a reformulation of theories that describe physical phenomena. The complex speed formalism for special relativity gives a mathematical model that circumvents the speed of light. If the math can be translated into real physical phenomena, perhaps it may someday help make possible interstellar travel at reasonable speeds with low fuel costs and minimization of effects such as time dilation. Analogies with dispersion and quantum processes offer insight into the physical meaning of complex speed and experiments in quantum tunneling provide a possible means to verify its existence.

ACKNOWLEDGEMENTS

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NEXT DOCUMENT

A Plan For Exceeding The Light Barrier

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Abstract:

The research of astronomers, and physicists has shown
that the speed of light might not be an absolute
constant. This could help open up avenues for exceeding
light speed. Draining increasing mass energy, and
altering the gravitational constant would also be helpful
for both propulsion and exceeding light speed.
Propellantless propulsion and the application of
zero-point-energy could help provide the energy to travel
faster-than-light.

Speed Of Light Problem

Einstein's theory outrules material objects achieving the
speed of light. But it does not outrule faster-than-light
travel. If we consider the speed of light to be a true
absolute constant, exceeding light speed would require
more energy than that contained in the Universe. Time
dilation, and mass increase are also associated with
approaching the speed of light. Satellites measurements
have confirmed time dilation by comparing communication
signals with satellite orbital speeds.

1. Mitchell Pfenning and Larry Ford, of Tufts University,
in Massachetts, calculated that the proposed Alcubierre
Warp Drive would require a region smaller than an atom,
and be sustained by the energy of 10 Billion universes.
Although Alcubierre of the Max Planck Institute, in
Germany, suggests that the quantum effects of gravity
might hold a solution to the problem.

Tachyon Theory

2. General relativity does not outrule material objects
that travel faster than light from birth. These proposed
tachyons can't slow down to the speed of light. 3. As
tachyons lose energy, they speed up. 2. Tachyons tend to
pop up in the calculations for unified field theories,
especially string theory. Alan Chosdos of Yale
University, suggests that some netrinos might actually be
tachyons. Aharon Davidson of Ben-Gurion University, in
Israel, suggests that all elementry particles become
tachyons when examined in four spatial dimensions.

4. Relating to faster than light travel, Kinio Fujiwara,of the University of Tokoyo, has proposed that high energy gamma rays could travel faster than light. Divergence in field theories assume that every line segment in three-dimensional space has a quantum structure similar to an atomic chain of atomic distance. This relationship becomes nonlinear at sufficiently high momentum. The symmetry is broken. Wave and particle properties of light break and travel at different speeds in relativistic quantum field theories. Energies between 10 to the 11th electron volts and 10 to the 12th Ev is required for the effect as measured from Earth.

One problem with tachyon theory is the causality problem. Two observers might see a tachyon coming from opposite directions. 2. With extra dimensions, causality might not be a problem, according to Davidson. 3. A preferred reference frame in space-time could eliminate causality problems in the calculations; but this would contradict the special theory of relativity. Easically, the problem of causality itself shows that the physics of tachyon theory is probably incomplete. Backward time travel in excess light speed, is an assumption of general relativity, based on the speed of light being an absolute constant. Perhaps time would speed up again in the future direction after light speed is exceeded. I propose that the speed of light might not be an absolute constant.

The Speed Of Light As A Variable

5. Energy and linear momentum are considered true tensors in space-time. But parity and angular momentum are psuedotensors. But if light speed involves broken symmetries, it might not be an absolute constant, but possibly a psuedotensor, permitting faster-than-light travel.

4. Using the rotation of the Earth to change direction in the propagation between two signals, results in a one way drift rate between clocks to within 0.001% of the speed of light. The departure from linearity for the separated clocks was 1.5ns 30% of the time, ard 1 to 3ns most of the time. The results indicate anisotropic distribution of matter in the Universe in dynamical absolute space.

In other research, it was found that the Crab Nebula emits light at 7Mhz, which is far above the limit of light speed suggested by quantum electrodynamics. There could be variability in the speed of light dependant on frequency, and power source conditions. The phase velocity was not constant for two sources for fast rotating pulsars in a close binary system.

The conventional speed of light has been found to be constant to 4.8 parts in 10 to the 17th. But there is possible vector anisotropy in the speed of light, according to Paul Nachman and associates at the University of Colorado.

7,8. According to research conducted by Borge Nodland of the University of Rochester, and John P. Ralston of the University of Kansas, radiations in the Universe rotate in a subtle corkscrew pattern, with propagation through the Universe. There is g.cater rotational approaching a parallel direction of travel. Not all space is equal. On the internet, the researchers stated that their results took into consideration measuring errors. "here research indicated that light travels through space in a polarized pattern, at two slightly different speeds. This effect of space motion also takes Faraday rotation into consideration.

10. The speed of light might be slowing down over time. Alan Montgomery of Kanata, Ontario, Canada, showed over a 250 year period, a light speed decay rate at a cosecant-squared curve, with a correlation coefficient better than 99%.

9. As an explanation, Chuck Missler, Personal UPDATE, Jan. 1993, page 12, states that if electrical permittivity, magnetic permeability, zero-point-energy, or intrinsic impedance change isotopically; then both atomic behavior and the speed of light would vary throughout the Universe. Permeability has been shown to have changed over time, suggesting the possibility of decreasing light speed.

10. Alan Montgomery and Lambert Dolphin, reported in 1993, in Galilean Electrodynamics, that there actually has been a decrease in the speed of light over 250 years, after measurement errors are considered. Constants involving atomic phenoma, and units of time have also changed over time in relation to the speed of light.

Today, atomic clocks and dynamical clocks run out of step with each other, due to changes in the speed of light over time. Comparison with lunar orbital decay has indicated a slowing of atomic clocks. Data was analyzed with weighted regression, time distribution, accuracy, and precision. They confirmed another study by Setterfield and Norman.

I propose that the light barrier can be broken by jumping between two light speed change variations, and coming out in the tachyon range.

Changing The Gravitational Constant

A change in the gravitational constant of a spacecraft could serve both as a propellant source, and a mass reducer, as the spacecraft approaches the speed of light.

11. In Reanalysis of the Eotvos Experiment, Ephraim Fischbach discovered an intermediate range coupling related to baryon number or hypercharge field, connected with various elements. The experiment performed well outside the error bars, but Dr. Fischbach's explanation, regarding the relationship of metal properties to the experiment, was open to debate.

12. This experiment confirmed an experiment done by Dr. Ervin J. Saxell, a postdoctrate student of Einstein's, where he demonstrated variation in the gravitational constant, using a torque pendulum, Faraday cage, and an electrical charge, baring equal potential environment. He was able to raise and lower the gravitational constant of the materials studied.

4. D.F. Bartlett and associates, at the University of Colorado, suggested that Eotvos experiment sensitivity would increase up to a hundredfold with the use of solid hydrogen for comparison. The experinent measures the relationship of binding energy to nuclear mass. N.C. Ritter, of the University of Virginia, suggested using superconducting spheres in rotation, to detect changes in the gravitational constant. He also suggested that the Eotvos experiment showed that the gravitational force was independant of physical state and chemical structure, down to 10 to the -9 gravitational constant level.

H.A. Chan and H.J. Paik, of the University of Maryland, at College Park, suggests that the spatial dependence of the gravitational constant could imply the existence of a 5th force of nature.

T.C. Van Flandern, of the U.S. Naval Observatory, indicated that lunar occultation, and lunar laser ranging experiments, show that the gravitational constant is decreasing at a rate of $(-6.4+-2.2 \times 10$ to the -11th) per year. It is changing with respect to atomic time. Dr. James E. Faller, of the National Institute of Standards and Technology, informed the author of this paper, that a recent measurement of the gravitational constant, in Germany, was apparently carried out well, and showed a result substantially away from the accepted answer.

Draining Mass Energy Increase With Acceleration

12,14. The Newman machine may deliver net energy output via
electron spins coupled to the electro-weak interaction,
conserved under supersymmetry, according to Paul Bruney,
of Silver Spring, Maryland. The Newman machine has been
scientifically tested, and does hold to conservation
laws, considering that there must be an energy source in
the process of the machine.

Use of the Newman effect, in acceleration of a
spacecraft, would involve a cycle which involves a
temporary short circuit to the impeller to add power to a
power source. This increased power is used to strengthen
the impeller's field, which then repeats the cycle at a
higher energy level. The process continues until
resonance is achieved. The Newman effect produces from 2
to 7 times the output power from input power.

It would be possible to connect an AC transformer to an AC
power source, connected to the primary winding. The
secondary winding load would vary continously from high
resistance to short circuit. As short circuit is
approached, the field would increase in the primary
winding.

Mark Solis of Shreveport, La, suggests that an atomic
particle approaching the speed of light, might increase in
mass due to the kinetic energy imparted to it, by the
accelerator. Drain off this imparted energy, as the
particle approaches light speed, the mass would decrease,
and the particle might exceed light speed.

I propose that this mass increase energy could be used in
conjunction with a Newman effect engine, to accelerate the
spacecraft past light speed, while draining the mass
energy increase from the spacecraft, if this theory is
true. Also, its state in motion would be affected by the
charge and spin associated with the magnetic field,
possibly helping to alter the gravitational constant
around the spacecraft, as it accelerates.

Propulsion Needs

15. There is a problem in using propellant to travel to
the stars. Traveling to Alpha Centari in 50 years, would
require 100,000 supertankers of antimatter.

16. Gravitational fields accelerate masses, and electric
fields accelerate charges.

16. If a spacecraft could induce a f.eld around itself, and then couple to the gravity of a distant mass, it could conserve momemtum, and accelerate continously. It would be like dropping through a constant gravitational well. The gravitational constant wou..d be increased behind the craft and reduced in fron: of the craft.

5,6,21. Physicist Alan Holt, formally of NASA Johnson Space Center, suggests generating extremely coherent electromagnetic energy patterns to affect the gravitational constant around the craft, and then set up a resonance with a distant space-time point, tunneling through the speed of light energy barrier, almost instantaneously to a distant star system.

5. F.E. Alzafon suggested an alinement and disalinement cycle of dynamic nuclear orientation. which would create an electrogravity coupling, to escape the Earth's gravitational field cheaply without propellant.

18. The zero-point-energy of the vacuum of outer space could power the starships of the future. Gravity itself could be a drag on the ZPE force, according to H.E. Puthoff, as reported in Physical Review Letters. Interia might also be a side effect of ZPE. This ZPE could be used to alter a spacecraft's gravitational constant, as well as propel it to light speed and beyond.

17. Throughout space, for every cubic centimeter, there is 10 to the 54th +-10 to the 38th grams of mass energy density. At 100% efficiency, this would contain enough energy to vaporize the Earth's oceans. But it should only be possible to extract this energy at low efficiencies, but still sufficient to power interstellar spacecraft, as well as make solar system spaceflight very cheap. The Casimir effect shows evidence that ZPE exists.

5. R.L. Vallee of France suggests that ZPE could affect the gravitational constant around a spacecraft.

19,20. Perhaps the most impressive evidence for ZPE and electrogravity effects can be shown in the research of John Hutchison, of New West, B.C., Canada. George Hathaway of Toronto, Canada told the author of this paper, that he has confirmed these experiments to a limited extent. The Hutchison work has been supported by R.L. Vallee of France, the Japanese government, the King of Belgium, and Dr. Hal Puthoff.

6,19,20. John Hutchison has demonstrated electromagnetic
levitation of non-magnetic objects at an increasing rate
of acceleration. Objects can fly both up, and sideways.
The shape of the objects with respect to gravity effects
the results of take off. A shield could be placed behind
a spacecraft and the Hutchison effect used to accelerate
it. This effect might involve electrogravity coupling.

He uses Telsa systems, Van de Graaf generators, and
signal generators to achieve results. He launched a 19
lb. bushing that accelerated to 45 MPH by the time it hit
the ceiling. He has achieved acceleration up to 132.15
M/sec.

The Hutchison effect can also be used in metal
disruption. The effects required 1000 to 10,000 times the
amount of energy applied, suggesting the possibility he
has tapped into zero-point-energy.

John has told the author of this paper, that some of his
research is classified. In the 80s he worked with
Lockheed. But he has also stated that he wishes his
research to be used for peaceful purposes.

One problem with the experiments is controllability and
replication. It might takes days of work to see these
effects. But John is confident that these effects can be
controlled with increased energy and research. John has
used some of this technology to produce controllable
energy cells, whose energy levels, he can only explain
with zero-point-energy.

5,6. R.G. Zinsser, of Idar-Oberstein, Germany, has
developed an electrogravity coupled propellantless
thruster that is 1000 times more efficient than the Xenon
ion thruster.

Conclusion

Using speed of light variations, manipulating the
gravitational constant, kinetic energy draining of
relativistic mass, and by using zero-point energy, and
electrogravity for power and thrust, the means will be
found for star travel.

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NEXT DOCUMENT

Wormhole Induction Propulsion (WHIP)

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ABSTRACT:

Space flight by means of wormholes is described whereby the traditional rocket propulsion approach can be abandoned in favor of a new paradigm involving the manipulation of spacetime. Maccone (1995) extended Levi-Civita's 1917 magnetic gravity solution to the Morris and Thorne (1988) wormhole solution and claimed that static homogeneous magnetic/electric fields can create spacetime curvature manifesting itself as a traversable wormhole. Furthermore, Maccone showed that the speed of light through this curvature region is slowed by the magnetic (or electric) induced gravitational field there. Maccone's analysis immediately suggests a way to perform laboratory experiments whereby one could apply a powerful static homogeneous magnetic field in a vacuum, thereby creating spacetime curvature, and measure the speed of a light beam through it. Magnetic fields employed in this scenario must achieve magnitudes $> 10^{10}$ Tesla in order for measurable effects to appear. Current magnetic induction technology is limited to static fields of $\sim$ several $\times 10^3$ Tesla. However, destructive chemical (implosive/explosive) magnetic field generation technology has reached peak rate-of-rise field strengths of $\sim 10^9$ Tesla/sec. It is proposed that this technology be exploited to take advantage of the high rate-of-rise field strengths to create and measure spacetime curvature in the lab.

INTRODUCTION:

Rapid interplanetary and interstellar space flight by means of spacetime wormholes is possible, in principle, whereby the traditional rocket propulsion approach can be abandoned in favor of a new paradigm involving the use of spacetime manipulation. In this scheme, the light speed barrier becomes irrelevant and spacecraft no longer need to carry large mass fractions of traditional chemical or nuclear propellants and related infrastructure over distances larger than several astronomical units (AU). Travel time over very large distances will be reduced by orders of magnitude. Einstein published his General Theory of Relativity (GTR) in 1915. In 1917, physicist Tullio Levi-Civita read a paper before the Academy of Rome about creating artificial gravitational fields (spacetime curvature) by virtue of static homogeneous magnetic or electric fields as a solution to the GTR equations. This paper went largely unnoticed. In 1988, Morris and Thorne published an exact solution to the GTR equations which describe the creation of traversable wormholes in spacetime by virtue of exotic (mass-energy $\rho c^2 <$ stress-energy τ) matter-energy fields (see figures 1 and 2). Visser (1995) has extended and added to the knowledge base of this research. The essential features of these solutions are that wormholes possess a traversable throat in which there is no or singularity. For the purpose of this study, we also impose the additional constraint that travel through wormhole is causal, although, this is not a necessary constraint in general. When these properties are combined together with the GTR field equations, it becomes necessary to introduce an exotic material in the wormhole's throat which generates its spacetime curvature.

Maccone (1995) extended and matched Levi-Civita's solution to the Morris and Thorne solution and claimed that the earlier describes a wormhole in spacetime. More specifically, Maccone claims that static homogeneous magnetic/electric fields with cylindrical symmetry can create spacetime curvature which manifests itself as a traversable wormhole. Although the claim of inducing spacetime curvature is correct, Levi-Civita's metric solution is not a wormhole. A near-term lab experiment based on Maccone's analysis will be discussed. It is my intent to introduce a new space propulsion concept which employs the creation of traversable wormholes by virtue of ultrahigh magnetic fields in conjunction with exotic matter-energy fields. I call this propulsion concept "Wormhole Induction Propulsion" or WHIP. It is speculated that future WHIP spacecraft could deploy ultrahigh

magnetic fields along with exotic matter- energy fields (e.g. radial electric or magnetic fields, Casimir energy field, etc.) in space to create a wormhole and then apply conventional space propulsion to move through the throat to reach the other side in a matter of minutes or days, whence the spacecraft emerges several AU's or light-years away from its starting point. The requirement for conventional propulsion in WHIP spacecraft would be strictly limited by the need for short travel through the wormhole throat as well as for orbital maneuvering near distant worlds. The integrated system comprising the magnetic induction/exotic field wormhole and conventional propulsion units could be called WHIPIT or "Wormhole Induction Propulsion Integrated Technology."

THEORETICAL BRIEF:

Levi-Civita's spacetime metric for a static uniform magnetic field was originally conceived by Pauli (1981):

$$ds^2 = (dx^1)^2 + (dx^2)^2 + (dx^3)^2 + \frac{(x^1 dx^1 + x^2 dx^2)^2}{c^2 - [(x^1)^2 + (x^2)^2]} - \left[c_1 \exp\left(\frac{x^3}{a}\right) + c_2 \exp\left(\frac{-x^3}{a}\right) \right]^2 (dx^4)^2 \quad (1),$$

where c_1 and c_2 are integration constants which are determined by appropriate boundary conditions and $x^1 ... x^4$ are Cartesian coordinates ($x^1 ... x^3 = space$, $x^4 = time$) with orthographic projection. The important parameter in (1) is:

$$a = \frac{c^2}{\sqrt{4\pi G}\, B} = 3.4840 \times 10^{18}\, \frac{1}{B}\quad meters \quad (2)$$

which measures the radius of spacetime curvature induced by a homogeneous magnetic field with cylindrical symmetry (axis, $x^3 = z$) about the direction of the field (G = universal gravitation constant, c = speed of light, B = magnetic field intensity in Tesla, μ_0 = vacuum permeability - all in mks units). From the coefficient of dx^4 in (1), Maccone derived the "speed of light function" which gives the gravitationally induced variation of light speed within the curvature region:

$$v(z) = 2c \frac{\exp\left(\frac{z}{a}\right)}{\exp\left(\frac{z}{a}\right) + 1} \cosh\left(\frac{z}{a}\right) \quad m/sec \quad (3).$$

At the center of this region ($z = 0$), this becomes:

$$v(0) = 2c \frac{\exp\left(\frac{z}{2a}\right)}{\exp\left(\frac{z}{a}\right) + 1} = 2c \frac{\exp\left(\frac{B}{2K}\right)}{\exp\left(\frac{B}{K}\right) + 1} \quad m/sec \quad (4),$$

for $0 < L << a$, where $K = \frac{c^2}{\sqrt{4\pi G}} = 3.4840 \times 10^{18}$ $Tesla \bullet meter$. Equation (4) is based on the assumption that the magnetic field is created by a solenoid of length l, oriented along the z-axis, and that $c = 3 \times 10^8$ m/sec at the solenoid's ends ($z = \pm L/2$), while at $z = 0$, c slows down according to (4) because of the presence of the artificially induced spacetime curvature. Further, Maccone inverted equation (4) and solved for B to get:

$$B = \frac{2K}{l} \ln\left[\frac{c + \sqrt{c^2 - v^2(0)}}{v(0)} \right] \quad Tesla \quad (5).$$

Equations (2), (4) and (5) are formulae to use for creating and detecting spacetime curvature in the lab

Technical Issues

Traversable wormholes are creatures of classical GTR and represent non-trivial topology change in the spacetime manifold. This makes mathematicians cringe because it raises the question of whether topology can change or fluctuate to accommodate wormhole creation. Black holes and naked singularities are also creatures of GTR representing non-trivial topology change in spacetime, yet they are accepted by the astrophysics and mathematical communities - the former by Hubble Space Telescope discoveries and the latter by theoretical arguments due to Kip Thorne, Stephen Hawking, Roger Penrose and others. The Bohm-Aharonov effect is another example which owes its existence to non-trivial topology change in the manifold. The topology change (censorship) theorems discussed in Visser (1995) make precise mathematical statements about the "mathematician's topology" (topology of spacetime is fixed!), however, Visser correctly points out that this is a mathematical abstraction. In fact, Visser (1990) proved that the existence of an everywhere Lorentzian metric in spacetime is not a sufficient condition to prevent topology change. Furthermore, Visser (1990, 1995) elaborates that physical probes are not sensitive to this mathematical abstraction, but instead they typically couple to the geometrical features of space. Visser (1990) also showed that it is possible for geom. to al effects to mimic the effects of topology change. Topology is too limited a tool to accurately characterize a generic traversable wormhole; in general one needs geometric information to detect the presence of a wormhole, or more precisely to locate the wormhole throat (Visser, private communication, 1997).

Landis (1997) has made technical criticisms of Maccone's (1995) work suggesting that the Levi-Civita metric in the presence of a uniform magnetic field does not form a wormhole within the Morris and Thorne (1988) framework. While the latter view is correct, the technical arguments are not accurate or complete. Changing the coordinate system from Cartesian to cylindrical ($x^1 = r\cos\varphi$, $x^2 = r\sin\varphi$, $x^3 = z$, let $x^4 = t$) puts equation (1) into the form (Maccone, 1995):

$$ds^2 = -\left[c_1 \exp\left(\tfrac{z}{a}\right) + c_2 \exp\left(\tfrac{-z}{a}\right)\right]^2 dt^2 + \left(1 - \tfrac{r^2}{a^2}\right)^{-1} dr^2 + r^2 d\varphi^2 + dz^2 \quad (6).$$

This is a cleaner form, but what is the Levi-Civita metric really? We can find out from making a change of (radial) variable by letting $r = a\sin\theta$, $dr = a\cos\theta d\theta$ and substituting these into equation (6):

$$ds^2 = -\left[c_1 \exp\left(\tfrac{z}{a}\right) + c_2 \exp\left(\tfrac{-z}{a}\right)\right]^2 dt^2 + a^2\left[d\theta^2 + \sin^2\theta d\varphi^2\right] + dz^2 \quad (7).$$

where a is the constant radius defined by equation (2). The spatial part of (7), $d\sigma^2 = a^2\left[d\theta^2 + \sin^2\theta d\varphi^2\right] + dz^2$, is recognized as the three-metric of a hypercylinder $S^2 \times \mathfrak{R}$. So equation (7) shows that Levi-Civita's spacetime metric is simply a hypercylinder with a position dependent gravitational potential: no asymptotically flat region, no flared-out wormhole mouth and no wormhole throat. Maccone's equations for the radial (hyperbolic) pressure, stress and energy density of the "magnetic wormhole" configuration are thus incorrect.

In addition, directing attention on the behavior of wormhole geometry at asymptotic infinity is not too profitable. Visser (private communication, 1997; Hochberg and Visser, 1997) demonstrates that it is only the behavior near the wormhole throat that is critical to understanding what is going on, and that a generic throat can be defined without having to make all the symmetry assumptions and without assuming the existence of an asymptotically flat spacetime to embed the wormhole in. One only needs to know the generic features of the geometry near the throat in order to guarantee violations of the null energy condition (NEC; see Hawking and Ellis, 1973) for certain open regions near the throat (Visser, private communication, 1997). There are general theorems of differential geometry that guarantee that there must be NEC violations (meaning exotic matter-energy is present) at a wormhole throat. In view of this, however, it is known that static radial electric or magnetic fields are borderline exotic when threading a wormhole if their tension were infinitesimally larger, for a given energy density (Herrmann, 1989; Hawking and Ellis, 1973). Other exotic (energy condition violating) matter-energy fields are known to be squeezed states of the electromagnetic field, Casimir (electromagnetic zero-point) energy and other

quantum fields/states/effects. With respect to creating wormholes, these have the unfortunate reputation of alarming physicists. This is unfounded since all the energy condition hypotheses have been experimentally tested in the laboratory and experimentally shown to be false - 25 years before their formulation (Visser, 1990 and references cited therein). Violating the energy conditions commits no offense against nature.

EXPERIMENTAL APPROACH:

Table I below shows the radius of curvature generated by a range of magnetic field strengths via equation (2). Equations (2), (4) and (5) suggest a way to perform a laboratory experiment whereby one could apply a powerful static homogeneous (cylindrically symmetric) magnetic field in a vacuum, thereby creating spacetime curvature in principle, and measure the speed of a light beam through it. A measurable slowing of c in this arrangement would demonstrate that a curvature effect has been created in the experiment. The achievable precision in measuring this

Table I. Radius of Spacetime Curvature Induced by B-Field

B (x 3.484 Tesla)	a (meters)
1	10^{18} (105.7 ly)
10^2	10^{16} (1.06 ly)
10^3	10^{15} (0.11 ly)
10^5	10^{13} (66.7 AU)
10^7	10^{11} (0.67 AU)
10^9	10^9 (1.44 Solar Radii)
10^{12}	10^6 (0.16 Earth Radii)
10^{15}	10^3
10^{18}	1

ly - light-year, AU = Astronomical Unit

would be c - $v(0)$ or c^2 - $v^2(0)$ as seen from equation (5). Electric fields could also be used to create the same effect, however, the field strengths required to accomplish the same radius of curvature or slowing of c is seventeen times larger than magnetic field strengths (Maccone, 1995).

From Table I, it is apparent that laboratory magnetic field strengths would need to be > 10^7 - 10^{18} Tesla so that a significant radius of curvature and slowing of c can be measured. Experiments employing chemical explosive/implosive magnetic technologies would be an ideal arrangement for this. The limit of magnetic field generation for chemical explosives/implosives is ~ several x 10^3 Tesla and the quantum limit for ordinary metals is ~ 50,000 Tesla. Explosion/implosion work done by Russian (MC-1 generator, ISTC grant), Los Alamos National Lab (ATLAS), National High Magnetic Field Lab and Sandia National Lab (SATURN) investigators have employed magnetic solenoids of good homogeneity with lengths o' ~ 10 cm, having peak rate-of-rise of field of ~ 10^9 Tesla/sec where a few nanoseconds is spent at 1000 Tesla, and which is long enough for a good measurement of c (J. Solem, private communication, 1997). Further, with picosecond pulses, c could be measured to a part in 10^5 or 10^6. At 1000 Tesla, c^2 - $v^2(0) \approx 0$ m²/sec² and the radius of curvature is 0.368 light-years. If the peak rate-of-rise of field (~ 10^9 Tesla/sec) can be used, then a radius of curvature $\leq$ several x 10^6 km can be generated along with c^2 - $v^2(0) \geq$ several x 10^4 m²/sec².

It will be necessary to consider advancing the state-of-art of magnetic induction technologies in order to reach static field strengths that are > 10^9 - 10^{10} Tesla. Extremely sensitive measurements of c at the one part in 10^6 or 10^7 level may be necessary for laboratory experiments involving field strengths of ~ 10^9 Tesla. Magnetic induction technologies based on nuclear explosives/implosives may need to be seriously considered in order to achieve large magnitude results. An order of magnitude calculation indicates that magnetic fields generated by nuclear pulsed energy methods could be magnified to (brief) static values of $\geq 10^9$ Tesla by factors of the nuclear-to-chemical binding energy ratio ($\geq 10^6$). Other experimental methods employing CW lasers, repetitive-pulse free electron lasers, neutron beam-pumped UO₂ lasers, pulsed laser-plasma interactions or pulsed hot (theta pinch) plasmas

either generate insufficient magnetic field strengths for our purposes or cannot generate them at all within the operating modes (see also Table II).

Table II. Current High and Ultrahigh Magnetic Field Generation Technologies

Magnetic Field Strength (*Tesla*)	Field Generation Technology
10 - 300	Superconductivity, Hybrid Magnets, Pulsed Magnets[a]
360	Magnetic flux compression by electromagnetic force[a]
400	One-turn coil connected to strong laser produced plasma[a]
~ 10^3	High powered pulsed lasers[a]
1000 - 3000	Magnetic flux compression by chemical explosion[b]
10^2 - 10^5	White Dwarf stars[c]
10^7 - 10^9	Neutron stars[c]
$\geq 10^9$	Magnetic flux compression by nuclear explosion[a]

[a] D. Judd, private communication, 1997
[b] J. Solem, private communication, 1997
[c] S. Stephens, private communication, 1995

WHIP SPACECRAFT CONCEPT:

WHIP spacecraft will have multifunction integrated technology for propulsion. The Wormhole Induction Propulsion Integrated Technology (WHIPIT) would entail two modes. The first mode is an advanced conventional system (chemical, nuclear fission/fusion, ion/plasma, antimatter, etc.) which would provide propulsion through the wormhole throat, orbital maneuvering capability near stellar or planetary bodies, and spacecraft attitude control and orbit corrections. An important system driver affecting mission performance and cost is the overall propellant mass-fraction required for this mode. A desirable constraint limiting this to acceptable (low) levels should be that an advanced conventional system would regenerate its onboard fuel supply internally or that it obtain and process its fuel supply from the situ space environment. Other important constraints and/or performance requirements to consider for this propulsion mode would include specific impulse, thrust, energy conversion schemes, etc. Further discussion of these is beyond the scope of this paper and is left for the reader to explore on their own.

The second WHIPIT mode is the stardrive component. This would provide the necessary propulsion to rapidly move the spacecraft over interplanetary or interstellar distances through a traversable wormhole. The system would generate a static, cylindrically symmetric ultrahigh magnetic field to create a hypercylinder curvature envelope (gravity well) near the spacecraft to pre-stress space into a pseudo-wormhole configuration. The radius of the hypercylinder envelope should be no smaller than the largest linear dimension of the spacecraft. As the spacecraft is gravitated into the envelope, the field-generator system then changes the cylindrical magnetic field into a radial configuration while giving it a tension that is greater than its energy density. A traversable wormhole throat is then induced near the spacecraft where the hypercylinder and throat geometries are patched together (see figure 3). The conventional propulsion mode then kicks on to nudge the spacecraft through the throat and send its occupants on their way to adventure. This scenario would apply if ultrahigh electric fields were employed instead. If optimization of wormhole throat (geometry) creation and hyperspace tunneling distance requires a fully exotic energy field to thread the throat, then the propulsion system would need to be capable of generating and deploying a Casimir (or other exotic) energy field. Although ultrahigh magnetic/electric and exotic field generation schemes are speculative, further discussion is beyond the scope of this paper and will be left for future work. A hypothetical WHIP spacecraft concept is depicted in figure 4.

CONCLUSIONS:

A candidate for breakthrough propulsion physics has been identified in the form of a traversable wormhole created by virtue of ultrahigh magnetic or electric fields with an additional exotic energy component. Maccone (1995) claimed that cylindrically symmetric ultrahigh magnetic (electric) fields can create a traversable wormhole in the

Morris and Thorne (1988) framework. It has been shown that this is incorrect. Instead, a hypercylinder curvature effect having a position dependent gravitational potential is induced. This effect can be used to create a wormhole by patching the hypercylinder envelope to a throat that is induced by either radially stressing the ultrahigh field or employing additional exotic energy. Maccone correctly showed that the speed of light through the hypercylinder region is slowed by the magnetic induced gravitational field there. This suggests a way to perform laboratory experiments whereby one could apply an ultrahigh magnetic field in a vacuum, thereby creating a hypercylinder curvature effect, and measure the speed of a light beam through it. While chemical explosive/implosive magnetic induction technology has achieved static field strengths of ~ *several* x 10^3 *Tesla*, the peak rate-of-rise of field is ~ 10^9 *Tesla/sec*. Field strengths > 10^9 - 10^{10} *Tesla* would need to be generated to impart a measurable slowing of light speed in this scenario. It is proposed that the peak rate-of-rise of field be exploited as a means to achieve this goal in the near-term. Magnetic induction technologies based on nuclear explosives/implosives may need to be considered in order to achieve results of larger magnitude. A Wormhole Induction Propulsion system has been introduced to exploit the possibilities of traversable wormholes.

ACKNOWLEDGEMENTS:

Figure 1 Embedded space representation of a Morris and Thorne (1988) traversable wormhole.

Figure 2 What a wormhole mouth might look like to space travelers.
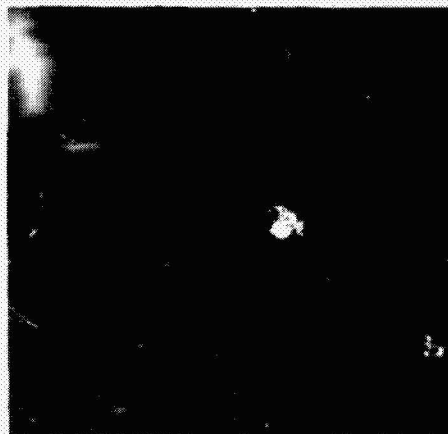

Figure 3 Hypothetical view of two wormhole mouths patched to a hypercylinder curvature envelope. The small (large) configuration results from the radius of curvature induced by a larger (smaller) ultrahigh magnetic field.
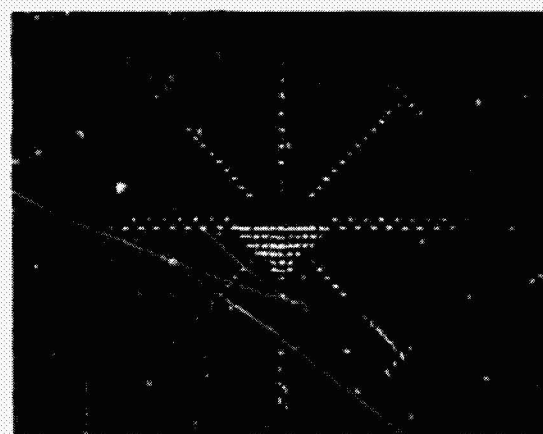

Figure 4 Hypothetical WHIP spacecraft concept.

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NEXT DOCUMENT

Study of M-Theoretic Alcubierre Type Warp Drives

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ABSTRACT

This article examines the various hints which suggest an Alcubierre Type Warp Drive can be constructed under the assumption that the physics of this world is described by M-Theory. In particular, this article will review the relevant physics, Superstring Theory and M-Theory, and examine the physical states of M-Theory which suggest that an Alcubierre Type Warp Drive may be possible within the framework of M-Theory.

1.   INTRODUCTION

The universe is large, and the speed of light is painfully slow. Briefly, this summarizes the fundamental obstacle to interstellar travel. As an example, let us consider a round-trip to Vega, a relatively close star. If we were to set off on a round-trip to Vega using a light sail and traveling at one-half the speed of light, we would arrive back on Earth 100 years later according to an Earth-bound observer. If we were to attempt such a round-trip using the Space Shuttle, we would arrive back on Earth in 1.3 billion years. What is obvious from such numbers is that if we are to ever embark upon practical, interstellar travel, we must circumvent the light-speed barrier imposed by the theory of Special Relativity. The question then becomes, how...

One of the most famous methods of circumventing the light-speed barrier, and the method on which we will focus, is the so-called Alcubierre Type Warp Drive [Alcubierre 94]. Such a warp drive functions by making use of a "loop-hole" in the theory of General Relativity which allows for "faster than light" travel. Special Relativity forbids superluminal velocities; however, General Relativity states that Special Relativity is only valid locally, within "small" regions of spacetime. Thus, General Relativity leaves open the possibility that "superluminal" velocities may be achieved when one considers "large" regions of spacetime. It is this "loop-hole" which is exploited by an Alcubierre Type Warp Drive. In contrast to the light sail and Space Shuttle, if we were to take a round-trip to Vega using an Alcubierre Warp Drive, we could arrive back on Earth in an arbitrarily small amount of time. The catch is that an Alcubierre Type Warp Drive requires so-called "exotic matter."

Exotic matter is matter with a mass density ρ which is less than zero, $\rho < 0$. General Relativity, in and of itself, does not describe matter, and thus, General Relativity makes no predictions as to whether such *exotic matter* exists. General Relativity simply tells us that if such *exotic matter* exists, then it is possible to create an Alcubierre Type Warp Drive. To ascertain whether such *exotic matter* exists and whether such *exotic matter* may be employed in the creation of an Alcubierre Type Warp Drive, one must examine a theory which describes both gravitation and matter in a self-consistent manner. The only known theory which does so is M-Theory.

M-Theory is a proper superset of Superstring Theory. Superstring Theory, previous to two years ago, was the best candidate for a unified theory of all interactions. However, Superstring Theory is actually not *a* theory but a set of five theories, each of which describes the most fundamental particles of the universe at little lengths or loops of "string." The various vibrational modes of such a "string" correspond to the various possible particles which such a "string" may represent. M-Theory encompasses all five consistent Superstring Theories. Each one of the five Superstring Theories is a different limit of M-Theory. For example [Witten 95], the so-called Type IIA Superstring Theory on a spacetime M is equivalent to M-Theory on a spacetime[1] M×S¹. Similar relations also exists between M-Theory and the four other Superstring Theories.

M-Theory, in addition to expanding upon Superstring Theory, predicts the existence of *exotic matter* [Witten 95A][Linde 95]. If we denote a dimensional torus as T^n and a half-circle as S^1/Z_2, then [Witten 95A][Linde 95]

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[1] If M is a generic spacetime and N a generic *manifold* a spacetime without a time direction, a point p in M×N is given by specifying a point q in M along with a point r in N. In our case we take N to be circle S¹.

upon examining M-Theory on a spacetime of the form $M \times T^6 \times (S^1/Z_2)$, we find an interesting set of states. On such a spacetime, M-Theory predicts the existence of a class of states which are "BPS saturated" and thus stable. In addition, these states have a "core" which consists of *exotic matter*. Hence, M-Theory provides the missing ingredient required for an Alcubierre Type Warp Drive, *exotic matter*. However, much work remains to be done to determine if such *exotic matter* leads to an Alcubierre Type Warp Drive within the framework of M-Theory.

2.   ALCUBIERRE TYPE WARP DRIVE

As one will recall, an Alcubierre Warp Drive functions by making use of a "loop-hole" within the theory of General Relativity. Let us now review the physics of such a "loop hole." The theory of General Relativity is basically a modification of the theory of Special Relativity; the theory of General Relativity, among other things, states that the theory of Special Relativity is valid only locally, in "small" regions of spacetime. The theory of Special Relativity, on the other hand, states that a massive body must go slower than the speed of light. Thus, the theory of General Relativity states that locally a massive body must go slower than the speed of light. However, General Relativity does not forbid a massive body from moving "faster than light" when global considerations are taken into account. Let us illuminate this point with an example.

Consider two observers A and B separated by a distance D in a pre-inflationary universe. As the process of inflation begins [Guth 81], the actual fabric of spacetime between A and B begins to stretch in such a manner that D increases. Thus, according to observer A, observer B is moving away at a speed dD/dτ. If the spacetime is being stretched quickly enough, one may have (dD/dτ) > c, where c is the speed of light, and, in point-of-fact, General Relativity places no upper-bound on dD/dτ [Wald 84]. So, to observer A observer B can appear to be moving with an arbitrarily high speed. In addition to this seemingly spectacular result, one may note that as the spacetime itself is expanding and neither observer A nor observer B has fired a rocket of any sort, observer A and observer B are locally stationary, thus not violating the tenets of Special Relativity.

Next, let us examine, from a moderately technical point-of-view, how an Alcubierre Warp Drive employs the above "inflationary" effect. As one will recall [Wald 84], a *metric* $g_{\rho\zeta}(x)$ defines how distance is measured in a spacetime. Two points x^ρ and $x^\rho + dx^\rho$ according to the *metric* $g_{\rho\zeta}(x)$ are separated by a distance ds given by

$$ds^2 = g_{\rho\zeta}(x)\, dx^\rho\, dx^\zeta := g_{00}(x)dx^0dx^0 + g_{01}(x)dx^0dx^1 + \ldots + g_{dd}(x)dx^d dx^d.$$

So, one may see that to describe a stretching of spacetime, as we encountered in the above inflationary example, one requires a *metric*. Alcubierre's contribution [Alcubierre 94] was to find a *metric* which "pushed" a spaceship along a trajectory described by an arbitrary function of time $x_s(t)$. It is given by

$$ds^2 = -c^2 dt^2 + (dx - v_s(t)f(r_s)dt)^2 + dy^2 + dz^2$$

where

$$v_s(t) = \frac{dx_s}{dt}$$

and

$$f(r_s) = \frac{\tanh(\sigma(r_s+R)) - \tanh(\sigma(r_s-R))}{2\tanh(\sigma R)}$$

with σ and R constants and $r_s^2 = (x-x_s(t))^2 + y^2 + z^2$. If a spaceship is situated at ($x_s(t)$, 0, 0) at time t, then it will be "pushed" along the trajectory ($x_s(t)$, 0, 0) by a stretching and contracting of spacetime in a manner similar to that encountered in the above inflationary example [Alcubierre 94]. However, $x_s(t)$ is an arbitrary function of time; thus, one can have a spaceship travel at an arbitrarily high velocity. The catch is that such a set-up requires *exotic matter*. Let us next prove this fact.

General Relativity describes how spacetime is curved in response to the presence of matter. In other words, it relates a *metric* $g_{\rho\zeta}(x)$ on a spacetime to the matter present in that spacetime. In the case of the above Alcubierre *metric*, General Relativity requires that a stationary observer see a mass density ρ given by [Alcubierre 94]

$$\rho = -\left(\frac{v^2_s(t)(y^2+z^2)}{32G\pi r^2_s}\right)\left(\frac{df}{dr_s}\right)^2,$$

where G is Newton's constant. As one may see, $\rho \leq 0$; so, an Alcubierre Warp Drive requires *exotic matter*. If we cons'jer the case in which $x_s(t)$ is given by $x_s(t) = ct$, $\sigma = 8m^{-1}$ and $R = 3m$, then at a time $t = 0s$ we can graph the density ρ by suppressing z; it is shown in Figure 1.

Figure 1 Alcubierre mass density
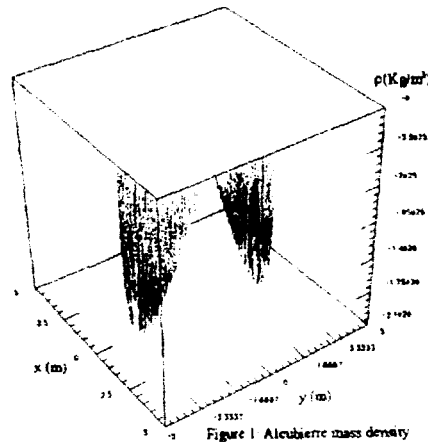
Now, from Figure 1 we can see some of the problems associated with an Alcubierre Warp Drive. First, as $\rho \leq 0$, an Alcubierre Warp Drive requires *exotic matter*; from our everyday experience we know *exotic matter*, if it exists, is rare. Second, upon examining the values of ρ in Figure 1, one finds an Alcubierre Warp Drive requires a "large" quantity of *exotic matter*. If General Relativity is "tacked" onto the *Standard Model*[2], then the classical answer as to whether *exotic matter* exists tends to be [Kaku 93] a "no," but the quantum answer tends towards a "yes" for very "small" quantities of matter [Ford 96]. However, we should, in all likely-hood, not trust the answers produced by the joining of the *Standard Model* and General Relativity when dealing with gravitation as such an amalgamation is ill-defined as a quantum field theory [Kaku 93]. We should turn to a theory which unites General Relativity and quantum field theory in a consistent manner. The only known theory to do so is M-Theory. Let us next review M-Theory and the theory it encompasses, Superstring Theory.

3. SUPERSTRING THEORY

Consider the *Standard Model*. If we simply "tack" on General Relativity, then [Kaku 93] it is well known that one obtains a theory which is inconsistent when quantum effects are taken into account. So, one might wish to extend the *Standard Model* and General Relativity by adding extra symmetries so as to allow a harmonious marriage between General Relativity and the *Standard Model*. One finds [Wess 92] that the only possible symmetries which one may add to such a model and maintain consistency with General Relativity are the so-called "supersymmetries[3]." *Supersymmetries* are symmetries of a theory which exchange the "matter" fields of a theory, the *fermions*, with the force cary. .g" fields of a theory, the *bosons*. Furthermore [Wess 92][Duff 95], one finds that upon introducing two or more of these *supersymmetries* into the *Standard Model* and General Relativity one introduces *strings*, one-dimensional extended objects, into the theory. This leads one to study these *strings* in and of themselves.

Upon considering such *strings*, one finds [Witten 87] that there are five consistent theories containing such *strings*, these are the so-called *Superstring Theories*. Each one of these five *Superstring Theories* merges gravitational and non-gravitational forces in a self-consistent manner [Witten 87]. These five theories go by the names Type IIA, Type IIB, Type I, SO(32)/Z_2 Heterotic and $E_8 \times E_8$ Heterotic *Superstring Theory*. Each one of these *Superstring Theories*,

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[2] The *Standard Model* is the prevailing theory of non-gravitational "low-energy" physics.
[3] The exact statement [Wess 92][Haag 75] is: Of all the graded Lie algebras, only the supersymmetry algebras generate symmetries of the S-matrix consistent with relativistic quantum field theory.

to maintain internal consistency [Witten 87], must reside in a spacetime of ten-dimensions. This may seem a bit strange; however, it is really not so unusual to propose a theory with more than four-dimensions and is quite an old idea [Kaluza 21][Klein 26]. If we consider a ten-dimensional spacetime of the form $M \times K_6$, where M is our normal, four-dimensional spacetime and K_6 is a "small" "compact" six-dimensional *manifold*, then one can show relatively easily [Witten 87] that all *low-energy*[4] experiments on M can not detect K_6. So, our world could in fact be ten-dimensional, but in doing only *low-energy* experiments, we would not be able to detect any higher dimensions.

Even though *Superstring Theory* successfully merges gravitational and non-gravitational interactions in a self-consistent manner [Witten 87], it is not without its problems. *Superstring Theory* essentially has two major problems. First, it is not known which of the five consistent *Superstring Theories* describes the physics of our world. Second, as we live in a world which is four-dimensional at *low-energies*, whichever *Superstring Theory* describes our world must be formulated on a spacetime of the form $M \times K_6$, where M is our normal, four-dimensional spacetime and K_6 is a "small" "compact" six-dimensional *manifold* The problem is: No one knows which K_6 to choose. Furthermore, these problems are intertwined. If we consider putting a *Superstring Theory* on $M \times K_6$, then the *low-energy* physics on M is dependent upon the choice of a K_6 and the choice of a *Superstring Theory*. As we base our choice of a *Superstring Theory* and our choice of a K_6 upon the *low-energy* physics we observe on M, the choice of which *Superstring Theory* describes the physics of our world and which K_6 this *Superstring Theory* is formulated on must be made in parallel as the only data with which we are working is the *low-energy* physics on M. As a next step in examining the *exotic matter* present in M-Theory let us review M-Theory and its relation to the five consistent *Superstring Theories* as well as how it solves some of the above problems.

4. M-THEORY

M-Theory, as previously mentioned, encompasses and extends *Superstring Theory*. It is able to explain all properties of the five consistent *Superstring Theories* by way of a single, unifying theory. However, unlike *Superstring Theory*, all fundamental particles in *M-Theory* are *membranes*, two-dimensional extended objects; in addition, *M-Theory* is formulated in eleven-dimensions [Witten 95], not ten as is the case for all *Superstring Theories* [Witten 87]. Let us next examine how *M-Theory* is related to *Superstring Theory*.

As *M-Theory* is formulated in eleven-dimensions [Witten 95] and all five *Superstring Theories* are formulated in ten-dimensions [Witten 87], the relation between *M-Theory* and *Superstring Theory* is analogous to the relation between *Superstring Theory* and the *Standard Model*. In particular [Witten 95], the Type IIA *Superstring Theory* on a spacetime M is equivalent to *M-Theory* on a spacetime $M \times S^1$. Likewise [Witten 95A], the $E_8 \times E_8$ Heterotic *Superstring Theory* on a spacetime M is equivalent to *M-Theory* on a spacetime $M \times (S^1/Z_2)$. Similarly [Witten 95][Seiberg 89], the Type IIB *Superstring Theory* on a spacetime $M \times S^1$ is equivalent to *M-Theory* on a spacetime $M \times S^1 \times S^1$, and [Witten 95A][Ginsparg 87] the $SO(32)/Z_2$ Heterotic *Superstring Theory* on a spacetime $M \times S^1$ is equivalent to *M-Theory* on a spacetime $M \times S^1 \times (S^1/Z_2)$. Finally [Witten 95][Ginsparg 87][Witten 95A], the Type I *Superstring Theory* on a spacetime $M \times S^1$ is equivalent to *M-Theory* on a spacetime $M \times S^1 \times (S^1/Z_2)$. So, one can see that all five *Superstring Theories* are related to *M-Theory* and all are derivable from some limit of *M-Theory*. In addition, with a little thought one can see how the *strings* of *Superstring Theory* are related to *membranes* of *M-Theory*. Consider the Type IIA *Superstring Theory* as an example. If we wrap the M-Theoretic *membrane* about the S^1 of $M \times S^1$, then it will appear on M [Duff 87] as a *string*. It is this wrapped *membrane* [Duff 87] which takes on the role of the Type IIA *string*. Similar relations are also true of the various other *Superstring Theories* and their respective *strings*.

As one will recall, one of the main problems with *Superstring Theory* s that *Superstring Theory* is not a theory but a collection of five theories, and it is not known which of these five theories describes the physics of our world. However, in *M-Theory* this problem is solved as *M-Theory* is a theory and we have no choice in the matter of which theory describes the physics of our world. It is *M-Theory*. However, the second main problem with *Superstring Theory* still persists in *M-Theory*. As we live in a world which is four-dimensional at *low-energies*, if *M-Theory* is to describe our world, it must be formulated on a spacetime of the form $M \times K_7$, where M is our normal, four-dimensional spacetime and K_7 is a "small" "compact" seven-dimensional *manifold*. The problem is: No one knows which K_7 to choose. However, there are some severe constraints imposed upon K_7 by way of the *Standard Model*

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[4] By *low-energy* we mean an energy E such that $E < (1/R)$, where R is a length characteristic of K_6

and General Relativity. But, none-the-less, it is still unknown which K_7 enters this M-Theoretic construct. Let us next review the general properties of the so-called "BPS saturated states," properties which we will employ in examining the *exotic matter* present in *M-Theory*.

5.   BPS SATURATED STATES

Many of the interactions within the *Standard Model* are described by a so-called "Yang-Mills Theory." *Yang-Mills Theory* is simply a modification of electromagnetism in which the gauge field A_ρ is matrix valued. One can also construct *Yang-Mills Theories* which possess *supersymmetries* (or a *supersymmetry*) [Wess 92]. These are the so-called *Supersymmetric Yang-Mills Theories*. If a *Supersymmetric Yang-Mills Theory* has one *supersymmetry*, then it is called a *N=1 Supersymmetric Yang-Mills Theory*. If a *Supersymmetric Yang-Mills Theory* has two *supersymmetries*, then it is called a *N=2 Supersymmetric Yang-Mills Theory*. In general, a *Supersymmetric Yang-Mills Theory* with n *supersymmetries* is called a *N = n Supersymmetric Yang-Mills Theory*. For now, let us consider a *N=4 Supersymmetric Yang-Mills Theory* on a four-dimensional spacetime. As *M-Theory* on $M \times T^6 \times (S^1/Z_2)$ yields a *N=4 Supersymmetric Yang-Mills Theory* on the four-dimensional spacetime M coupled to a *N=4 Supergravity Theory*, a version of General Relativity with four *supersymmetries*, an examination of such a theory will be useful.

N=4 Supersymmetric Yang-Mills Theory on a four-dimensional spacetime has four *supersymmetries*; each of these four *supersymmetries* has an associated *supersymmetry generator*. Let us denote these generators as Q^L_α, where L varies from 1 to 4 and labels the particular *supersymmetry* and α is a so-called "Weyl spinor index." α varies from 1 to 2 and determines how Q^L_α transforms under rotation, it is similar to the vector index of the gauge field A_ρ. One can think of Q^L_α as being similar to a matrix. A matrix generates rotations of vectors; it can rotate one vector into a second vector. Q^L_α, in contrast, rotates *bosons* into *fermions* and *fermions* into *bosons*. Furthermore, like matrices, the Q^L_α need not commute. In fact, the various commutation and anti-commutation[5] relations of the Q^L_α with a few other generators are important enough to garner a name, the *N=4 Supersymmetry Algebra*. Let us next examine a portion of this *N=4 Supersymmetry Algebra*.

To examine the so called "BPS Saturated States" we will not have need of the full *N=4 Supersymmetry Algebra*. We will only need to consider the various commutation and anti-commutation relations of the Q^L_α with a few other generators when the index L is limited to the values 1 and 2. This is the so-called *N=2 Supersymmetry Algebra*. If we denote momentum as P_ρ and introduce a constant Z, the so-called *central charge*, then the portion of the *N=2 Supersymmetry Algebra* with which we will be concerned is [Wess 92]

$$\{ Q^L_\alpha, (Q^M_\beta)^\dagger \} = 2\sigma^\rho_{\alpha\beta} P_\rho \delta^L_M$$

$$\{ Q^L_\alpha, Q^M_\beta \} = \varepsilon_{\alpha\beta} \varepsilon^{LM} Z,$$

where $\sigma^\rho_{\alpha\beta}$ is a set of four 2×2 matrices with $\sigma^0_{\alpha\beta} = -I_{2\times2}, \sigma^1_{\alpha\beta} = ...$; $\delta^L_M = 1$ if L=M and is zero otherwise; $\varepsilon_{12} = -\varepsilon_{21} = -1$ and $\varepsilon_{\alpha\beta}$ is zero otherwise; likewise, $\varepsilon^{12} = -\varepsilon^{21} = 1$ and ε^{LM} is zero otherwise. Let us consider the form this portion of the *N=2 Supersymmetry Algebra* takes for a particle of mass M which is at rest in our frame of reference. In that case $P_\rho=(-M,0,0,0)$. So, our above portion of the *N=2 Supersymmetry Algebra* takes the form

$$\{ Q^L_\alpha, (Q^M_\beta)^\dagger \} = 2M\delta^L_M \delta^\beta_\alpha$$

$$\{ Q^L_\alpha, Q^M_\beta \} = \varepsilon_{\alpha\beta} \varepsilon^{LM} Z.$$

Now, we are free to define two new *supersymmetry generators* q^L_α which are linear combinations of the Q^L_α. We define the q^L_α by,

$$q^1_\alpha := \frac{1}{\sqrt{2}}(Q^1_\alpha + \varepsilon_{\alpha\beta}(Q^2_\beta)^\dagger)$$

$$q^2_\alpha := \frac{1}{\sqrt{2}}(Q^1_\alpha - \varepsilon_{\alpha\beta}(Q^2_\beta)^\dagger)$$

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[5] The commutator of A and B is [A,B]:=AB-BA; the anti-commutator of A and B is {A,B}:=AB+BA.

By way of our original relations in terms of the Q^1_α and the mass M, we find,

$$\{ q^1_\alpha, (q^1_\beta)^\dagger \} = (2M + Z) \delta^\beta_\alpha$$

$$\{ q^2_\alpha, (q^2_\beta)^\dagger \} = (2M - Z) \delta^\beta_\alpha.$$

These two equations together imply [Wess 92] that M≥IZI/2. This is a so-called *BPS Inequality*. States which saturate this inequality, states with a mass M=IZI/2, are known as *BPS Saturated States*. As we will now show, such states have some remarkable properties. But, before doing so, we must examine the *central charge* Z in a bit more detail.

The actual form of the *central charge* Z is theory dependent. So, to give some feel for what Z corresponds to physically, we will consider a specific example. In the *Standard Model* there exists a so-called *SU(2) Yang-Mills Theory* which along with a so-called *U(1) Yang-Mills Theory* describes the weak force and electromagnetism. We will consider a *N=2 Supersymmetric SU(2) Yang-Mills Theory*, a version of the *SU(2) Yang-Mills Theory* from the *Standard Model* but with two *supersymmetries*. This theory undergoes a so-called "spontaneous symmetry breaking" [Witten 94] in which it is reduced to a *N=2 Supersymmetric U(1) Yang-Mills Theory*, a version of electromagnetism with two *supersymmetries*. In this *N=2 Supersymmetric U(1) Yang-Mills Theory* there arise two different complex numbers [Witten 94] which we denote as a and a_D. If a particle in this theory has an electric charge n_e, an integer, and a magnetic charge n_m, also an integer, then it has an associated *charge vector* $Z := n_e a + n_m a_D$. This *charge vector* [Witten 94] is related to the *central charge* Z by way of Z =2IZI. Let us now see what this implies about the stability of *BPS Saturated States*.

Consider a *BPS Saturated State* with electric charge n_e, magnetic charge n_m and mass M = IZI = I n_ea +$n_m a_D$ I. Let us examine the stability of such a state. Assume it decays into a set of particles with masses M_i, electric charges $n_{e,i}$ and magnetic charges $n_{m,i}$. As with our original state, associated to each particle of mass M_i is a *charge vector* $Z_i = n_{e,i}$ a + $n_{m,i}$ a_D. Furthermore, the mass M_i also obeys a *BPS Inequality* $M_i \geq$ IZ_iI. Let us assume a/a_D is not real[5]. As a/a_D is, by assumption, not real, charge conservation implies $Z = \Sigma_i Z_i$. Th s equation in concert with the *BPS Inequalities* $M_i \geq$ IZ_iI and the *BPS Equality* M = IZI implies that M $\leq \Sigma_i M_i$. However, conservation of momentum implies that M < $\Sigma_i M_i$ is impossible. Thus, M = $\Sigma_i M_i$ This, in turn, only occurs if all the Z_i and Z are collinear. This occurs only if n_e and n_m are not relatively prime, i.e. there exist integers n,m and q such that n_e=qn and n_m=qm However, we are free to consider an initial *BPS Saturated State* in which n_e and n_m are relatively prime. In this case, as we have proven above, the state with mass M = IZI can not decay. Thus, a *BPS Saturated State* with relatively prime n_e and n_m is stable and does not decay. The importance of this result can not be overstated. It lies at the core of many modern results in *Superstring Theory* and *M-Theory*. Furthermore, as we will see, the *exotic matter* present in *M-Theory* is *BPS Saturated*, i.e. it is a *BPS Saturated State*, and thus it is stable against decay and hence a real, long-lived state in *M-Theory*, not a short-lived bound state. This is critical if we are to ever employ such *exotic matter* in an Alcubierre Type Warp Drive.

So, let us next examine the *exotic matter* present in *M-Theory*. As one will remember, *M-Theory* on a spacetime M×(S^1/Z_2) is equivalent to the E_8×E_8 Heterotic *Superstring Theory* on a spacetime M. Hence, any physical principle which we derive for the E_8×E_8 Heterotic *Superstring Theory* on the spacetime M is valid for *M-Theory* on the spacetime M×(S^1/Z_2). So, let us, for the moment, examine the E_8×E_8 Heterotic *Superstring Theory* on the spacetime M. The *low-energy limit*[7] of the E_8×E_8 Heterotic *Superstring Theory* on the spacetime M is a so-called N=1 Supergravity Theory." This N=1 *Supergravity Theory* is simply a ten dimensional version of General Relativity with one *supersymmetry*. However, as one might expect, the *low-energy limit* of the E_8×E_8 Heterotic *Superstring Theory* is not the whole story. In taking the *low energy limit* we are taking the limit in which the *string* tension is infinite. In this limit it takes an infinite amount of energy to excite any of the *string*'s higher modes of vibration. So, no truly "*string*y" behavior is really being seen. If we do not take the *low energy limit*, then the *string* tension is finite and we begin to see "*string*y" effects. These effects are manifested as corrections to the N=1 *Supergravity Theory*. The action of the N =1 *Supergravity Theory* is corrected by powers of the *string* tension[8]. In fact there are an infinite set

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[5] One can also consider [Witten 94] more complicated cases in which a/a_D is real. But, we will not do so here as it only serves to add details which are not essential to our exposition.

[7] By *low energy limit* we mean the limit in which the *string* tension is infinite.

Much as a function f(x) can be expressed as a power series in 1/x about the point x=∞, the action of the E_8×E_8 Heterotic *Superstring Theory* can be expressed as a power series in 1/T about the point T = ∞ of infinite *string* tension

of corrections [Kallosh 93A] to the $N=$ˉ Supergravity Theory. Hence, one can see that it is relatively difficult to obtain exact solutions to the equations of motion for the $E_8 \times E_8$ Heterotic Superstring Theory as its equations of motion contain an infinite set of terms. However. [Kallosh 93A] one may solve this seemingly intractable problem by examining in detail these various corrections. One finds that the bosonic portion of this action's power series in one over the string tension has a pattern [Kallosh 93A]. In particular [Kallosh 93A], all of the terms in such a power series are constructed of a few elementary term., so-called [Kallosh 93A] "T-Tensors." So, if one can understand these "T-Tensors," [Kallosh 93A] then it is possible to set the fermionic portion of the action to zero and then solve the equations of motion for the bosonic portion of the action. This is exactly what Bergshoeff et. al. [Kallosh 93A] accomplished. However, in doing so they found [Kallosh 93A][Kallosh 93B] that one must also require one-half of the supersymmetry of the $E_8 \times E_8$ Heterotic Superstring Theory to be broken[9]. If we look back at our portion of the $N=2$ Supersymmetry Algebra involving q^1_α, then we see that when $M=|Z|/2$. i.e. when a state is BPS Saturated, one of the generators q^1_α is zero. In other words, one-half of the supersymmetry of the theory is broken. This suggests that the solutions of Bergshoeff et. al. [Kallosh 93A] may be related to BPS Saturated States and thus be provably stable. We will see that this is indeed the case.

In examining the exact solutions of the $E_8 \times E_8$ Heterotic Superstring Theory found by Bergshoeff et. al. [Kallosh 93A][Kallosh 93B], Kallosh and Linde [Linde 95] decided to examine such solutions from the point-of-view of the $E_8 \times E_8$ Heterotic Superstring Theory on a spacetime $M \times T^6$ or equivalently from the point-of-view of M-Theory on a spacetime $M \times T^6 \times (S^1/Z_2)$. What they found was amazing! First, they found that upon examining the exact solutions of the $E_8 \times E_8$ Heterotic Superstring Theory of Bergshoeff et. al. [Kallosh 93A][Kallosh 93B] on $M \times T^6$, or equivalently, the corresponding exact solutions of M-Theory [Kallosh 93A][Kallosh 93B][Witten 95A] on $M \times T^6 \times (S^1/Z_2)$, these solutions are BPS Saturated States. Thus, they are exact solutions of M-Theory on $M \times T^6 \times (S^1/Z_2)$ which are stable and do not decay. In fact, these BPS Saturated States are resident in a $N=4$ Supersymmetric Yang-Mills Theory of just the type we have studied. Second, and more relevant to the study of an Alcubierre Type Warp Drive, the; found that such solutions possessed a form of [Linde 95] exotic matter. More specifically, among the fields[10] present in this solution of M-Theory on $M \times T^6 \times (S^1/Z_2)$ they found that the metric of this solution in spherical coordinates is given by

$$ds^2 = \left(1 + \frac{4M}{r} - \frac{4q^2 g^2}{r^2}\right)^{-\frac{1}{2}} dt^2 - \left(1 + \frac{4M}{r} - \frac{4q^2 g^2}{r^2}\right)^{\frac{1}{2}} dr^2 - r^2 d\Omega^2,$$

where M, which is positive semi-definite, is the mass of the solution [Linde 95]. r is the "distance" from the solution's center and q and g are charges of the solution. Let us next examine why such a solution is said to possess exotic matter.

6.   M-THEORY ON $M \times T^6 \times (S^1/Z_2)$ AND THE ALCUBIERRE TYPE WARP DRIVE

Let us consider why our above exact solution of M-Theory on $M \times T^6 \times (S^1/Z_2)$ is said to possess exotic matter. General Relativity [Wald 84] allows us to extract a Newtonian gravitational potential from the above metric. This, in turn, leads to the following gravitational field in spherical coordinates

$$\left(\frac{2q^2 g^2 - Mr}{r^3 \left(1 - \frac{4q^2 g^2}{r^2} + \frac{4M}{r}\right)^{\frac{3}{2}}}\right) \hat{r}$$

where $\hat{r}$ is the outward pointing radial unit vector. Graphically, the coefficient of $\hat{r}$ is represented, for the values $q=1$, $g=1$ and $M=2$, as

[9] A supersymmetry is said to be broken when its associated supersymmetry generator is zero.
[10] The fields present in this solution are scalars, a metric and an anti-symmetric tensor; that is all.
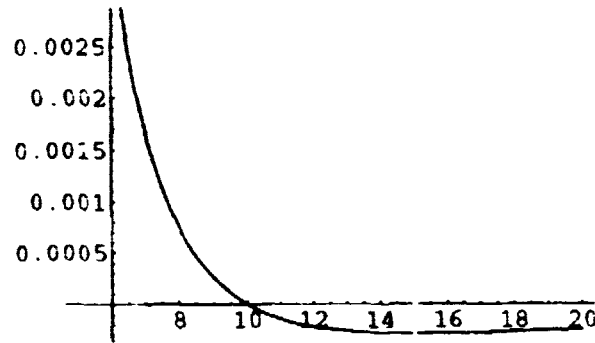
Figure 2: Graph of "r-hat" coefficient vs. radius for M-Theoretic exotic matter.

So, one may see that for $r > 10$ one has a normal attractive gravitational force[11]; for $r = 10$ the gravitational force is zero, and for the portion of $r < 10$ depicted on the graph, the gravitational force becomes repulsive! Hence, for the region $r<10$ depicted on the graph, one can see that this solution behaves as if its mass is negative! However, if we look at the limit of the above gravitational field as $r\to\infty$, then we see that it takes the standard $(-M/r^2)\hat{r}$ form. Hence, as mass is measured at infinity [Wald 84], this solution has a mass $M \geq 0$ and not disallowed by the BPS Inequality, which requires $M \geq 0$. One can see the exotic matter explicitly by computing the Newtonian mass within a sphere of radius r for such a configuration. One finds this quantity is r dependent and goes to M as $r\to\infty$. For the values $q=1$, $g=1$ and $M=.2$ it has the form
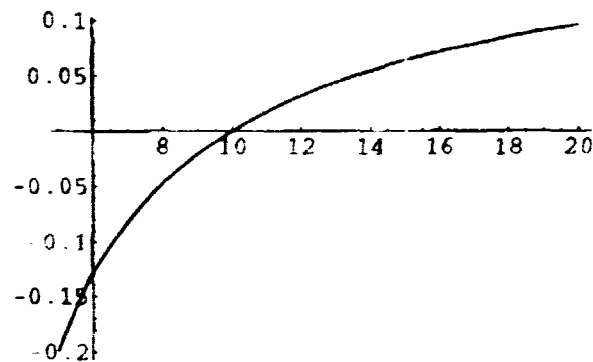

Figure 3: Graph of Newtonian mass in a shell of radius r vs. r

As one can see, the "core" of this solution is exotic matter. This, at least partially, solves the "exotic matter problem," as we now have proof that such exotic matter exists in a bound state with normal matter. But, we do not know how to employ the above states, or similar states, in a Alcubierre Type Warp Drive. This is what must be studied.

Such a study must address many questions.... What other exotic matter states exist in M-Theory? Does there exist an Alcubierre Type Warp Drive based upon the above states, or similar states. in M-Theory? By what physical processes can such states be generated? etc. These are some of the topics which must be touched upon in a further study of Alcubierre Type Warp Drives in M-Theory.

7.   COST OF STUDY

The study will mainly consist of theoretical work, i.e. pencil and paper work, along with some computational work which will be needed to confirm some of the M-Theoretic results. The results may contain an infinite sum of higher order membrane tension terms which are hard to check by hand. The main cost will be for labor at $40K per year, office space will cost approximately $10K per year, computers and various office supplies will be approximately $3K a year. For a sum total of $106K for a two year study, which s the suggested period over which such research should be conducted.

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[11]Remember. $\hat{r}$ is an outward pointing radial unit vector.

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NEXT DOCUMENT

Michelson-Morley on the Space Shuttle:
A Possible Experiment to Test Dinowitz's Field Distortion Theory

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ABSTRACT:

The prospects for interstellar travel under Einstein's Special Relativity Theory are dim. Dinowitz's Field Distortion Theory (FDT) is intended to replace Einstein's Special Relativity Theory (SRT). To date, all experimental data that appear to support SRT also support FDT, and under most conditions the equations of FDT reduce to those of SRT. However, under certain conditions, Field Distortion Theory predicts that matter can be accelerated to light speed, and beyond, without experiencing the increase in mass or dilation of time associated with near-light speeds under Special Relativity Theory. Such a possibility would have enormous implications for the prospect of interstellar travel. The amount of propellant currently believed necessary to reach near-light speeds would be greatly reduced. More importantly, because there is no limiting velocity under FDT, the minimum amount of time currently believed necessary to reach other star systems would be greatly reduced. Field Distortion Theory can be experimentally tested by conducting the Michelson-Morley experiment on NASA's space shuttle. This possible experiment is described along with specific estimates of the magnitude of the predicted effect. It is found that the predicted effect is well within the detectable range of current instrumentation.

INTRODUCTION; PROSPECTS FOR INTERSTELLAR TRAVEL UNDER SPECIAL RELATIVITY THEORY (SRT):

At the speed of light one could reach the Moon in a mere instant, like flicking a light switch. One could reach Mars in an average of 13 minutes (depending on the position of the Earth and Mars in their orbits), and Jupiter's moon Europa in an average of 43 minutes, like a drive from the suburbs into the city. Even distant Pluto would be less than 6 hours away, like a flight from New York to Los Angeles. Thus, in terms of travel within our solar system the light speed limit stipulated by Einstein's Special Relativity Theory (SRT) will not prove too bothersome. The stars, however, are a different matter.

At the speed of light one could reach the nearest star system, the Alpha Centauri star system, in 4.3 years. Unlike the aforementioned cases however, there is no analogy for this situation. Interstellar travel would be like nothing we have ever done before, and perhaps like nothing we would ever be willing to do. Even Columbus was not called upon such an arduous task. The Nina, Pinta, and Santa Maria set sail from Spain on August 3, 1492, stopped at the Canary Islands for repair and reprovisioning on September 6, and arrived in the Americas on October 12, a voyage of less than two and a half months [1]. Under Einstein's light speed limit it is simply not possible to travel to even the nearest stars and back in times measured by those on Earth in less than decades.

Under SRT a civilization engaging in the task of interstellar travel cannot possibly reap any benefits of this endeavor for a time of at least 2d/c, where d is the distance to the star system in question, and where c is the speed of light. Thus if we sent a probe at the velocity of light to the nearest star system, 4.3 light-years away, we could not receive any data back until 8.6 years had passed. If we sent a probe at the velocity of light to a star system 430 light-years away (which, for all we know may be the distance to the nearest extraterrestrial civilization) we could not receive any data back until 860 years had passed.

One must realistically consider the willingness of our civilization, or any other, to engage in such a vast and costly enterprise as interstellar travel when the fruits of this endeavor cannot possibly benefit the civilization until decades if not centuries have passed.

Under Einstein's Special Relativity Theory (SRT) as one approaches the speed of light time passes more slowly. (We will not debate the logic of this statement here or whether it is actually true). For example, under SRT if one can attain a speed of .999c then only about 2½ months would pass for the crew of a starship whereas 4.3 years would pass for those on Earth. Thus as far as the crew of the starship is concerned they could travel to the Alpha Centauri star system in the same amount of time it took Columbus to reach the new world. There is no limit to which one can carry this 'time dilation' effect. If one wanted to travel to the nearest extraterrestrial civilization, assuming it lies in a star system 430 light-years away, then a speed of .9999999c would be required in order that 2½ months pass for the crew of a starship. Of course 430 years would pass for those on Earth.

While providing no incentive for those on Earth, the time dilation effect certainly, at least in terms of the amount of time that passes on board ship, makes the prospect of travel to the stars more palatable for any perspective starship crew. However, the time dilation effect is only significant near the speed of light. Let us consider the amount of propellant required to reach near-light speeds under SRT.

The rocket principle - throw something backward and, by the law of conservation of momentum, you move forward - is currently the only known way to travel in the vast depths of interstellar space. The amount of propellant required for a rocket reach near-light speeds under SRT is,

$$
\frac{M_i}{M_f} = \left(\frac{1 + \dfrac{v}{c}}{1 - \dfrac{v}{c}} \right)^{\dfrac{c}{2v}}
\tag{1}
$$

where M_i is the initial mass (propellent plus payload), M_f is the final mass (payload), v is the velocity relative to the observer, c is the velocity of light, and v_e is the rocket exhaust velocity.

Assuming the highest rocket exhaust velocity possible under SRT, $v_e = c$, we find by equation 1 that a ship velocity of .999c is possible if the initial mass of the ship is about 45 times its final mass, and a ship velocity of .9999999c is possible if the initial mass of the ship is about 4500 times its final mass. These mass ratios reflect only what is required to achieve these velocities, the equivalent of a one way fly-by mission. A one way decelerated mission, or a round trip mission would impose additional exponential multipliers to these values. By comparison the initial mass of the Saturn 5 moon rocket, mankind's most extreme case to date, was only around 68 times its payload (consisting of the Command Module and the Lunar Excursion Module (LEM)) [2].

In light of this difficulty it has been suggested that rather than carry fuel along it be obtained from the environment. Designs for interstellar solar sails, grand affairs dwarfing the clipper ships of the past, which would use the feeble pressure of sunlight for propulsion have been suggested. Interstellar ramjets which, by pounding the space ahead of them with powerful lasers, would ionize the thin hydrogen gas in the near vacuum of interstellar space, and then use huge electric or magnetic fields to draw the ionized gas into the ship as fuel have also been suggested. However, both these schemes have tremendous problems of their own and lack the capability to realistically reach speeds greater than .1c [3, 4].

Assuming that the velocity of light is the highest possible velocity in the universe, and that Einstein's Special Relativity Theory is a perfect reflection of reality, the prospects for interstellar travel are not good. However, perhaps Special Relativity Theory is not the last word on reality.

FIELD DISTORTION THEORY:

In 1996 Field Distortion Theory (FDT) was published [5]. Field Distortion Theory (FDT) is intended as a replacement for Einstein's Special Relativity Theory (SRT). The equations of FDT reduce to those of SRT under all conditions that SRT has so far been tested. However, under certain conditions that have yet to be tested, FDT makes several clear predictions that contradict SRT.

Einstein's Special Relativity Theory (SRT) is based on two fundamental postulates: (1) The laws of physics are the same in all inertial frames of reference (i.e. there is no preferred frame of reference) and, (2) the velocity of light is independent of the velocity of its source. A logical consequence of these postulates is that the velocity of light is independent of the motion of the source or observer. For this consequence to be tenable the Galilean transformations are rejected and a new set of transformations, commonly referred to as the Lorentz transformations are adopted. These transformations distort space and time so that the velocity of light is independent of the motion of the source or observer. All the other consequences of Special Relativity Theory (SRT), such as the increase of mass with increasing velocity relative to the observer and the slowing of time with increasing velocity relative to the observer, follow from these transformations as well.

Field Distortion Theory (FDT) is also based on two fundamental postulates: (1) the Galilean transformations are valid, and (2) the field distortion principle - the electric field around a charge experiences an aerodynamic-like distortion when the charge moves through a gravitational field. Based on these two postulates a theory of light propagation is developed where, rather than distort space and time, it is the distortion of the electric field around a light source that accounts for the experimental evidence concerning the propagation of light.

Under FDT it postulated that a body's inertial mass is related to this field distortion. The result is a new equation for mass in which motion relative to the gravitational fields with the locally dominant field energy densities, not motion relative to the observer, is the critical factor in determining changes in mass. Under all conditions tested to date the field distortion mass equation reduces to Einstein's equation for mass. However, under certain conditions, the mass of a body does not become infinite when its velocity is equal to the velocity of light, as is the case in Special Relativity, but remains finite. Under these conditions it should be possible to accelerate matter to hyperlight velocity.

In FDT the relationship between mass and time is examined. It is found that an increase in the mass of a system will result in a slowing of the time that system keeps, provided that the forces governing the system are not mass-dependent. A new equation for time is derived in which, as is the case for mass, motion relative to the gravitational fields with the locally dominant field energy densities, not motion relative to the observer, is the critical factor in determining changes in time. Under all conditions tested to date the field distortion time equation reduces to Einstein's equation for time. However, under certain conditions, the time a system keeps does not slow to a standstill when its velocity is equal to the velocity of light, as is the case in Special Relativity, but continues unabated.

PROSPECTS FOR INTERSTELLAR TRAVEL UNDER FIELD DISTORTION THEORY (FDT):

According to Field Distortion Theory a body can be accelerated to light speed, and beyond, without experiencing the increase in mass or dilation of time associated with near-light speeds under SRT when the gravitational field energy density of the body in question is much greater than the gravitational field energy densities due to all other bodies at the location of the body in question. This condition is never realized at the Earth's surface, where the gravitational field energy density of the body in question (such as an electron or proton in a particle accelerator) is invariably much less than the gravitational field energy density of the Earth. In this case the equations of Field Distortion Theory reduce to those of Special Relativity Theory (except at extremely high energy). However, this condition occurs quite naturally in the case of a spacecraft leaving the solar system.

Consider a test particle located on a spacecraft leaving the solar system. The field energy density of a gravitational field i is,

$$u_i = \frac{g_i^2}{8\pi G} \qquad (2)$$

where g_i is the gravitational field strength due to gravitational field i at the location of the test body, and G is the gravitational constant (6.67×10^{-11} Nm^2/kg^2). Suppose that the test particle is su _jected to a gravitational field energy density due to the spacecraft itself of $u_a = 6.0 \times 10^{-3}$ J/m^3. (This is the same gravitational field energy density a test particle located on the surface of a lead sphere one meter in radius would experience). Table I shows the gravitational field energy density at the location of the test particle due to the spacecraft, u_a, and due to the Sun, u_O, as the distance (in Astronomical Units) of the spacecraft from the Sun increases.

Table I: Gravitational Field Energy Density Due to Spacecraft, u_a, and the Sun, u_O, at Location of Test Particle

Distance (AU)	u_a (J/m^3)	u_O (J/m^3)
1	6.0×10^{-3}	2.1×10^{4}
10	6.0×10^{-3}	2.1
100	6.0×10^{-3}	2.1×10^{-4}
1000	6.0×10^{-3}	2.1×10^{-8}

The gravitational field energy density that the test particle experiences due to the spacecraft, u_a, does not change since the test particle does not change position relative to the spacecraft. However, the gravitational field energy density that the test particle experiences due to the Sun, u_O, does change since the test particle's position relative to the Sun changes.

When the gravitational field energy density at the location of the test particle due to the spacecraft is much less than the gravitational field energy density due to the Sun, $u_a \ll u_O$, as is the case when the distance of the spacecraft from the Sun is less than 10 AU, the equations of Field Distortion Theory reduce to those of Special Relativity Theory (except at extremely high energy).

However, when the gravitational field energy density at the location of the test particle due to the spacecraft is much greater than the gravitational field energy density due to the Sun, $u_a \gg u_O$, as is the case when the distance of the spacecraft from the Sun is greater than 100 AU (.0016 light-year), the test particle can be accelerated to light speed, and beyond, without experiencing the increase in mass or dilation of time associated with near-light speeds under Special Relativity Theory. Since every particle of the spacecraft can be regarded as a test particle subject to the gravitational field energy density due o all the other particles that make up the spacecraft, it follows that the spacecraft itself can be accelerated to light speed, and beyond, without experiencing the increase in mass or dilation of time associated with near-light speeds under Special Relativity Theory.

Thus under Field Distortion Theory future interstellar craft having a gravitational field energy density greater than the gravitational field energy density due to any other body a the location of the craft will not experience the increase in mass or dilation of time with increasing velocity relative to the stars. In theory such craft could attain velocities relative to the stars many times the velocity of lig it.

Let us consider the implications of such a possibility for the prospect of interstellar travel. Imagine a "space-drive" capable of subjecting every atom of a spacecraft to an acce eration of 1000 m/s^2 (approximately 100 g). Suppose the craft is subjected to a constant acceleration of 1000 n /s^2 to the midpoint of its journey, and then a constant deceleration of 1000 m/s^2 from the midpoint of its journey to its destination.

Table II shows the amount of time required for the journey for a given distance under Special Relativity Theory (SRT) and under Field Distortion Theory (FDT).

Table II: Time Required to Cover a Given Distance Under Special Relativity Theory, t_{SRT}, and Under Field Distortion Theory, t_{FDT}

Distance (light-years)	t_{SRT} (years)	t_{FDT} (years)
5	5.02	0.44
10	10.02	0.62
50	50.01	1.38
100	100.01	1.95
500	500.00	4.36
1000	1000.00	6.17

Clearly, if Field Distortion Theory (FDT) is a more accurate reflection of reality than is Special Relativity Theory (SRT) the implications for the prospect of interstellar travel would be enormous.

The example above, employing a "space drive", was useful for illustrating the potentially tremendous difference in travel time to the stars under Special Relativity Theory (SRT) versus Field Distortion Theory (FDT). However, we presently have no idea how to construct a "space drive". Let us return to the rocket and examine the amount of propellant required to reach near-light speeds, and beyond, under FDT.

The amount of propellant required to reach a given velocity under FDT, provided the spacecraft has a gravitational field energy density greater than the gravitational field energy density due to any other body at the location of the craft, is,

$$\frac{M_i}{M_f} = e^{\frac{v}{v_e}} \tag{3}$$

where M_i is the initial mass (propellent plus payload), M_f is the final mass (payload), v is the velocity relative to the observer, and v_e is the rocket exhaust velocity. This equation is known as the "classical rocket equation" (as contrasted with the "relativistic rocket equation" that one obtains by assuming SRT's variation of mass with velocity).

The key to the amount of propellant that a rocket must carry is the rocket exhaust velocity, v_e. A final rocket velocity, v, much in excess of the rocket exhaust velocity, v_e, requires a tremendous amount of propellent. This is why any rocket that has been built (or is ever likely to be built) has a final velocity only a few times its rocket exhaust velocity.

Table III shows the ratio of the initial mass (propellent plus payload) to the final mass (payload), M_i/M_f, for a given final rocket velocity, v, when the rocket exhaust velocity, v_e, is equal to the velocity of light, c.

Table III: Ratio of Initial Mass to Final Mass, M_i/M_f, for a Given Final Rocket Velocity, v, When the Rocket Exhaust Velocity, v_e, is Equal to the Velocity of Light, c

v/c	M_i/M_f
1	2.72
10	2.20×10^4
100	2.69×10^{43}

Assuming a rocket exhaust velocity equal to the velocity of light, $v_e = c$, we find that rocket velocities in excess of a few times the velocity of light would require a tremendous amount of propellent. However, if the rocket exhaust velocity could be raised to hyperlight velocity then rocket velocities many times the velocity of light could be achieved without requiring a tremendous amount of propellent.

Under Field Distortion Theory (FDT) it is possible to raise rocket exhaust velocity to hyperlight levels. Recall that under FDT body can be accelerated to light speed, and beyond, without experiencing the increase in mass or dilation of time associated with near-light speeds under SRT when the gravitational field energy density of the body in question is much greater than the gravitational field energy densities due to all other bodies at the location of the body in question. Though this condition occurs quite naturally in the case of a spacecraft leaving the solar system, it is not the case for small bits matter (i.e. the rocket exhaust) leaving the spacecraft. The gravitational field energy density of the rocket exhaust (such as stream of protons) is invariably much less than the gravitational field energy density of the spacecraft. In this case the equations of Field Distortion Theory reduce to those of Special Relativity Theory and it is impossible to raise rocket exhaust velocity to hyperlight levels because the mass of the rocket exhaust goes to infinity as its exhaust velocity v_e goes to c. However this is not the case if a second moving body having a gravitational field energy density comparable to the spacecraft is introduced. Consider a spacecraft with the configuration shown n Figure 1. A mass, m_2, orbits about the main body of the craft, m_1, at the short end of a long boom with an orbital velocity, v_2.

According to Field Distortion Theory, for a spacecraft with the configuration shown in Figure 1, the mass of the hyperlight rocket exhaust is,

$$m_{e\cdot} = m_{\alpha\cdot}\frac{v_{e\cdot}\left(g_1^2 + g_2^2\right)}{v_2 g_1 g_2} \quad (4)$$

where $m_{e\cdot}$ is the mass of the hyperlight rocket exhaust, $m_{\alpha\cdot}$ is the rest mass of the hyperlight rocket exhaust, $v_{e\cdot}$ is the hyperlight rocket exhaust velocity, v_2 is the orbital velocity of mass m_2, g_1 is the gravitational field strength due to the main body of the spacecraft, m_1, at the location of the rocket exhaust, and g_2 is the gravitational field strength due to the orbital mass, m_2, at the location of the rocket exhaust.

If $g_1 = g_2$, $v_2 = 3.0 \times 10^4$ m/s, and $v_{e\cdot} = 1.5 \times 10^{11}$ m/s (500c), then the mass of the hyperlight rocket exhaust is 1.0×10^7 times its rest mass. This is about 100 times the mass magnification factor record currently held by the Large Electron/Positron (LEP)

Figure 1. Configuration for a possible hyperlight rocket. A mass, m_2, orbits about the main body of the craft, m_1, at velocity v_2.

particle collider located on the French/Swiss border. However, there is no doubt that in the future the size of these devices will come down, even as their energy goes up [6, 7] With a rocket exhaust velocity of 500 times the velocity of light the spacecraft itself could attain a velocity of 500 times the velocity of light carrying only 1.72 times its empty weight in propellent.

Clearly, if correct, Field Distortion Theory would have revolutionary implications for the prospect of interstellar travel.
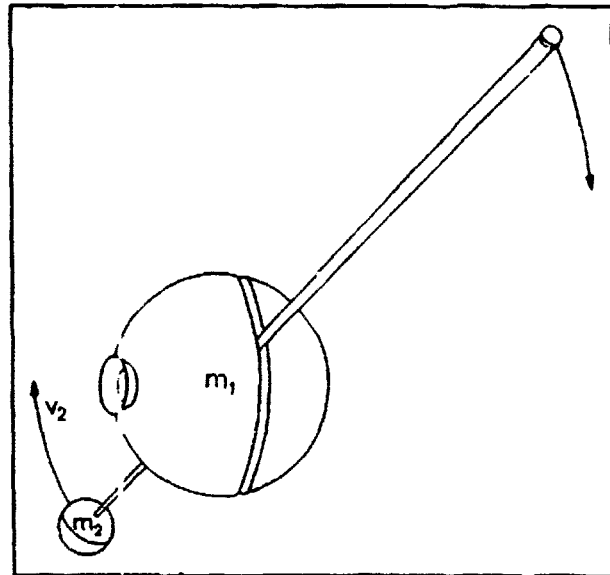
TESTING FIELD DISTORTION THEORY; CONDUCTING THE MICHELSON-MORLEY EXPERIMENT ON NASA'S SPACE SHUTTLE:

Field Distortion Theory can be tested by conducting the Michelson-Morley experiment on NASA's space shuttle. The Michelson-Morley experiment was conducted in 1887 at the Case Institute (now Case Western Reserve University) in Cleveland Ohio. It was this crucial experiment that, in conjunction with other experimental data, led to the downfall of the Newtonian world view and paved the way for the acceptance of Einstein's Special Relativity Theory. The experiment made use of an optical interferometer, a device of Michelson's own design, and for which he was awarded the Nobel Prize in 1907. Basically, the experiment involved observing any changes in an interference pattern (fringe shift) produced by the recombination of two light beams that had been directed along paths at right angles to each other.

According to Special Relativity Theory a Michelson interferometer should not experience a fringe shift. Indeed, it was the lack of an observed fringe shift in the Michelson-Morley experiment of 1887, in conjunction with other experimental data, that served as experimental evidence for Special Relativity in 1905.

However, according to the Field Distortion Theory of light propagation a Michelson optical interferometer should experience a fringe shift of,

$$N = \frac{4lv_{\oplus}^2}{\lambda c^2} \qquad (5)$$

where l is the path length, $v_{\oplus}$ is the velocity of the light source relative to the Earth's gravitational field (i.e. the velocity of the interferometer relative to the center of the Earth), λ is the wavelength, and c is the velocity of light.

Using $l = 11$ m, $\lambda = 5.5 \times 10^7$ m, $c = 3.0 \times 10^8$ m/s, which were the values used in the Michelson-Morley experiment, and $v_{\oplus} = 3.5 \times 10^2$ m/s, which is the velocity of the interferometer relative to the Earth's gravitational field at the latitude of Cleveland Ohio, we find that the fringe shift, $N = 1.1 \times 10^{-4}$. This result is 100 times smaller than the sensitivity of the Michelson interferometer. Updated versions of the Michelson-Morley experiment performed since 1887 have steadily increased in sensitivity over the years, but not by enough to detect so small an effect [8].

Thus, according to the Field Distortion Theory of light propagation the Michelson-Morley experiment failed to detect a fringe shift because the interferometer was not moving through the Earth's gravitational field fast enough to produce a detectable fringe shift. If the interferometer's velocity through the Earth's gravitational field could be increased by an order of magnitude the fringe shift would be 100 times greater and thus, provided FDT is correct, detectable.

NASA's space shuttle is a reusable space-plane that transports men and cargo into low Earth orbit. The shuttle's orbital velocity, and thus its velocity relative to the Earth's gravitational field, is 7.9×10^3 m/s. Suppose the Michelson-Morley experiment was conducted on an orbiting space shuttle.

Using $l = 11$ m, $\lambda = 5.5 \times 10^7$ m, $c = 3.0 \times 10^8$ m/s, and $v_{\oplus} = 7.9 \times 10^3$ m/s, we find that the fringe shift, $N = 5.6 \times 10^{-2}$. This result is 500 times larger than the effect at the Earth's surface. It is also well within the detection capabilities of even the original 1887 Michelson interferometer.

Let us consider the cost of such an experiment. One important fac to consider is that to conduct the Michelson-Morley experiment on the space shuttle no new technology is needed and nothing new, at least in theory, need even be built - Michelson interferometers of the required sensitivity have existed for over a century, and NASA's space shuttle has existed and continues to operate since 1981. One need only bring these two existing devices together for this unique experiment. On this basis one would expect costs to be low. However, space on the shuttle is at a premium and it may be necessary to design a Michelson interferometer that is specifically geared, perhaps in terms of size and weight of components, for use on the space shuttle.

It should be noted that even on Earth in the 1880's Michelson was faced with similar considerations. In 1881, Michelson conducted his experiment using an interferometer with a path length of 1.2 m. However, to leave no doubt of their results, the 1887 Michelson-Morley experiment made use of a newly designed interferometer which made use of repeated reflection of the light beams, made possible by the precise placement of additional mirrors, to increase the path length (and thus any fringe shift) over 9 times in the same size device [9]. If necessary, given today's precision technology, it should certainly be possible to repeat Michelson's feat and design an interferometer to fit within one of the shuttle's cubby-like experimental bays at a reasonable cost.

We should also consider the political costs of such an experiment. News of the creation of NASA's Breakthrough Propulsion Physics Program [10] was well received in publications such as Ad Astra and Final Frontier [11, 12]. However, a news brief in Science magazine was entitled "NASA's Fling With Anti-Gravity" [13]. The brief article, which concerned one of the experiments being conducted under NASA's Breakthrough Propulsion Physics Program, asked: 'Anti-gravity - this year's "cold fusion"?', and then clearly implied that the answer is yes. Valid or not, articles of this type can be written because experiments of this sort cannot be regarded as a legitimate investigation into currently accepted theory.

Fortunately, conducting the Michelson-Morley experiment on the space shuttle can be regarded as a legitimate investigation into currently accepted theory. Consequently conducting the Michelson-Morley experiment on the space shuttle would be considered 'good science' by the scientific community. In fact the author is not alone in suggesting that this experiment be performed [14]. Conducting the Michelson-Morley experiment on the space shuttle, regardless of the outcome, would represent a no-lose scenario for NASA. At worst the experimental results would be a unique and spectacular confirmation of Einstein's Special Relativity Theory, which has never been tested under conditions in which the observer's frame of reference is in motion relative to the Earth. At best the experimental results of the conducting the Michelson-Morley experiment on the space shuttle would usher in a revolution in physics that may eventually pave the way for manned journeys to the stars.

CONCLUSION:

The distances to even the nearer stars are vast by human standards. If ship velocity is limited to the velocity of light, as dictated by Einstein's Special Relativity Theory, then the prospects for interstellar travel are dim. In 1996, Field Distortion Theory (FDT), a new theory of the fundamental physics of light propagation and motion, intended as a replacement for Einstein's Special Relativity Theory (SRT), was published. Under certain conditions FDT predicts that matter can be accelerated to light speed, and beyond, without experiencing the increase in mass or dilation of time associated with near-light speeds under SRT. Thus, Field Distortion Theory has potentially revolutionary implications for the prospect of interstellar travel in terms of the amount of time required to reach other star systems as well as the amount of propellant required to reach near-light speeds, and beyond. Field Distortion Theory can be tested by conducting the Michelson-Morley experiment on the space shuttle. Since one need only bring two existing devices, the Michelson interferometer and the space shuttle, together to conduct such an experiment, costs are expected to be low. Considering the impact that Field Distortion Theory would have, if correct, on the prospect of interstellar travel and man's view of the nature of the universe in general it is recommended that this new theory be tested by conducting the Michelson-Morley experiment on the space shuttle.

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NEXT DOCUMENT

QED CASIMIR FORCE ELECTRICAL POWER SUPPLY

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This paper describes two embodiments of the same basic concept on greatly different size scales, intended for different applications. One machine is a large scale device and is a rotary machine and is capable of substantial output power. The other device is a Silicon Nanomachine that would be useful for producing microwatts to milliwatts of power for use as part of other microelectronic integrated circuit devices, such as cardiac pacemakers, other medical implants quartz crystal wrist watches, pocket calculators, and other low power devices. If the same Silicon Nanomachine version is used in arrays of dozens to hundreds of devices, working cooperatively, produced by IC technology on the same Silicon wafer, it could power low power portable computers, or with the use of rechargeable batteries in the computer, do all the things portable notebook and laptop compute. s do now and supply all the required recharging power during the time the computer is shut down.

In effect, both embodiments of this principle act as if they are "Perpetual Motion Machines" in the classic normally thermodynamically "impossible" manner. They however can produce usable electrical output power with no apparent input power source by virtue of an interaction of a Quantum Electrodynamic force or effect known as the Casimir force, Mechanical motion and Electrostatic forces. This three way interaction of the QED Casimir force, Mechanical and Electrostatic forces, in no way violates any thermodynamic laws or the conservation of energy, because of the ability to extract energy from the Zero Point Fluctuations (hereafter called ZPF), which is a known QED phenomenon.

The reason that these Casimir forces exist at all is a very complex QED explanation that in short states that all space, including a vacuum, is filled with an enormous amount of energy. This energy is in the form of $\frac{1}{2}$ photons that are not normally observable. If one takes two close spaced, metallic mirror plates, facing each other, this forms a typical flat-flat interferometer cavity. Since all space is filled with $\frac{1}{2}$ photons of all wavelengths and all their possible modes from DC to the high frequency cut-off wavelength (the Planck frequency limit), calculated to be 10^{33} cm, this leaves all space filled with an enormous virtual energy density. By placing two parallel metal mirror plates close together, as in any interferometer cavity, any wave that has a half wavelength longer than the spacing between the boundary mirrors of the interferometer cavity cannot exist inside that cavity. Since the outside surfaces of the interferometer mirrors are bombarded by ALL the possible wavelengths and the inside surfaces are being bombarded by ALL possible wavelengths MINUS the ones excluded by the $\frac{1}{2}$ wavelength limit set by the cavity plate spacing, the closer the interferometer plates are spaced to each other the more wavelengths on the low frequency end of the spectrum that are excluded. This means that there is an unbalance in the radiation pressure forces tending to drive the plates together. This radiation pressure force differential only becomes significant at very small spacings but increases as the inverse FOURTH power as the spacings become very tiny in terms of wavelengths of light. One then has an almost astronomically large number, from which one subtracts this astronomically large number minus a very small number. This small number increases rapidly as the plate spacing decreases to very small values like nanometers. - - - (At this point, please read the related paper, "A PROPOSED LIMIT ON THE EXTENT OF THE CASIMIR FORCE AT VERY CLOSE SPACINGS". This paper proposes that the Casimir force in practice reaches a limit that is much smaller than the theoretical limit.) - - The content of this paper on the limit to the extent of the Casimir force is quite important to this paper as will be seen later.- - - This net force unbalance is what then drives the plates together and is the Casimir force.

Note that these are VERY small spacings indeed. Even 20 nm is only about 1/10 of a wavelength of short ultraviolet light. 50 Angstrom units is the length of a modest X-ray photon. At this time in history no one has built a piece of conventional moving machinery at anything like even 20 nm tolerances between moving parts. There is one exception however and this is in the fields of "Scanning Tunneling Microscopy". (STM) and Atomic Force Microscopy" (AFM). In this case a

very fine point or whisker is maintained at these kind of distances from the object to be examined or imaged. This fine point is motion scanned in a raster like manner to form a TV image of the, current / voltage / distance variations between the whisker point and the object to be observed and magnified. The motion is applied to the support for the point or whisker by means of piezoelectric transducers, while the object to be examined is held stationary. The entire travel of the whisker traveling in a TV raster scan manner is only a matter of microns or less. Since piezoelectric transducers are fast in response and very controllable over small travel distances they are ideal for the small motions needed in STM and AFM. They are controlled by fast act ng electronic servomechanisms. This form of spacing control will be utilized in these devices, as will be described later.

The basic operating principle involved in both devices described in this paper depends on a difference in the way the two forces, the Casimir force and the electrostatic force behave. The mechanical force is only used as a means of causing the required interaction between the other two forces by means of their different properties. The electrostatic force, or the attraction between two oppositely electrically charged bodies, (in this case two flat plates), one charged positively and the other charged negatively, acts to attract these plates toward one another regardless of the position of the plates relative to one another. In the case of unlike point charges, the attraction between the point charges behaves as the inverse SQUARE law of the separation distance between the point charges. In the case of unlike charged, flat parallel circular plates that are facing one another, when the separation distance is small compared to the area of the plates, the attractive force will increase at a rate that is LESS THAN the inverse SQUARE law. This electrostatic force can be significant even at substantial plate separations, (several cm or more), depending on the voltage difference between the plates.

In the case of the Casimir force, the attractive force only acts at very close spacings, like tens of nanometers or so and has the other property of increasing at a much greater rate with decreasing plate separations. The Casimir force increases as the inverse FOURTH power of the plate separation. The unique difference between the electrostatic force and the Casimir force is that two flat, parallel plates facing each other and charged with opposite electrical polarities will exhibit an attractive force between one another whether the plates are pushed or pulled toward or away from one another or, in this case, more importantly, whether the plates are slid or sheared toward or away from one another while maintaining a constant plate spacing. The Casimir force on the other hand only exhibits an attractive force between the plates if they are pushed or pulled apart. There is no force required to slide or shear the plates apart when a constant spacing is maintained between the plates. This odd difference in the behavior of the two types of forces is the heart of this invention.

THE PRIMARY CLAIM OF THIS INVENTION IS THAT:- Energy can be extracted from the Casimir force and coupled or transferred into an enhanced electrostatic force if the proper mechanical motion is applied in a cyclical manner to two p rallel electrically conductive (mirror polished metal) plates that are subjected to both types of forces at the same time. The pattern of mechanical motion of the two metal mirror plates that also carry unlike electrical charges, is a "Push - Slide - Pull - Slide" repetitive, four cycle or stroke motion done at extremely close plate spacings. (See Figure #1). Without the effect of the Casimir force, th electrostatic forces simply cancel out, (a zero sum process) and no net energy can be extracted and the system "runs down" to a stop from normal machine (frictional), losses. With the Casimir forc also acting the plates are attracted toward one another with a much greater force than the electrostatic forces alone could apply for a given voltage difference due to the intense Casimir attraction at very close plate spacings. By allowing the mechanical system to store displacement energy, like stretching or bending a spring, energy is transferred to the mechanical force part of the system. Th s is the first "Push" part of the four stroke operating cycle.

In the next part of the motion cycle, the two, now very closely spaced, oppositely electrically charged plates, are now slid or sheared apart while maintaining a constant plate spacing. This is the first "Slide" motion in the four cycle or four stroke process. Work is required against the

electrostatic force to separate the plates in a shearing motion but IS NOT required to overcome the powerful Casimir attractive force. When the two plates are now separated laterally the Casimir force is nil but some electrostatic force still exists, but is much reduced below the value when the plates were facing each other. As the charged plates move laterally, the electrical capacitance between the plates decreases greatly (like a factor of fifty or so), and hence the voltage between the plates increases greatly if they are isolated from other external circuitry. This is the result of Q = EC, or, Coulombs equals Voltage times Capacitance. Q, or Coulombs is conserved or constant as the capacity of the capacitor is changed if no charge is allowed to flow into other parts of the external circuit. With Q held constant, and C decreasing, E, the voltage across the capacitor will increase (by a factor of fifty or so), in proportion.

The total energy stored in Joules, increases as ½ of the square of the voltage and decreases linearly as the capacitance decreases, $J = \frac{1}{2} E^2 \times C$. This means that as work is done in separating charges by moving the capacitor plates to a lower capacitance configuration, the energy shows up as an increased number of Joules stored in the capacitor. The Casimir force is used to augment the change in capacitance beyond what the electrostatic forces are capable of. This Casimir force contribution to the change in the ratio of maximum to minimum capacitance during the four stroke cycle, in effect, comes for "free", that is requiring no external energy input source to provide this additional available electrostatic energy. Since the Casimir force comes from the ZPF virtual energy that fills all space, a small amount of the ZPF energy is "tapped" for free to supply the required extra energy without any apparent ordinary energy source being required. This is why the machine, in either embodiment, appears to look like a classic "perpetual motion machine", without violating any of the usual thermodynamic laws, or the conservation of energy. The stored kinetic mechanical energy of the vibrating "tuning fork" like tines supplying the "Push and Pull" motion on the one set of capacitor plates, along with the other mechanical lateral "Slide" motion, is merely an intermediate energy transfer process that allows for the complex four stroke "Push - Slide - Pull - Slide" cyclical process to operate. The only really difficult part of the process is the requirement that the mechanical operating distances are so tiny in order for the Casimir force to come into play. No one has ever built a large machine with anything like these close spacings between high speed moving parts. The only way that such a system can be built without the moving parts crashing together is to use fast acting servomechanisms with input spacing measurement transducers and piezoelectric actuators borrowed from the STM and AFM technologies.

Since one of the plates is attached to the mechanical spring system it is deflected more by the combined electrostatic plus the Casimir force than it would have been by only the electrostatic force acting alone. This additional spring deflection is a form of stored mechanical energy and can be utilized later in the operational cycle. This is the first part of the "Push" part of the four part cycle. The second part of the four stroke cycle is the "Slide" motion. As the plates are slid or sheared apart, the forces attracting the plates in the direction perpendicular to the faces of the plates is greatly reduced and the stored energy in the spring deflection of the plate attached to the spring is now very much reduced. This allows the spring to "snap back" past its neutral or resting position and recoil so as to increase the spacing between the plates. This is the "Pull" part of the four stroke process. This further reduces the electrical capacitance between the plates a bit more. If the spring-mass (plate) mechanical time constant is set to be operating at its natural mechanical resonant frequency, like a tuning fork, and the "Push - Slide - Pull - Slide", cyclical motion is also repeated at this same frequency, the spring - mass oscillations of the moving plate will build up to a substantial amplitude. In the case of the application to this invention, the spring is very stiff and the maximum amplitude is only a few microns, but the oscillation frequency is quite high, like 5 to 15 Kilohertz or more. Under these conditions depending upon plate area, plate spacing, the spring constant, the mass of the movable plate, the total travel (microns) of the plate (tuning fork tine) and the mechanical resonant operating frequency, considerable kinetic mechanical energy can be stored which will be coupled out later into the electrostatic force part of the process.

Mechanical losses are also greatly reduced, (i.e. - the mechanical "Q" increased) - (this "Q", or "quality factor", is a different Q than is used as the symbol for Coulombs above), - since the entire system is operated in a high vacuum for a number of reasons. Aerodynamic drag of course is reduced to essentially zero in a high vacuum. The other reason for the very high vacuum requirement is to obtain very good electrical insulation between the very close spaced bare metal moving parts. Electrical insulation values of as much as 3000 volts per mil (0.001 inch) are possible in a very high vacuum. As will be shown later, the use of a very high vacuum is also necessary as thermal insulation for some of the parts that are operated at cryogenic temperatures in the large scale embodiment of this invention.

As this cyclical process proceeds, the spring - plate (mass) tuning fork like oscillation reaches the far end of the recoil travel and starts to move forward again, toward the other plate. This is the end of the "Pull" part of the cycle and the beginning of the "Push" part of the cycle. Meanwhile the next "Slide" part of the cycle is operating. The other plate is moving again in line with the spring loaded plate and the "Push" part of the operational cycle starts over again. The "Push & Pull" cycles are 90 degrees out of phase with the two "Sliding" motion parts of the overall cycle. As it does so it is again attracted by both the electrostatic and Casimir forces and moves even closer toward the fixed plate. To prevent the plates from crashing together, sensors must detect the sub-microscopic separation between the plates and cause a servo loop to withdraw the spring loaded (tuning fork like) stator plate tines back away slightly from the fixed plate to prevent a collision between the two plates as the tuning fork (plate) oscillation amplitude increases.

One can make a vague parallel of this "Push - Slide - Pull - Slide" Casimir device, to the four strokes of a four cycle piston engine. One could look at the "Push" stroke as the "Compression" stroke of a piston engine. The next "Slide" motion of the Casimir device would be much like the "Power" stroke of a piston engine. The "Pull" stroke would be akin to the "Exhaust" stroke of the piston engine and the last "Slide" motion would be like the "Intake" stroke of the piston engine. The analogy is not perfect, but it gives a flavor for the energy utilization parts of the Casimir device four part cycle. As a further analogy to the four cycle piston engine, the closer the plates can be spaced at the peak of the "Push" cycle the greater the contribution of the Casimir force to the operation of the overall device and the greater the overall output efficiency.

The analog here is that reducing the plate spacing at the point of closest approach is much like increasing the compression ratio in a four cycle piston automobile engine. At very close spacings, like five nanometers or so, the Casimir forces are very high, like tens of atmospheres, so very large amounts of mechanical energy can be transferred to the mechanical oscillator part of the system. This all tends to increase the amplitude of the mechanical oscillation and hence the ratio of maximum to minimum electrical capacitance. This then couples to the electrostatic force as part of the three way interaction and increases the electrical output power. The danger with working with ever decreasing plate spacings in the hope of gaining additional machine output efficiency is the increased risk of "crashing" the plates together and destroying the machine Since the Casimir force, which in theory, increases at the incredible inverse fourth power rate, would make it very difficult to prevent a "snap action Crash" or closure of this already very small gap spacing. The requirements on the response of the distance sensing servo loop to prevent a "Crash" would be very severe if not impossible. - - - Again referring to the pressure vs. distance curves in the other paper, the Casimir force should flatten out and not get very much greater at decreasing spacings below a few nanometers. This will be a great help to preventing the "snap closed Crash" problem that would be very difficult for the servo loop to prevent if the Casimir force continued to increase for decreasing spacings like the theoretical Casimir force curve would predict. Hence the importance of the information given in the other paper to this Casimir machine.

A further analogy to piston type internal combustion engines to my "Casimir device" is that of comparing engine displacement to overlapping "Casimir force active working area" and engine

RPM to the Casimir device operating frequency. Both these effects increase the output power of their respective devices.

Energy is extracted from the overall system as rectified high frequency electrical power by means of the well known, old, "Charge Pump" circuit, which depends on the cyclical increasing and decreasing of the electrical capacitance of a motor driven variable capacitor, connected through two diode rectifiers. (See Figure #2). The classic "Charge Pump" requires power to drive the motor that operates the moving variable capacitor and only acts to increase the voltage supplied to a load. It consumes power rather than producing any. With the application of the energy extracted from the Casimir force to increase the ratio of minimum to maximum capacitance of the motor driven variable capacitor the output voltage produced by the "Charge Pump" is greatly increased and consequently the output power of the Casimir enhanced "Charge Pump" is greatly increased. With the proper scaling of the device, whether large or small, more output power should be produced than is required to operate the drive motor that operates the variable capacitor. Considerable circulating power is required to power the drive motor from the Casimir force enhanced output voltage of the "Charge Pump", but there should be considerable power produced to power external loads. Hence the machine, in whichever form it takes, will continue to run "forever", or at least until some part fails, once started by an external starter motor power supply. The startup motor power supply is just like an automobile piston or a gas turbine engine requirement. Once operating at the self resonant frequency of the tuning fork tines, which are one of the capacitor plates, external power should be produced and the starter motor power supply can be disconnected and the drive motor powered by the power produced by the device itself. There of course would be excess power produced to drive other external useful electrical loads.

The first embodiment I will describe is the Silicon Micro Electro Mechanical System, (or MEMS machine version). This would consist of a device made by integrated circuit technology on a single crystal Silicon wafer that would consist of a suspended flat polished plate supported only by four cantilever beams, two on each side of the suspended plate and etched free of the Silicon substrate on the underside of the Silicon wafer. The flat plate would also carry interdigitated or "comb finger" capacitor plates on the opposing pair of edges. (See Figure #3). These interdigitated "comb finger" capacitor plates would be interleaved with stationary "comb finger" capacitor plates attached to the solid frame of the Silicon wafer. This combination is thus far a well known MEMS device that is often used as a linear accelerometer. This device if enclosed in a high vacuum enclosure has a high mechanical "Q" (like a few times 10^4), and a high mechanical resonate frequency, (like tens of kHz), depending of the spring-mass constants of the structure. This device also can operate as a linear electrostatic oscillator motor when a high frequency electrical signal is applied across the two sets of interdigitated "comb finger" capacitor plates. When the high frequency electrical drive signal is tuned to the mechanically resonant frequency of the described vacuum encased MEMS device, the amplitude of the linear vibration will increase greatly and the device will behave like an electrically driven tuning fork, oscillating back and forth. Unfortunately this kind of mechanical oscillator will couple vibrational energy to the Silicon wafer frame and unless restrained, or compensated for, will seriously spoil the mechanical "Q" of the MEMS device. One way of compensating for this unbalanced force on the wafer is to place two identical devices on the same wafer, in line and close together. These two devices will then be operated at the same resonant frequency but 180 degrees out of phase so that the vibrations coupled into the wafer will cancel out. This requires good matching of the device structures during fabrication so as to achieve matching resonant frequencies and nearly identical masses of the moving parts. This is like matching the two tines of a conventional tuning fork so very little vibrational energy is coupled into the support rod, also called "clamping loss". If this is carefully done, the overall mechanical "Q" of the MEMS pair operated at resonance would be very high and the high frequency electrical drive requirement quite low as long as the MEMS mechanical oscillator was not operated at excessive displacement amplitudes. So called Microresonators have feature sizes of about one micron by 5 or 6 microns. Macroresonators have feature sizes on the order of several millimeters and have mechanical "Q"s that are generally much higher but have generally lower resonant frequencies due to the increased mass of the suspended platform.

If this kind of device is combined with a torsional oscillator of the same general type, the tips on a torsional oscillator would move up and down while the platform of the linear resonant motor would move back and forth. If both systems are operated at the same resonant frequency but the torsional oscillator was timed so as to be 90 degrees out of phase with the linear oscillator the relative motions between the linear platform motion and the paddle tips of the torsional oscillator located just above the edges of the platform would move in the "Push-Slide-Pull-Slide" manner needed to become a Casimir power producing machine. The spacing between the paddle tips of the torsional oscillator and the platform of the linear motion motor would have to be carefully controlled by servo loops so that the two sets of parts on the Casimir MEMS device did not collide and "Crash". External to the Casimir MEMS device, but probably on the same wafer would be the high frequency driver electronics, the charge pump fast recovery diodes, the required distance controlling servo and associated feedback circuitry. In effect this would constitute an I.C. chip that provides power to operate itself plus powering some external circuitry. It would only require external power for a fraction of a second, long enough to start the Casimir MEMS device operating. The spacing between the two sets of moving members on the MEMS device would still have to come within 20 nanometers or closer at the point of closest approach in order for the Casimir forces to be significant enough to overcome all other loss mechanisms.

Fabrication of such Casimir MEMS devices with the required on chip control and drive electronics could probably be fabricated by the Cornell Nanofabrication Facility (CNF), (Dr. Noel C. McDonald's group in the E.E. Dept.) at Cornell University, or Sandia National Lab. in Albuquerque, NM., as well as a few other places that can do MEMS work. There are a number of themes and variations on the MEMS type devices related to the mechanical resonator design structures that would do the same basic "Push-Slide-Pull-Slide" function required by the basic patent concept.

In the large size scale, embodiment, (See Figure #4) two electrically conductive disks, roughly one meter in diameter, one rotating at high speed (the rotor) and one stationary are placed in very close proximity to each other and have their faces parallel to one another. Both disks have mirror finished surfaces on the ~ outer third of their diameters with a special small corrugated finish running radially. The stationary disk (the stator) is also cut into two halves across a diameter that are electrically insulated from each other. The split stationary disk pair (the split stators) also are slit, with a thin cutter, radially into an even number of segments about one third the way in from the outside edge (over the mirror surface region). The radial corrugations have their convex faces centered on the center of each slit segment. These radial segment mirrors located on the outer third of the split stator disk are arranged so they can vibrate like tuning fork tines in and out of the plane of the face of the disk. Each segment is arranged so it will vibrate at its natural resonant frequency out of phase with each of its neighboring tines, (i.e. - tines 1,3,5,7,9,11,etc. are moving toward the rotor, while tines 30,32,2,4,6,8,etc. are moving away from the rotor. All the tines are individually tuned so that they all have exactly the same natural resonant frequency by adjusting the mass of the back of the tine and the spring constant of the thinner flexing hinge near the root of the tine or the "flower petal".

Each split stator tine or "flower petal" only moves a very small distance, even at the tip of the tine, a distance measured in, like one or two microns. This makes the tines very "stiff" mechanically with the point of greatest flexure near the root of the tine. The mechanical resonant frequency, the spring - mass time constant, is at a high frequency, on the order of 5 to15 Kilohertz or so. The mechanical resonant "Q" is kept as high as possible. This means that the losses due to internal frictional properties of the stator segment material be kept as low as possible. For this and other reasons, the entire device is operated in a high vacuum (like 10^{-6} Torr or better). In a vacuum environment the "flower petal" like segments on the stator halves that are vibrating a tiny amount at a high frequency will have no aerodynamic drag that would lower the effective "Q" of these multiple tuning fork like tines. The outer parts of each "flower petal" like tine are stiffened on the back side so that it only flexes near the root of the tine, near the inside end of the thin radial slot. With an even

number of tines vibrating out of phase with their nearest neighbors, the "clamping loss" to the bulk of the split stator should be quite low which also improves the mechanical "Q" of this complex vibrating structure.

The outer third of both the rotor and the two stator halves have a very high qual   mirror surface with a special "figure" or astigmatism that is in the form of radial corrugations that are in the form of elongated raised islands that are only about one micron above the base plane "flat" with gentle sloping sides. These raised islands coincide with the center of the every other "flower petal" on the two stator segments and have half the number of "islands" on the rotor as on the stator halves. As the rotor turns with respect to the stator halves, the rotor and stator islands will move in and out of phase with respect to each other. (See Figure #5a, 5b, 5c & 5d). Every other vibrating stator "flower petal" with its island, will be at the point of closest approach to a rotor island at the same time and in between a pair of rotor islands, (facing a valley), at the next instant in time, (½ cycle later). The timing diagram (Figures #5 a,b,c,d) will make this clear.

The timing of the rotor RPM is matched to the stator "flower petal" mechanical resonant frequency so that the mechanical resonance of the stator "flower petals" is reinforced by the periodic electrostatic attraction and the much stronger Casimir force at the close spacings required to make the machine work. Since the electrical output coming directly from the rotor - split stator variable capacitor combination produces high frequency AC, superimposed on a DC voltage level, the high frequency component is used to drive an electrostatic synchronous motor that is the drive motor shafted directly to the rippled mirror surfaced rotor with suitable power conditioning electronics.

There are a number of unique properties of the electrostatic drive motor that is shafted to the rippled rotor mirror assembly. Since a high RPM rotor with ordinary ball or roller thrust bearings could not possibly hope to allow the rotor to run as close to the split stator plates as is required to get within the Casimir useful distance range (20 nanometers or less), without "Crashing", a special set of shaft end bearings are needed.

As one of the additional claims required by this large scale embodiment of this device, superconducting, liquid nitrogen cooled cryogenic (YCBO - HTS) hybrid bearings are required at both ends of the electrostatic motor, rippled mirror rotor assembly. These kinds of bearings are well developed by several institutions. One group at the University of Houston, the "High Temperature Superconductor, (HTS) Levitation Applications Laboratory", headed by Dr. Wei-Kan-Chu has produced high RPM, and fairly high load bearing HTS bearings that have fantastic vibration isolation capability. These HTS bearings also have very low (near zero) frictional loss which is very important to this application. Since this entire device must be operated in a high vacuum for both aerodynamic drag and electrical insulation reasons, as well as the thermal insulation required to keep the YCBO - HTS bearings at liquid nitrogen temperatures, it makes sense to encase the entire Casimir machine in a cold walled vacuum tank which is also a vacuum dewar for liquid nitrogen that surrounds the entire machine. This would also help maintain the high quality vacuum inside the entire device, a cryopump for condensable vapors.

The liquid nitrogen consumption rate should be quite low, about like a few hundred liter, super insulated liquid nitrogen dewar is now. Excess power would also be used to supply the small amount of power needed to maintain the high vacuum in the Casimir machine cold walled vacuum tank. Using a small "Vacion" type Titanium, Penning discharge vacuum pump, in addition to the cryogenic, cold walled vacuum tank, the vacuum pumping power requirements should be trivial. The largest ancillary power requirement would be a small nitrogen liquefier to recover the boil off LN2 gas so that the system would be totally self sufficient. The only other piece of external power equipment needed would be an automobile type storage battery needed to restart the machine in case of a safety "SCRAM" from a severe shock or heavy low frequency vibration. This would assume that the machine has been filled with LN2 and is under vacuum in the first place. This initial vacuum pump down and LN2 fill and cool down would require perhaps a day or so to get things operating for

the machine has been filled with LN2 and is under vacuum in the first place. This initial vacuum pump down and LN2 fill and cool down would require perhaps a day or so to get things operating for the first time and get the HTS bearings levitating and bring the rotor up to speed for the first time from a dead warm stop. This would require external power in the few kilowatt range for a little while plus the required LN2 to cool off the entire machine and fill the dewar jacket with LN2.

I would envision the machine as having the rotor assembly operate on a vertical axis and the machine housing, LN2 dewar and all, well isolated from room and floor vibrations. The fast response time distance measuring and controlling servo loops needed to maintain the correct Casimir required spacing between the rippled mirror face of the rotor and the split stator mirrors with the vibrating "flower petal" tines would use the STM or AFM sensors and the piezoelectric actuators combined with stepping motors to position the close spaced parts at the correct distances without "Crashing" the machine. At distances like 5 to 20 nanometer spacings, the typical rigid structures as used for optical benches are only a starting point and one has to depend on continuous, active measurement and control of the required spacings between the moving and stationary mirrors. Vibration and shock sensors located on the machine isolation supports can be used to actuate fast acting safety devices to quickly increase the spacing between the rotor and split stator mirrors by jerking back the split stator mirror assembly away from the rotor before the shock can cause a "Crash" between the moving rotor and the split stator mirrors. This is the only vibration and shock sensitive part of the entire system, but it must be well protected. Jerking back the split stator mirror assembly from the rotor mirror by a few millimeters, would temporarily stop the machine from producing any power and it would start to slow down and drop out of synchronization. This would require a restart sequence to begin by using a little external power from the automobile battery to bring the rotor speed up to sync with the vibrating "flower petals" on the split stator and then slowly inch the split stator assembly forward until it is within the Casimir distance range again to the rotor and the machine would again begin to produce output power. Such a shock induced protective "SCRAM" would probably require several to tens of seconds to recover and again produce full output power. The power drain on the automobile restart battery would be trivial.

Please read the related paper that discusses the limitations on the extent of the Casimir force at very close spacings.

George F. Erickson - August 6, 1997

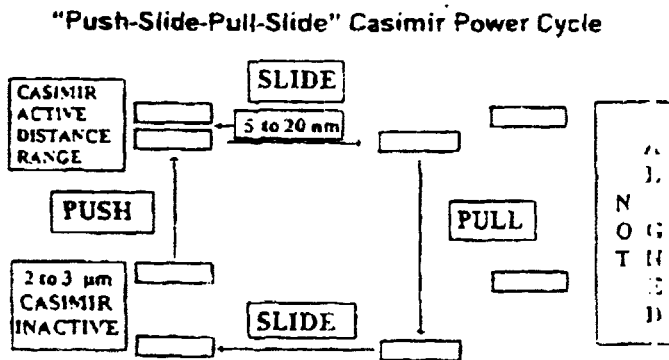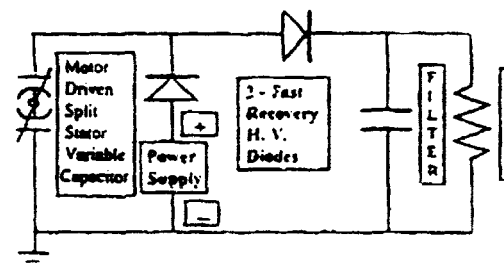Figure # 1

"Push-Slide-Pull-Slide" Casimir Power Cycle
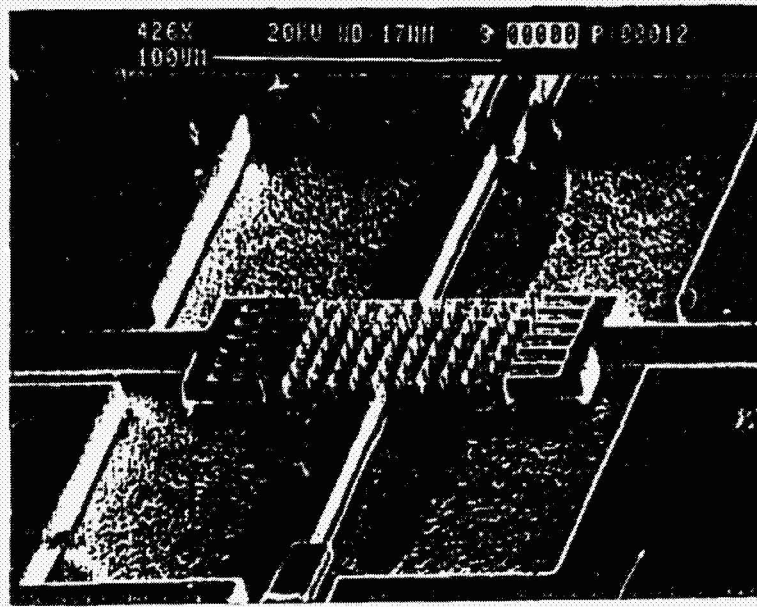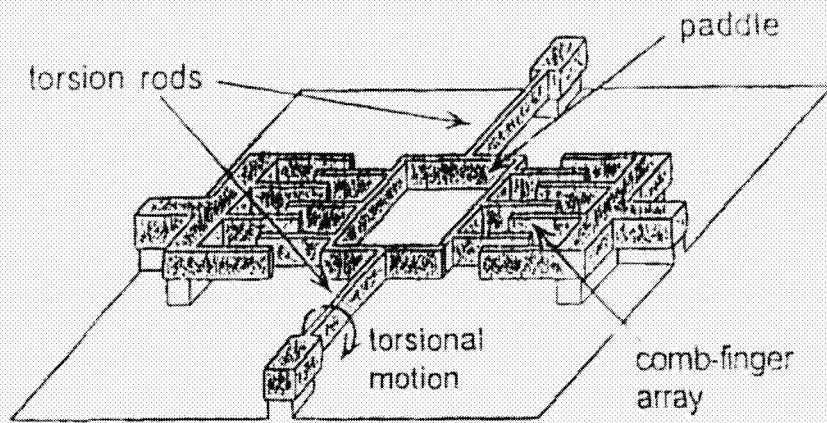
Figure # 2

Circuit Diagram of the "Charge Pump"

Fig. 3. Simple torsional microresonator. The microresonator shown in the SEM micrograph consists of beams of width ≈ 0.7 μm and height ≈ 5–6 μm.
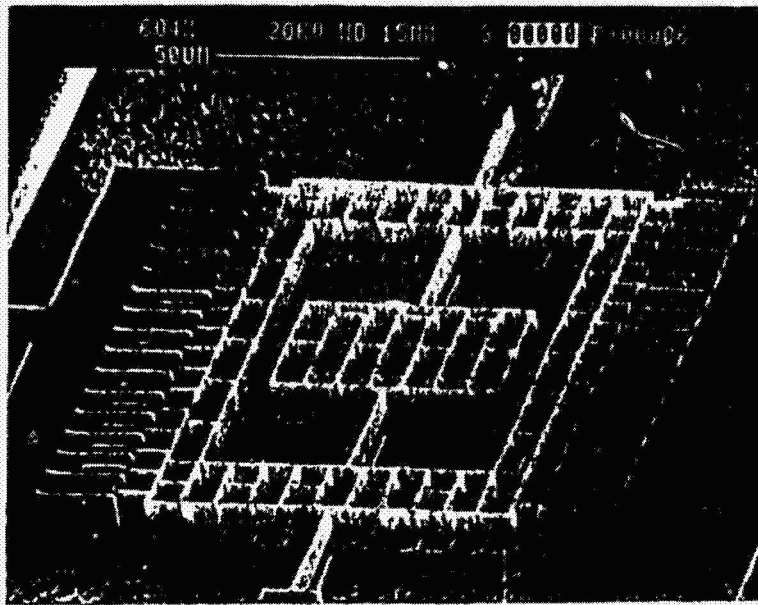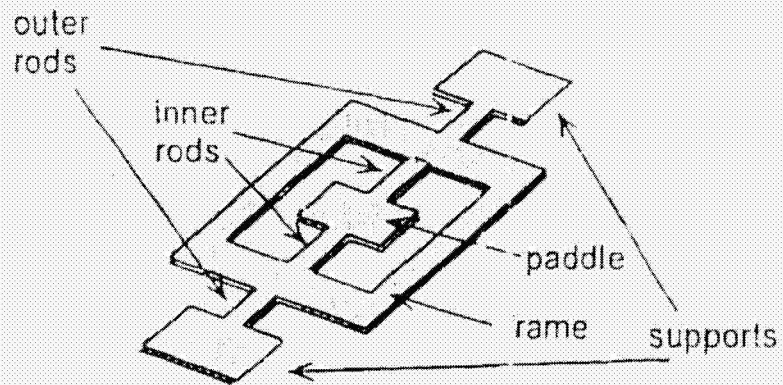
Fig. 3 Continued—Compound torsional microresonator. The compound microresonator of the micrograph also consists of beams of width ≈ 0.7 µm and height ≈ 5–6 µm.

Super Insulated Vacuum Dewar Jacket

YBCO – HTS Upper Bearing

LN2 Tank

Servo Actuators
And Sensors

Flex Hinge

"Flower Petal"

Split Stator

Power
Output

Mirror Surfaces

Casimir Active Region

Charge
Pump

High Strength – Light Weight
Composite Rotor

Insulated Shaft Coupling

Rotor Islands

HF/HV Synchronous
Electrostatic Motor

Split Stator Butterfly Variable Capacitor

YBCO – HTS Lower Bearing

HF/HV Synchronous Power Supply

Figure #4

Figure # 5a

Phase Angle = 0° "PUSH" Stroke # 1

Vibrating Stator "Petals"

2 to 3 microns

5 to 20 nanometers

Rigid   Rotor   Motion→ Islands

Figure # 5b

Phase Angle = 90° "SLIDE" Stroke # 2

Vibrating Stator "Petals"
Direction of motion of the moving Stator "Petals"

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Down | Up | Down | Up | Down | Up | Down |

Rotor to Stator spacing is about 1 to 1.5 microns

Rigid   Rotor   Motion→ Islands

Figure # 5c

Phase Angle = 180° "PULL" Stroke # 3

Vibrating Stator "Petals"

2 to 3 microns

Rigid   Rotor   Motion→

Figure # 5d

Phase Angle = 270° "SLIDE" Stroke # 4

Vibrating Stator "Petals"
Direction of motion of the moving Stator "Petals"

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Up | Down | Up | Down | Up | Down | Up |

Rotor to Stator spacing is about 1 to 1.5 microns

Rigid   Rotor   Motion→ Islands

A PROPOSED LIMIT ON THE EXTENT OF THE CASIMIR FORCE AT VERY CLOSE SPACINGS

The Casimir force, stated in a simplistic way, states that when two mirror smooth (preferably metallic) surfaces are brought together, parallel, to within very small distances, under a few microns to a few nanometers or less, a very powerful attractive force comes into play that increases at an inverse FOURTH power rate. As an example, at a plate separation of 20 nanometers the force is ~0.08 atmospheres, or 1.176 PSI, (one sea level atmosphere equals 14.7 PSI). At a plate separation of 10 nanometers (nm) the force is now sixteen times greater or 1.28 atmospheres or 18.8 PSI. Taking this to a five nanometer (nm) plate separation, the force is now 20.48 atmospheres or 301 PSI. If one cares to take this effect down to 2.5 nanometers or 25 Angstrom units, the force would be 4096 times larger than at 20 nanometers or 0.08 x 4096 = 327.7 atmospheres or 4317 PSI !! If one decreases the spacing another factor of two, down to 1.25 nm or 12.5 Angstroms and allow the force to increase another factor of 16, the force acting on the mirror plates v cld be 5243 atmospheres or 77,070 PSI !! Going to still smaller spacings, say, 6.25 Angstroms the force would be 83,886 atmospheres or 1,233,125 PSI. This is clearly ridiculous, as one is beyond the structural strength limits for all known materials and into the range where carbon would transform into diamond if heated. Clearly there is another limit that is coming into play at very small separations or everything in the world would collapse into some ultra high pressure phase modification.

What I am proposing is that when the Casimir force requires the invoking of wavelengths beyond the ultraviolet and into the X-ray region, the mirrors, whatever they are made of, start to become transparent to the radiation they are supposed to exclude. At this point the plate separations become "fuzzy" and probably lossy as the soft X-ray radiation begins to penetrate the plates and would be attenuated, if it could exist at all. This would then provide a high frequency or short wavelength cut-off that is very much lower than the quoted 10^{-33} cm Planck wavelength cut-off limit. The short wavelength, penetrating radiation, would pass through the plates from both the inside and the outside of the plates and would hence not produce much if any radiation pressure, either internal or external to the mirror interferometer cavity. This would also tend to explain why dielectric cavity boundaries or "mirrors" tend to have Casimir forces that are about one order of magnitude less than metallic mirrors since the dielectric "mirrors" are transparent to much of the radiation below the ultraviolet region of the spectrum. Since radiation pressure only acts on a surface if it is either reflected or absorbed and does not act on a surface that is transparent to that radiation, the dielectric "mirrors" are transparent to and

hence unaffected by the virtual radiation pressure. It is probably largely the ultraviolet and parts of the infrared spectrum that contribute to the Casimir force on dielectric "mirrors". Since an ultraviolet photon contains much more energy than an infrared photon, the UV portion of the spectrum up to the X-ray transmission limit I am postulating, probably contributes most of the remaining Casimir force on dielectric "mirrors".

This means that the Casimir force has a reasonable force upper bound and does not increase at the inverse FOURTH power rate much beyond this proposed X-ray transmission limit. This would mean that at distances of around 100 Angstroms or a little less, the Casimir force vs. distance curve would cease to rise at the incredible inverse FOURTH power rate but would gradually flatten out and become nearly a constant value at very close distances. These forces would then be well within the structural limits of ordinary materials. Most probably on the order of several hundreds to a few thousand PSI at even the closest of interferometer spacings, even with metallic mirrors.

As of June 27, 1997 we are having some experimental parts fabricated that hopefully will provide a few experimental points in that part of the Casimir force vs. distance curve that will fall into that region where the X-ray transparency limit would be acting. These will consist of hardened steel tensile bars made from 440C stainless steel that have optical flat faces of ~ ten square cm. cross sectional area, that are optically contacted and are held together by the Casimir force. These tensile bars are only held together by the Casimir force in the center section. They can easily be slid (or sheared) apart, just like any contacted optical flats, but fairly large forces will be needed to pull the optically contacted flat faces apart as a pure tensile force. These optically contacted flats will then be pulled apart in a tensile testing machine and the force per unit area needed to defeat the Casimir force will be noted. These two piece tensile bars should be reusable many times. This should provide a rough measure of the true, usable, Casimir force beyond the extreme limits posed by the "Planck cut-off" wavelength. At least these experiments should provide a few points in the proposed X-ray transparency region where the Casimir force vs. distance curve should flatten out. Several possible variations using these two piece tensile bars are proposed that might shed some additional light on the proposed X-ray limit suggested in this paper.
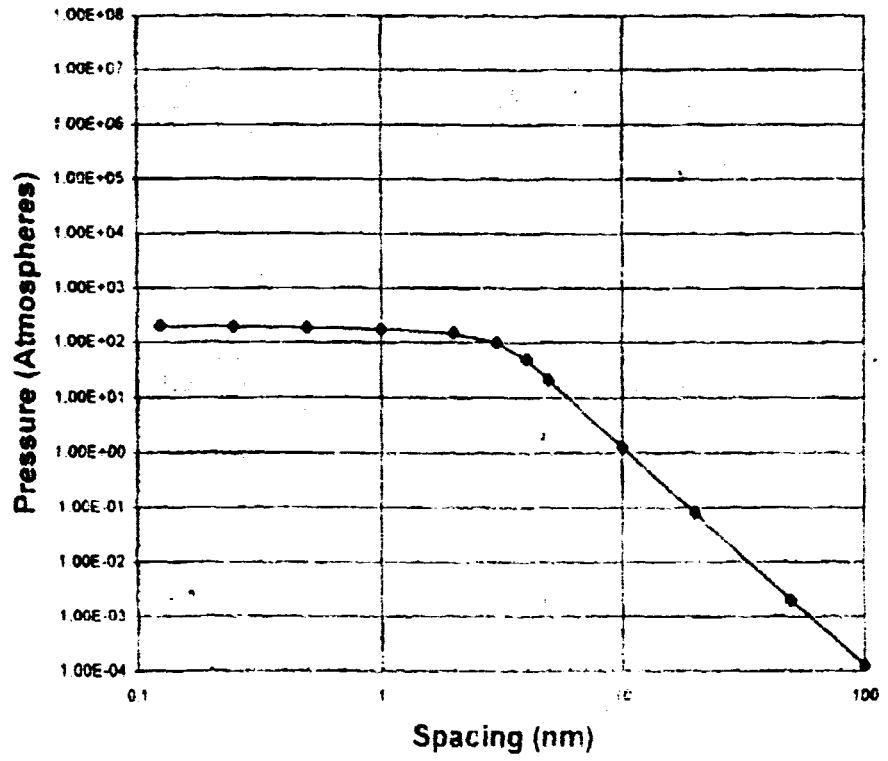
George F. Erickson - June 27, 1997
Los Alamos National Laboratory
P.O. Box 1663 - MS / G770
Los Alamos, New Mexico 87544

Casimir Presssure (Planck Cutoff)

Spacing (nm)
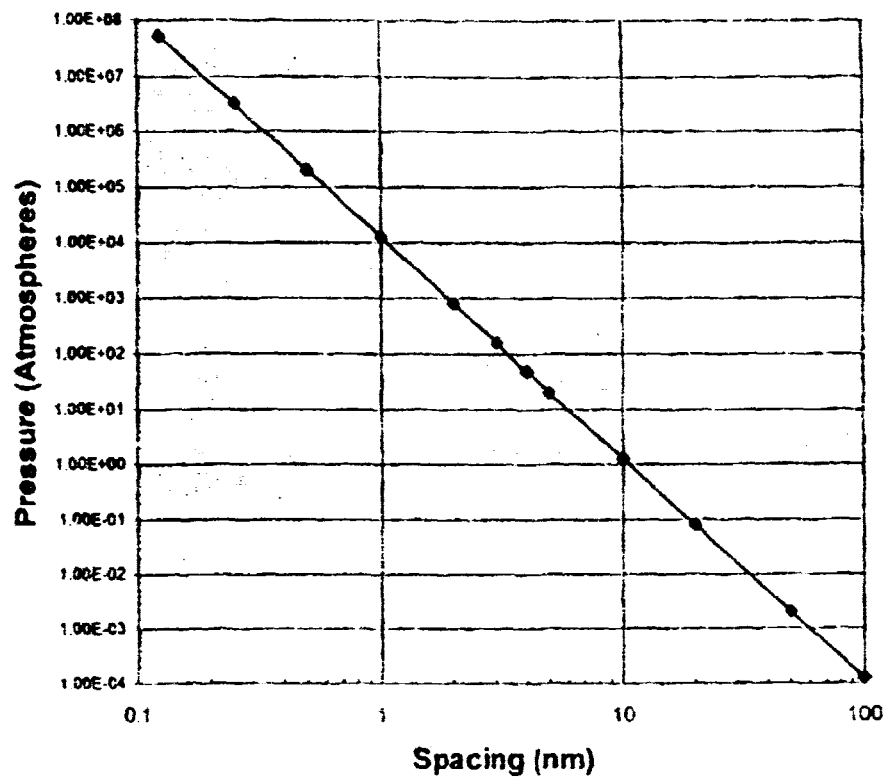
Estimated X-Ray Limit
of Casimir Pressure

Spacing (nm)

NEXT
DOCUMENT

Observational Search for Negative Matter
in Intergalactic Voids

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ABSTRACT:

Negative matter is a hypothetical form of matter with negative rest mass, inertial mass and gravitational mass. It is not antimatter. If negative matter could be collected in macroscopic amounts, its negative inertial property could be used to make an continuously operating propulsion system which requires neither energy nor reaction mass, yet still violates no laws of physics. Negative matter has never been observed, but its existence is not forbidden by the laws of physics. We propose that NASA support an extension to an ongoing astrophysical observational effort by da Costa, et al. (1996) which could possibly determine whether or not negative matter exists in the well-documented but little-understood intergalactic voids.

NEGATIVE MATTER:

Negative matter is a hypothetical form of matter with negative rest mass, inertial mass and gravitational mass. It is not antimatter, which has positive rest mass and inertial mass. Negative matter has never been observed, but, as I discussed in great detail in a previous paper (Forward 1990), its existence is not forbidden by any of the known laws of physics. Negative matter gravitationally repels both positive and negative matter. Thus, clouds of uncharged negative matter will not gravitationally clump to form stars and galaxies, but will disperse into empty space. Because of the negative inertial mass of negative matter, negative matter particles of opposite charge repel each other. Thus, a negative matter "electron" will not be pulled into a circular orbit around a negative matter "proton", but will be repelled into a hyperbolic orbit. As a result, clouds of negative matter ions will not even form into standard atoms. In contrast, negative matter particles with the same charge are attracted to each other. Depending upon the types of quantum mechanical restrictions that apply, this could lead to the formation of highly charged "bags" of quarks with exotic properties (Forward-1992).

If negative matter could be collected in macroscopic amounts, its negative inertial property could be used to make an continuously operating propulsion system that requires neither energy nor reaction mass (Forward 1990) and which violates no laws of physics including the Einstein General Theory of Relativity (Bondi 1957).

EVIDENCE FOR EXISTENCE OF NEGATIVE MATTER:

If negative matter is not forbidden by the laws of physics, then where is it? There exist clues that may point to one place where negative matter can be found--in the intergalactic voids. The clues were already strong in 1990 (see Forward 1990, especially pages 35 and 36), while a recent paper by da Costa, et al. (1996) makes the clues even stronger. Detailed discussions of the intergalactic voids can be found in de Lapparent, et al. (1986) showing the "foam-like" structure found in large-scale three-dimensional "maps" of the universe. The "bubbles" or "voids" in this "foam" are 100 million lightyears across (our Milky Way galaxy is a mere 0.06 million lightyears across). The voids are sharply defined by a large number of galaxies (Trimble 1987) that seem to lie on the surface of the bubbles. There are almost no galaxies in the voids, and those galaxies found there are very unusual, characterized by strong, high-excitation emission spectra.

In a previous paper (Forward 1990) I proposed an explanation for this "frothy" structure of the universe. The proposal was that the universe was initially formed out of nothing, with equal amounts of negative matter and positive matter. (This has the nice feature that the net mass of the universe is zero.) The regions of the early universe that started out with a slight excess of negative matter are now the regions containing the voids. The voids are full of negative matter particles trying to keep as far away from each other as possible, meanwhile pushing the positive matter particles to the surface of the voids where they gravitationally attract each other to form galaxies and stars. One way to test this hypothesis is to measure the effects of the gravity force generated by these voids on the visible matter nearby to see if the gravity force is positive, zero, or negative.

"WEIGHING" THE NEARBY UNIVERSE:

A matter density map of the nearby universe (see Figure 1) has recently been published by da Costa et al. (1996). The density map was generated from a three-dimensional map of the "peculiar" velocity of some 1300 individual field galaxies and 500 galaxies in clusters. The distances and peculiar velocities of each galaxy were obtained from a combination of radial Doppler redshift measurements and distance estimates (presumably based on brightness estimated from the galaxy type), adjusted to give a self-consistent velocity flow pattern.
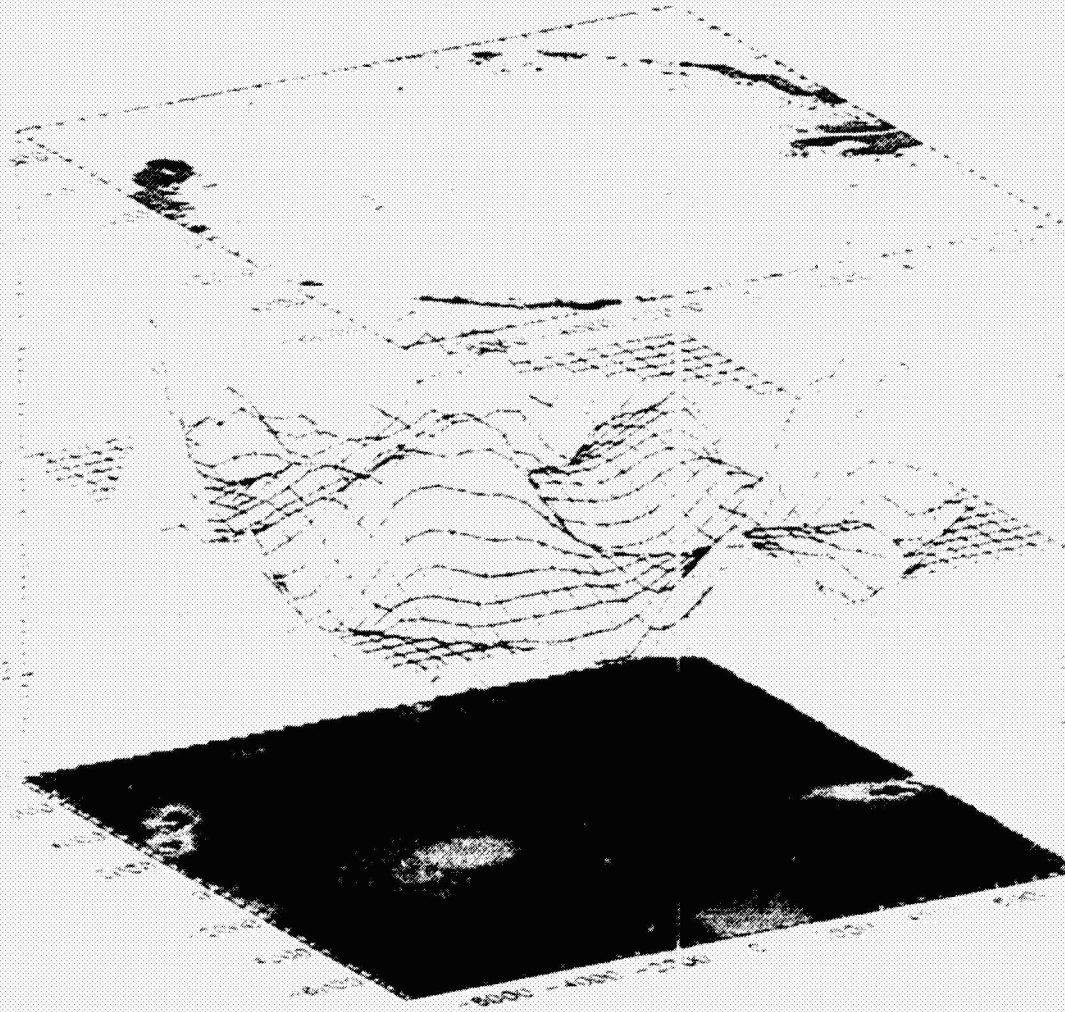
Fig. 1 - Matter density in the supergalactic plane with density contour intervals of δ=0.2. Surface density map with height proportional to δ showing compact positive overdensity regions and spheroidal negative underdensity regions.

The matter density map includes the density contributions of both the visible matter (the galaxies) and any unseen dark matter. The gravity forces due to the candidate matter density distribution are calculated. The gravity forces are then used to generate estimates for the velocities of the visible matter galaxies subjected to those gravity forces. The matter density map is then readjusted until a self-consistent solution is achieved. The resultant matter density map shows some interesting features: (a) The matter density map is characterized by positive matter overdensities which are compact and negative matter underdensities which are large in volume, have a roughly spherical shape, and have a high negative underdensity contrast. (b) The spheroidal voids have non-trivial negative density contrasts reaching δ=-0.6, which are comparable in magnitude to the more compact positive density contrasts which reach δ=+1.2. (c) Comparison with redshift maps suggests that the visible galaxies delineate real (very low matter density) voids in the matter distribution, rather than merely less luminous regions with normal matter density. These voids are separated by moderately low-density structures which correspond to the filamentary and wall-like structures observed in the galaxy distribution (da Costa, et al. 1996).

Although the matter density variations of the voids have been assigned negative values in Fig. 1, that does not mean the voids contain negative matter. The velocity field predictions would be the same if the matter density map had a constant value of matter density added to each point. This background matter density would only be observable in the velocity flow pattern of a much larger sample of the universe.

PROPOSED OBSERVATIONAL SEARCH FOR NEGATIVE MATTER:

It is proposed that NASA support an extension of the present program of da Costa, et al. (1996) to produce a larger, coarser, matter density map which includes near its center the region covered by Figure 1. This coarse matter density map should give an value for the total mass of a region containing one or more voids. Once this "background" matter density of the region is known, then using the more detailed distribution of Fig. 1, it should be possible to estimate the "absolute" matter density in the voids by subtracting the δ=-0.6 value of the voids from the coarse estimate of the positive background matter density. It is fully expected that the value finally obtained will be positive, although close to zero. If, however, a void is determined to have a significant negative matter density, then either there is negative matter in the voids, or there is a large underlying positive uniform matter density to the universe that is unobservable using peculiar velocity flow field maps. Either result is scientifically significant.

ACKNOWLEDGMENTS:

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NEXT DOCUMENT

Inertial Propulsion Plus/Device and Engine

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DEVICE DISPLAY ONLY

United States Patent [19]

Foster, Sr.

[11] Patent Number: 5,685,196

[45] Date of Patent: Nov. 11, 1997

[54] INERTIAL PROPULSION PLUS/DEVICE AND ENGINE

[76] Inventor: Richard E. Foster, Sr., 13849 Reed Ave., Baton Rouge, La. 70818

[21] Appl. No.: 683,051

[22] Filed: Jul. 16, 1996

[51] Int. Cl.⁶ F16H 33/20; B62D 57/04
[52] U.S. Cl. .... 74/84 R; 74/845; 180/7.1; 244/62; 244/172; 440/113
[58] Field of Search .... 74/84 R, 84 S; 180/7.1; 244/62, 172; 440/113

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Primary Examiner—Allan D. Herrmann

[57] **ABSTRACT**

Devices herein described utilize vehicles that are propelled, braked, and steered by means of a process called Inertial Propulsion Plus. This consists of a "power phase" to extend the weight(s) from the vehicle, alternated with a "null phase" to cancel out the return phase or stroke reactions. This process is made workable by selectively applying a pure external force derived from the pathway and opposing the movement of the weight(s) on the power phase. For non-travel-related applications, the inherent displacement can be harnessed by a treadmill or other ways for a power source to increase available power and reduce pollution.

7 Claims, 12 Drawing Sheets
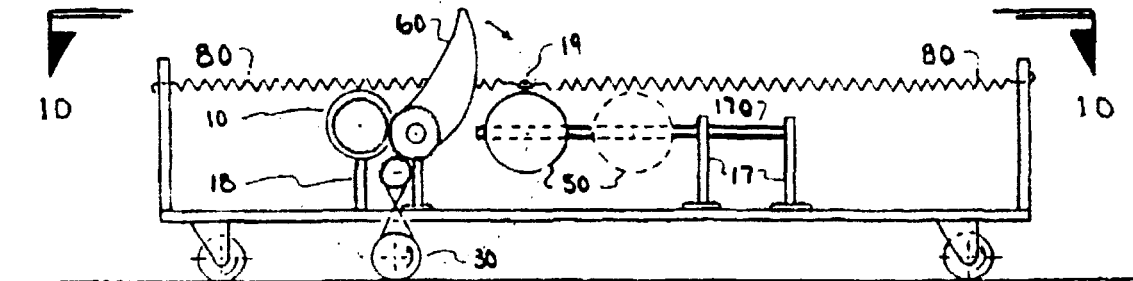
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Experiments to Explore Space Coupling by Specially Conditioned Electromagnetic Fields

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Abstract

Although the spacetime metric associated with gravitation can be distorted somewhat by electromagnetic influences (such as magnetic fields of stupendous strength) there is no strong interaction or coupling between ordinary electromagnetic (em) fields and those of gravitation because they are of a different essence and form. But if the fields associated with ordinary em radiation could be endowed with an essence and form similar to that which underlies gravitation, a much stronger coupling or interaction might be accomplished for propulsive use. This paper describes several ways of creating specially conditioned em radiation and, several ways that the fields associated with such radiation might interact with those associated with gravity or the vacuum's zero-point state.

Introduction

Space seems inert and empty but quantum field theory and stochastic electrodynamics views it as possessing vigor and vitality over scales of time and space that are too short for the material senses to perceive. A major contributor to such vigor and vitality are "zero point" energy (ZPE) fluctuations — innumerable electromagnetic energy pulsations of varying wavelength and frequency which manifest the energetics of the so called "vacuum electromagnetic zero-point field" (ZPF). Distributions of individual ZPE fluctuations are isotopic throughout undisturbed space and the spectral energy density of the ZPF is Lorentz invariant. Thus, the ZPF acts uniformly over bodies moving at constant speed, causing no net force. But the ZPF is not isotopic and Lorentz invariant in the accelerated frames of accelerating bodies, and Haisch, Rueda and Puthoff (1) have proposed that the inertia of bodies might be a consequence of spectral distortion of the ZPF in inertial frames of accelerating bodies and of a resisting em Lorentz force acting upon the bodies that arises from such distortion. One observed ZPF distortion is the Casimir force. Here, two parallel conducting plates placed closely together can be viewed as, either excluding ZPE fluctuations of longer wavelength from the region between the plates, or lowering their fluctuation frequency. Inward pushing forces, therefore, act upon the plates. In (2) Milonni associates a "radiation pressure" with each ZPE fluctuation, and views the Casimir force as caused by diminished radiation pressures associated with fewer (or lower frequency) ZPE fluctuations between the plates. And Scharnhorst (3) calculates that the velocity of light in such a region of reduced ZPE fluctuation density should be greater than light velocity in vacuo (unconfined space).

General Relativity allows gravitation to be described in terms of a "spacetime metric" which is associated with all cosmic distributions of matter throughout all time and space. And if Einstein's Correspondence Principle (which equates "gravitational" and "inertial" mass) is valid, perturbation of spacetime metric within a given region should not only change gravitational influences within the

perturbed region -- but the inertias of masses as well. Although no means have yet been found for perturbing gravity or the spacetime metric associated with it for propulsive use, Alcubierre (4) has shown a solution to the equations of General Relativity that allows development of enormous flight speed if an accelerating vehicle can "warp" spacetime metric. Expansion of the spacetime metric behind the ship "pushes" it in the desired direction, while contraction of spacetime metric ahead of it adds to impulsion by "pulling" the ship where it wants to go. Spacetime metric throughout the ship is warped into a "flat" configuration in this idealized example. Gravitational influences and inertia are, thus, zero within the ship and it undergoes unlabored motion while rapidly accelerating to (and decelerating from) speeds that can be enormous with respect to earth. Alcubierre points out that such favorable spacetime warping would require negative energy densities in the vicinity of the ship. And negative energy densities could be associated with reduced ZPE fluctuation energy density -- such as that existing between two closely spaced Casimir plates.

Gauge Field Symmetry and Form

Millis (5) notes that electromagnetism is a logical choice for creating an acceleration-inducing force, in that it is related in some degree to spacetime and gravity and is a technology in which we are fairly proficient. And Holt (6) has proposed the possibility of generating coherent patterns of em energy to accomplish field interactions that reduce or amplify gravitation in the vicinity of a hovering or moving ship. Unfortunately, patterns of ordinary em energy do not appear to interact intimately enough with gravitation. For although the spacetime metric associated with gravitation can be distorted somewhat by em influences (such as magnetic fields of stupendous strength) enormous levels of ordinary em energy appear to be required for such distortion. And this may be because the fields that underlie gravitation and ordinary electromagnetism are of different essence and form.

In this respect, the behavior of all matter and radiation can be described in terms of "gauge" fields, with the sources of such fields being conserved quantities. If the essence of the generated gauge field is different from the essence of its source, the field is "abelian". If the essence of the generated field and its source are identical, the field is "nonabelian". Nonabelian fields are, therefore, sometimes viewed as being generated by themselves. Gauge fields that describe ordinary em radiation and electrical attraction and repulsion of electrons and protons within atoms and molecules are abelian; while nonabelian fields are associated with processes such as weak and strong interactions within atomic nuclei. The more intricate configurations of nonabelian fields result in higher internal symmetries, with the Abelian fields associated with ordinary em radiation being of relatively modest U(1) symmetry, while the nonabelian fields associated with weak and strong interactions within nuclei being of SU(2) and SU(3) symmetry respectively.

If a nonabelian field underlies gravitation -- as suggested by field theorists such as Yang (7) -- significant interaction between nonabelian gravitational fields and Abelian electromagnetic fields is not likely. But one of us (Barrett) has shown the possibility of transforming ordinary em fields into specially conditioned em fields of nonabelian form and higher symmetry (8). And J postulates the possibility of such fields coupling globally with the nonabelian gauge fields that may be associated with spacetime/gravitation through a quantity that may be common to each -- the "A vector potential."

Does the ZPF Include a Nonabelian Field?

The preponderance of current scientific opinion is that gravity is one of 4 fundamental forces of nature. But investigators such as Sakharov and Puthoff (9) contend that gravity is not a fundamental force - but one that arises from the continual em interplay between all the charged particles of the universe and all the ZPE fluctuations of the ZPF. Here, the ZPF is usually described as a random electromagnetic field that is not intrinsically different from other electromagnetic fields -- especially when in its isotopic, Lorentz invariant configuration. The ZPF in such a configuration can therefore be considered an abelian field of U(1) symmetry. But if a nonabelian field underlies gravitation (as proposed by Yang) and gravitation is a consequence of the ZPF (as proposed by Sakharov and Puthoff) the ZPF, itself, could conceivably contain a nonabelian component of higher symmetry than U(1). And perhaps such a nonabelian field component would be manifested in accelerated frames -- where spectral distortion of the ZPF occurs. If so, there is the possibility of the inertia of accelerated matter being a consequence of both abelian and nonabelian gauge field interactions -- with these interactions - - as suggested by (1) being associated with: (a) the charged substructure of accelerated matter, and (b) the spectrally distorted ZPF in the matter's accelerated frame.

Ordinary and Specially Conditioned EM Radiation

Although even the most complex combinations of frequency and amplitude modulation do not transform ordinary em fields into nonabelian fields of higher symmetry, (8) and (10) show that such a transformation can be accomplished by modulating the polarization of em wave energy radiated from antennas or apertures of RF or laser transmitters, or by tuning the frequency or wavelength of em waveforms to the toroidal geometries thru which the cause of the waveforms -- alternating current -- moves. These two methods increase em field symmetry from U(1) to SU(2) and results in nonabelian gauge fields with ability to couple globally with fields of similar form through the action of something that may be common to each -- the A vector potential. Thus, if nonabelian gauge field configurations with SU(2) components are associated with gravitation or the ZPF, there should be a possibility for modifying gravitational or ZPF influences within specially conditioned beams of em radiation
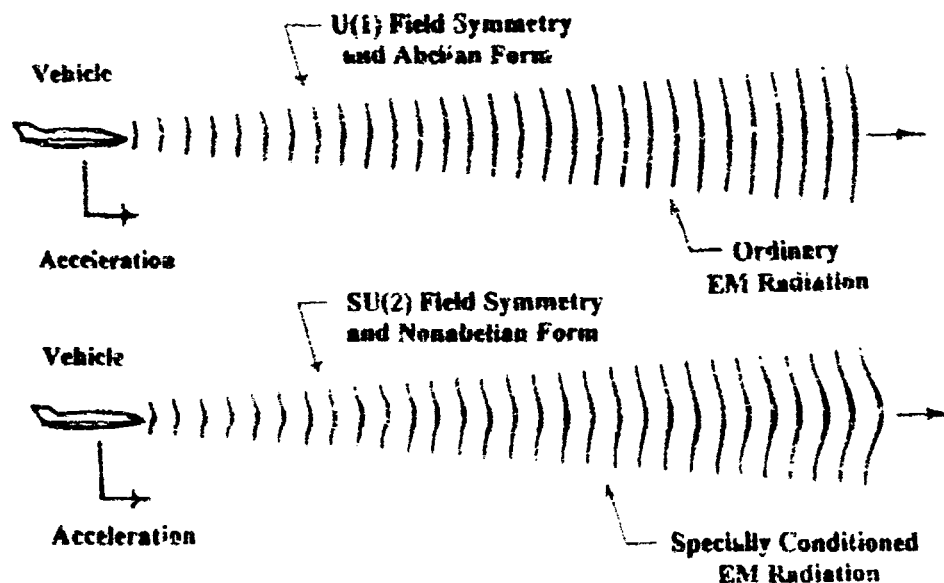

Figure 1 - Electromagnetic Radiation Comparison

The propagating speed (c) of electromagnetic disturbances within a given region of empty space is determined by the electrical permittivity and magnetic permeability of the vacuum through which they move, and throughout that region since ordinary em fields do not intimately interact with spacetime metric, electrical permittivity, magnetic permeability, and the speed of light in vacuo remain unchanged. Wave fronts within ordinary em beams therefore propagate as planar or spherical disturbances at constant c, as shown in Figure 1. However, if polarization modulated em beams interact with spacetime metric, permittivity, permeability and wave front speed wiu .^ changed within specially conditioned em beams -- and the em wave fronts will propagate as non-planar or non-spherical disturbances at variable c within the beams.

Expanded Maxwell Equations for Specially Conditioned Em Radiation

Ordinary em emanations are solutions to Maxwell's equations. But the U(1) field symmetry associated with them is lower than the SU(2) symmetry of specially conditioned em emanations. Electromagnetic emanations of SU(2) field symmetry must, therefore, be solutions to Maxwell equations of more expanded and symmetrical form. Barrett (8) has derived such expanded Maxwell equations, which are shown in Figure 2. Maxwell equations of more expanded and symmetrical form require additional terms that make the equations more symmetrical with respect to electric and magnetic phenomenon. These additional terms involve the coupling of electric and magnetic fields through the action of the A vector potential. And because the dot and cross products within the terms that include the A vector potential obey the commutation relations of nonabelian algebra and quantum mechanics, they are never equal to zero if SU(2) phenomena are present. The additional terms associated with specially conditioned em radiation are seen to be multiplied by the mathematical quantity (i). Viewing i as an operator that rotates quantities 90 degrees with respect to two other coordinate directions (rather than as the square root of minus 1.0) enables actions involving A vector potentials to be visualized as occurring in directions orthogonal to those in which ordinary em field disturbances move. Thus, specially conditioned em radiation involves actions that unfold upon our familiar spacetime plane of existence and also, actions that take place in orthogonal directions as well. And it is speculated that such orthogonal action (which would be invisible to ordinary observation) is that which could conceivably warp spacetime metric or cause spectral distortion within the ZPF.
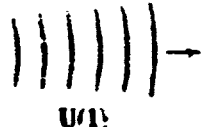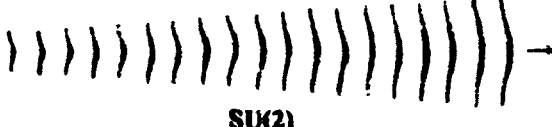
	Ordinary EM Radiation	Specially Conditioned EM Radiation
	U(1)	SU(2)
Coulomb's Law	$\nabla \cdot E = J_o$	$\nabla \cdot E = J_0 - iq(A \cdot E - E \cdot A)$
Ampère's Law	$\dfrac{\partial E}{\partial t} - \nabla \times B + J = 0$	$\dfrac{\partial E}{\partial t} - \nabla \times B + J + iq(A_0 E - E A_0) - iq(A \times B - B \times A) = 0$
Gauss's Law	$\nabla \cdot B = 0$	$\nabla \cdot B + iq(A \cdot B - B \cdot A) = 0$
Faraday's Law	$\nabla \times E + \dfrac{\partial B}{\partial t} = 0$	$\nabla \times E + \dfrac{\partial B}{\partial t} + iq(A_0 B - B A_0) + iq(A \times E - E \times A) = 0$

Figure 2 - Maxwell Equations

A means of creating polarization modulated em radiation of SU(2) symmetry and nonabelian form is described by Barrett in (8) and shown in Figure 3. Ordinary input em wave energy is seen to be divided into three fractions. One fraction is orthogonally polarized (has its polarity rotated 90 degrees) and phase modulated. Another fraction is expended in accomplishing the phase modulation of the polarization rotated wave energy. The remaining fraction of the input wave energy is then combined with that of the polarized and phase modulated wave energy at a "mixer", and emission of specially conditioned em radiation with continually varying polarization with respect to time results. If a fraction of input wave energy (beyond that dissipated by circuit resistance and reactance) is expended in accomplishing phase modulation, the electric and magnetic field intensity associated with polarization modulated radiation can be less than for ordinary em radiation for a given input power. But energy conservation requires that expended energy not truly vanish, but be transformed into another form. And one possibility would be increased A vector potential field intensity within the emitted radiation. If so, significant polarization modulation could significantly diminish electric and magnetic field intensity while increasing A vector potential intensity for coupling with the A vector fields that may be associated with spacetime metric or gravitation.
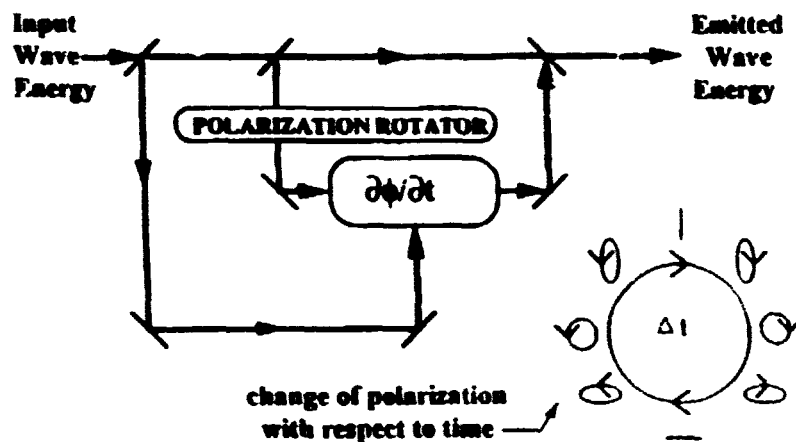
Figure 3 - Polarization Modulation

Figure 4 shows paths traced out by the "arrow" of the electric field vector of polarization modulated radar or laser radiation after the emitted radiation has traveled 50 and 500 wave lengths from the emitter. A phase modulation frequency that is 0.1 the frequency of the input waveform is used in this example. It is not obvious what portions of the em spectrum are most appropriate for interacting with spacetime metric/gravitation or the ZPF by means of polarization modulated radiation. Nor is it known what degree of polarization modulation would maximize the interaction. For a given input power, polarization modulated radiation can, of course, be focused into em beams with the narrowest width and highest intensity with laser systems, while the broader beamwidths of radar/RF systems enable a greater volume of space to be affected. Polarization modulation of both laser and radar systems is therefore being explored, and increasing amounts of modulation -- up to the highest achievable with modified hardware -- investigated.
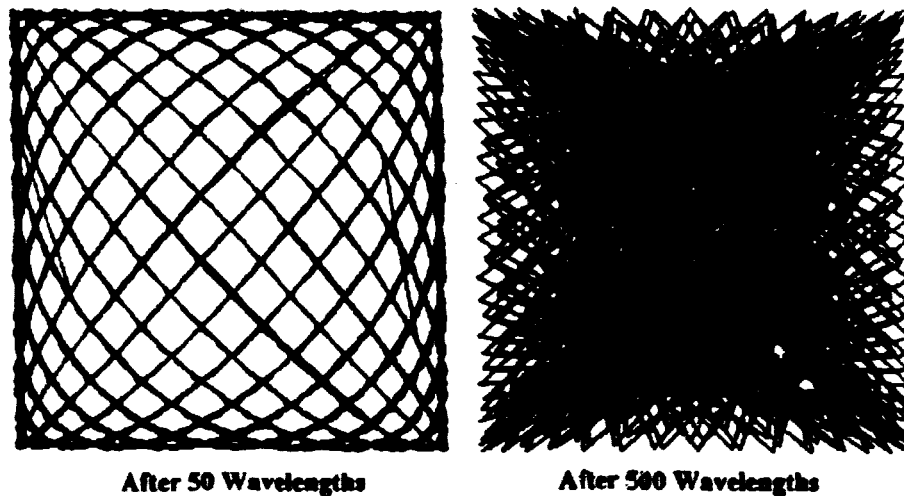
After 50 Wavelengths   **After 500 Wavelengths**

Figure 4 - Polarization Modulation

Vector Potential Wave Patterns

Specially conditioned em fields which consist almost entirely of A vector potential wave patterns can also be created, as described in (10), by flow of alternating current through a toroid with single windings. The resulting magnetic and electric fields to not extend significantly outside the toroid, but its geometry and the alternating current flow produces overlapping A vector potential patterns which extend outward from the toroid over significant distances - - as shown in Figure 5. The over lapping patterns combine into "phase factor" waves which represent disturbances in A vector potential. The pattern of these disturbances -- as shown in Figure 6 -- become almost spherical in shape at distances from the toroid of the order of its diameter or greater. At the present time, it is not known whether the phase factor waves are standing waves or waves that propagate at non-zero speed.
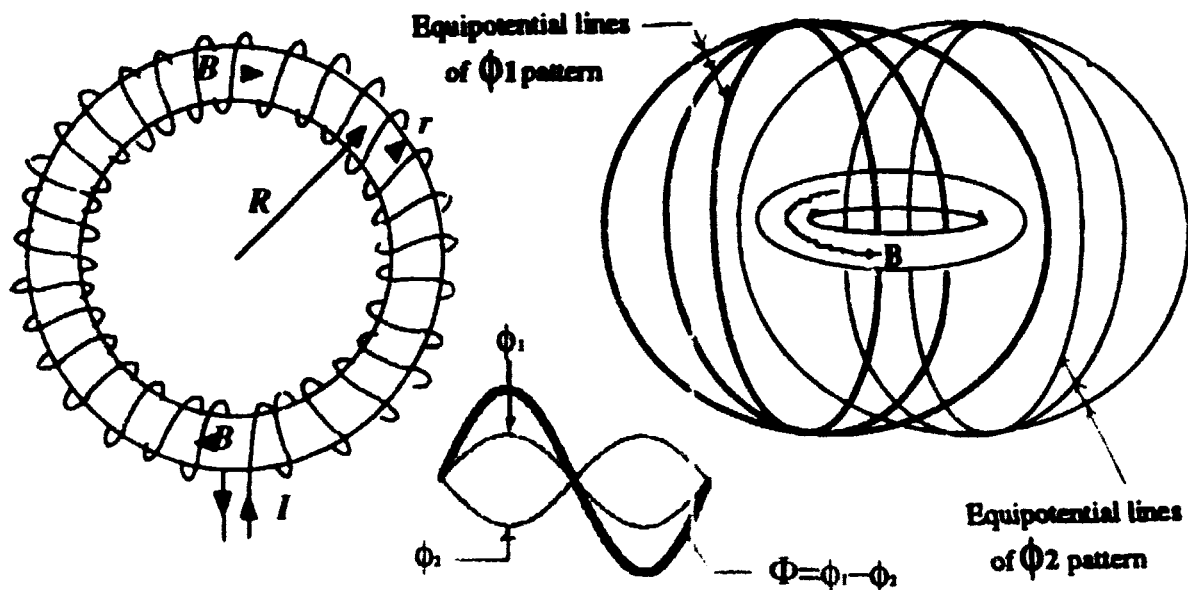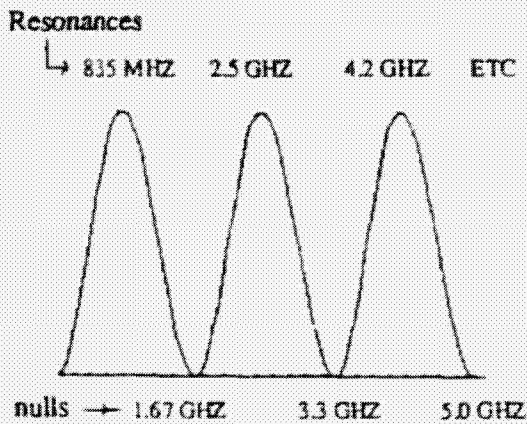

Figure 5 - Toroid Antenna
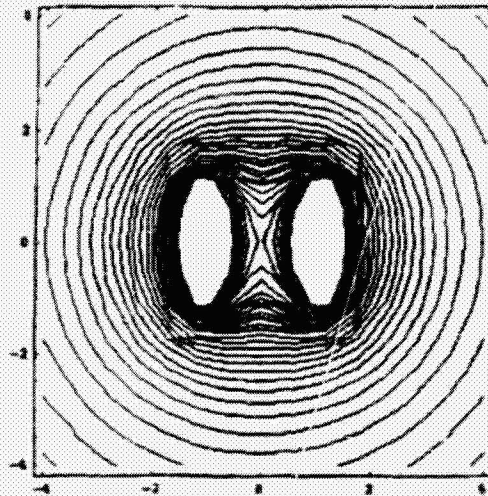
Figure 6 - A Vector Potential Patterns

The maximum disturbance in A vector potential occurs as phase factor wave intensity peaks at the various resonant frequencies - - where A vector potential patterns are exactly out-of-phase. Resonant frequencies for toroids with single windings occur in the RF/Microwave range, being determined by toroid geometry and propagating speed of the alternating current. Figure 6 shows that such resonances occur at different ac current frequencies for a given toroid geometry and current speed. And interactions with spacetime metric/gravitation or the ZPF would be expected to be the most intense at the various resonant frequencies (if an A vector potential field underlies the essence of gravitation or the ZPF).

Electrical Power Needs

It would be desirable that specially conditioned em beams used in operational field propulsion systems not require significantly greater electrical power than that required by powerful radar and laser systems in use or under development for military aircraft today. But although significant electrical power is likely to be required for generation of specially conditioned em radiation, such power would be invested primarily in creation of intense A vector potential disturbances -- not in generation of intense electric and magnetic fields. More advanced field propulsion systems that could interact more strongly with gravity or the vacuum's zero-point state could require greater power than is achievable for air flight or spaceflight today. Such power levels would have to be supplied by systems of extremely high energy density.

One example of this type of system might be the aneutronic fusion electric spacecraft power system proposed by Bussard (11) which emits no neutrons and causes no radioactivity. A more speculative possibility would be extraction of electrical energy for power from the vacuum of space itself. For if favorable warping of spacetime metric is associated with regions of negative energy density in the vicinity of an accelerating ship (4) and if diminished ZPE would be associated with such negative energy density regions, one could visualize such ZPE diminishment as being a consequence of successful ZPE extraction for shipboard power use.

Methods for Detecting Gravitational Changes within Specially Conditioned EM Beams

Specially conditioned em beams would be very attractive if they would require no more electrical power than high power airborne radar and laser systems in use or in development today. But such power levels are much more than that likely to be available for initial laboratory proof-of-principle tests. Thus, there is the challenge of detecting relatively small gravitational or ZPF changes within specially conditioned em beams generated by only modest amounts of electrical power. One means of detecting small gravitational or ZPF changes within such beams would be measuring slight changes in weights of objects bathed by the radiation, or slight changes in forces acting upon them. Another would be use of pendulums or clocks to detect slight temporal changes due to perturbation of spacetime metric or the ZPF. A third method would be use of a sensitive Sagnac Interferometer - - which is similar to ring laser gyros used to detect inertial changes due to acceleration. For Barrett (12) has shown that A vector potential field changes associated with gravitation changes can be sensed by a Sagnac Interferometer. Thus any change in A vector potential and gravitation caused by a coupling with specially conditioned em radiation should be detectable by such a device.

Summary and Conclusions

Ordinary em radiation can be conditioned with the same field essence and form as that which may underlie gravity/spacetime metric or the ZPF. And it may be able to couple propulsively with gravity/spacetime metric or the ZPF through the action of something that may be common to each – the A vector potential. The efficacy of specially conditioned em radiation in accomplishing field propulsion depends upon the underlying essence and behavior of gravity, spacetime metric and the ZPF – none of which is yet completely understood. But in the meantime, the propulsive potential of such radiation can be inexpensively proved or dis-proved experimentally by testing existing radar, laser and electrical systems modified for the generation of such radiation.

Specially Conditioned EM Radiation by:

superposition of orthogonally polarized em waveforms of different frequency (polarization modulation of laser or radar beams)

"A" Vector Field
Disturbance

"A" Vector Field
Disturbance
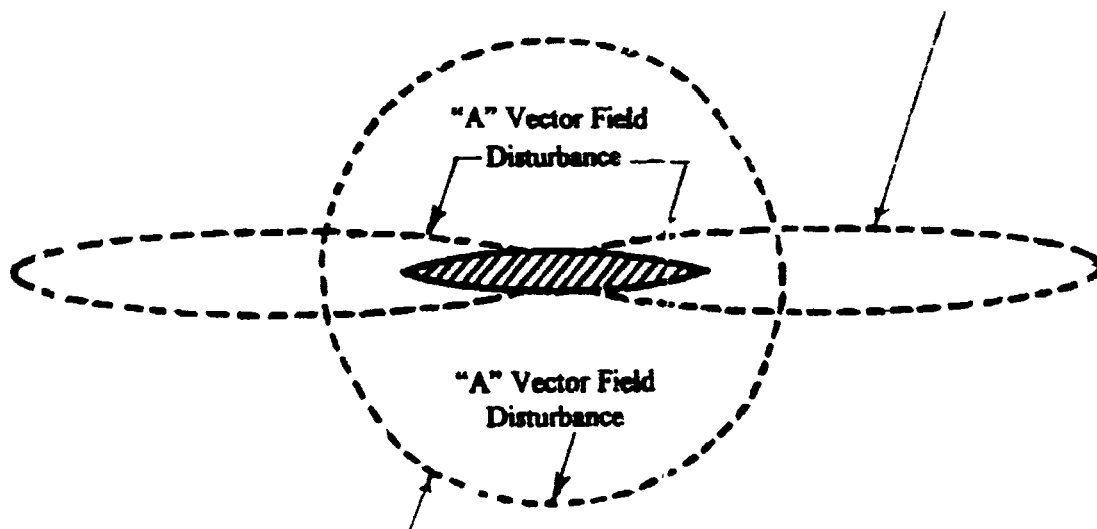
superposition of em waveforms caused by alternating current in toroidal shapes (amplified A vector potential at resonant frequencies)

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NEXT DOCUMENT

Nuclear Isomer Decay*
A Possibility for Breakthrough Space Propulsion

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ABSTRACT

A novel propulsion system for deep space missions that utilizes accelerated decay of nuclear isomers via induced gamma emission is proposed. The propulsion is accomplished by ejection of gamma particles resulting from controlled nuclear isomeric decay. The specific impulse per unit mass is comparable with that of chemical-thermal sources; however, the specific energy comparison on the same basis is about five orders of magnitude higher. It is expected that the nuclear isomers can be recharged while in space by gamma rays to "pump-up" the isomers. A prime candidate for this application is the isotope Hf-178. The nuclear isomeric transition is a transition of an excited nucleus to its ground state by release of energy as gamma particles. The accelerated nuclear decay is accomplished by further exciting the isomer so that the degree of forbiddenness of transition to the ground state is reduced and occurs rapidly.

The recharging is done by supplying energy in quantities that recreate the decay inhibited state. The rechargeability of the isomers in space makes accelerated nuclear decay attractive for long space missions. It may be possible to collect gamma rays while traveling in space to recharge the isomers. Further, it is possible that with controlled releases, the non-propulsion energy requirements of the spacecraft can also be met. Onboard power could be provided through the controlled release of gamma rays (i.e., photons) which can be converted to electricity via photoelectric or other effect. On long trips, gathered energy from space can be used for continued acceleration for about the first half of the trip and then for deceleration for the remaining half of the trip. The photons momentum provides the propulsion momentum. This concept is akin to the early light-sail (i e., photon pressure propulsion) concepts as proposed, for example, by Dr. Robert L. Forward in the 1970s, and earlier by others.

The major initial development areas proposed are: verification and confirmation of the principles; establish theory and develop physical control; quantitative control of energy and impulse release; direction and collimation of the release; development of the recharge ("pump-up") mechanism of the isomers and the controlled triggering of release(s); concept definition of applications as propulsion; and as an onboard energy storage and generation source.

HIT - Hot Isomeric Transition

The principle:
Decrease inhibition to transition by supplying some of the inhibiting quantum values, raising the level to a point whence it decays readily, releasing a large amount of energy.

CANDY

α DECAYS

Energetic photons trigger decay of heavy nuclides, displaying "giant resonances," that result in their accelerated decay.
The energetic photons are supplied by bremsstrahlung which triggers forward scattered energetic photons.
The α decays not be suitable for propulsion, and may not be renewable.

β DECAYS

Isotopes that display β-decay may be triggered by electromagnetic fields. The β decays are expected to be energy efficient. They may not be renewable, and there is no known focusing mechanism. They may be useful for reserve energy or as an interim step. However, it may be required as a developmental interim step to assist understanding and development.

γ DECAYS - ISOMER DECAY (HIT)

The γ decays are the subject of this paper. They are expected to be useful for deep space propulsion. The γ decays fulfill the goals of deep space propulsion:
> No propellant,
> Rechargeable, thus facilitating long missions and high speeds,
> In addition, they can supply the onboard power needs.

Propulsion and Energy

Momentum of photons vs mass propulsion:

Assuming 1 mole of 100 amu isomer with a 1 MeV gamma emission one gets:
$p = N_A h\nu/C = N_A E/C = 6.0 \times 10^{23} \times 1 \times 1.6 \times 10^{-13}/(3 \times 10^8) = 320 \text{ kg} \cdot \text{m/s}$

Assuming 1 mole of 100 amu molecule expelled at 1 km/s one gets:
$p = m \cdot v = 0.1 \times 10^3 = 100 \text{ kg} \cdot \text{m/s}$

Efficiencies and losses are not accounted for.

Energy to mass ratio

1 mole of 100 amu isomer with a 1 MeV gamma emission represents:

$E/m = N_A \cdot h\nu/m = 6.0 \times 10^{23} \times 1 \times 1.6 \times 10^{-13}/0.1 = 1 \times 10^{12} \text{ J/kg} = 1 \text{ TJ/kg}.$

1 mole of 100 amu molecule of 40 MJ/kg (10 kcal/g) represents:

$E/m = 0.1 \times 40 \times 10^6/0.1 = 40 \times 10^6 \text{ J/kg} = 40 \text{ MJ/kg}$

p - impulse; N_A = Avogadros Number; h - Planck Constant; C - Speed of light; E - energy; m - Mass; v - velocity.

Energy Comparison

	Base Information	MeV/(atomic reaction)	keV/(nucleon)	TJ/kg	TJ/mol
Fusion	T + D → He + n 17.6 MeV	20	4000	400	2
Fission	200 MeV/(fission)	200	1000	100	20
Radioactive decay	2 MeV (γ)	2	10	1	0.2
Chemical reaction	C + O_2 → CO_2 94 kcal/mol	4×10^{-6}	0.4×10^{-3}	40×10^{-6}	0.5×10^{-6}

CANDY Uncertainties

The feasibility of the basic accelerating decay possibility is confirmed. However the controllability of the discharge is not established.
The efficiency and completeness of the discharge must be established.
The ability to recharge (reestablish the isomer states) must be established.
The efficiency of recharging is not known. Also it is not known if the re are parasitic side effects or any unknown losses or attritions.
Quantitative evaluations have not been done and are needed.
There is need to develop effective ways of isomer separations.
The focusing and directing of the discharges need to be established.
Efficient energy transformations methods must be developed for the storage and for the retrieval.

CANDY Development

Initially there is need for the verification and confirmation of the associated phenomena:
- Establish a theory
- Confirm empirically the phenomena
  - measure the "giant cross sections"
  - measure the accelerated beta decay by electromagnet c fields.

There is need to select and test suitable isomer candidates.
Quantitative analyses and conceptual designs must be done.
Isomer separation and collection must be established.

CANDY

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NEXT DOCUMENT

Possible experimental test of Wheeler-Feynman absorber theory

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ABSTRACT:

Contemplate the vastness of the universe, examine the Hubble Deep Field and ask how such an enormous distance might be crossed. In such a case, it becomes necessary to contemplate speeds that are so large as to be effectively infinite. Step back a moment from crossing the universe to crossing a 10 meter laboratory. Can an experiment be realized in which something can cross the 10 meters in less than 30 nano seconds? Such an experiment would be a logical precursor to any larger effort that contemplates crossing light years and could hopefully be accomplished without the large expenditures of energy that are usually associated with such schemes. It is the purpose of this paper to present details of a proposed experiment on Wheeler-Feynman Absorber theory which has as it's ultimate aim the performance of such a demonstration.

INTRODUCTION:

Acausal communication as a logical precursor to superluminal space travel

When contemplating voyages spanning light years one quickly encounters enormous obstacles. Technically conceivable solutions exist for travel to nearby stars that are compatable with our conventional understanding of modern physics. For distances of galactic proportions, the time and energy requirements become nearly impossible. Even radio communication is reduced to one way shouts into the wilderness with round trip travel times extending over the millennia. As we continue to investigate novel means of interstellar travel and communications it is important to remember that the lightest payload of all is information and that a demonstration of communication against the arrow of time would be a significant and logical precursor to any form of superluminal space travel.

Wheeler-Feynman Absorber Theory

Wheeler and Feynman in 1945 acting on a suggestion made by Tetrode in 1922 developed what is commonly referred to today as "Absorber Theory", in which half-advanced fields originating with the absorber are responsible for the radiatiave reaction of the source. This approach is naturally time symmetric and replaces the imposition of causality constraints on the solution of Maxwell's wave equation with boundary conditions on the distant past and future. Wheeler and Feynman introduced absorber theory in the context of classical electrodynamics, but later authors extended the concepts to time symmetric quantum electrodynamics. Figure 1 illustrates the different viewpoints between the conventional viewpoint of QED and the

Figure 1. Diagrams showing the fundamental difference between standard interpretation of QED and Cramer's transactional interpretation

Wheeler-Feynman view. In the conventional view, emission and absorption are isolated events in which quantum states emit or absorb retarded photons in exchange with a field. Cramer (1980, 1986) introduced the idea of a microscopic transaction process involving a Wheeler-Feynman exchange of advanced and retarded waves.
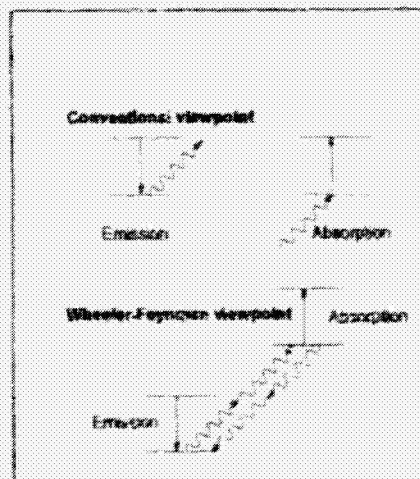
Cramer stresses that the transactional interpretation of quantum mechanics is a new way of thinking about quantum mechanics rather than a new theory.

PREVIOUS EXPERIMENTAL TESTS OF ABSORBER THEORY:

The null result of Schmidt and Newman

Schmidt and Newman (1980) performed an experiment that was intended to detect advanced radiation from a pulsed microwave source. A receiving antenna gated at t=-r/c failed to detect any radiation with a ratio of power received at t=-r/c to power received at t=r/c <10$^{-11.5}$. Figure 2 shows a schematic space time diagram of the experiment. In light of Cramer's transactional interpretation it is readily apparent why no signal is received at t=-r/c. Before the emission event at the transmitter, the advanced and retarded waves are precisely out of phase, resulting in a cancellation of any radiation prior to the emission event.

The proposed experiment of Heron and Pegg

Heron and Pegg (1974) proposed an experiment aimed at the detection of advanced radiation. The general outlines of the experiment are shown in figure 3. This experiment contains several of the elements present in the experiment proposed in this paper including the idea that some sort of power measurement of the radiation leaving the source is required. There are two aspects of the Heron and Pegg experiment which are fundamentally different from the experiments proposed here. One difference lies in attempting to influence the emission rate by varying absorption at t=-r/c. In the transactional interpretation, the advanced radiation from the absorption as well as the emission have canceled at this point and nothing remains which can influence the emission. The remote shutter at t=-r/c has the potential to influence the emission at the gated transmitter, provided that the transmitter and the remote absorber are aligned in a spatial direction where the probability of absorption is less than unity. Heron and Pegg appear to have had some insight into the spatial dependency of the cosmic absorption factor, but missed on proposing to attempt to measure spatial dependence on emission rates. (They proposed orienting the transmitter absorber line perpendicular to the plane of the galaxy.)

Bennett and microscopic causality violation

Bennett (1987) develops a quantum theoretical counterpart to the classical theory of electron preacceleration. By examining a mode of a harmonically bound, damped radiating charge and retaining solutions that violate causality they are able to obtain a better fit to the available proton Compton scattering data than any dispersion theory. One comment by Bennett which bears repeating here concerns spontaneous emission. Bennett states: "Spontaneous emission only appears to us macroscopic, forward-in-time-bound observers as spontaneous, since we are not able to control the advanced future interactions with remote particles". One of the
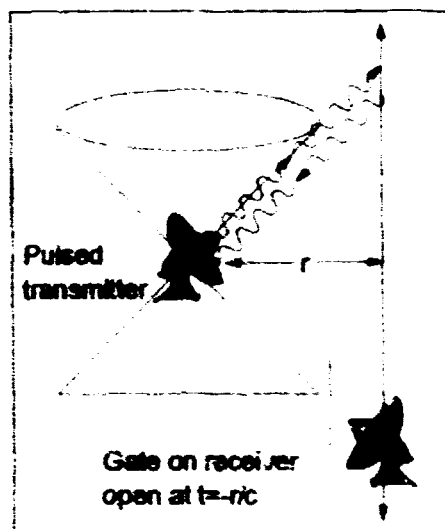

Figure 2. Schematic illustration of the experiment of Schmidt and Newman
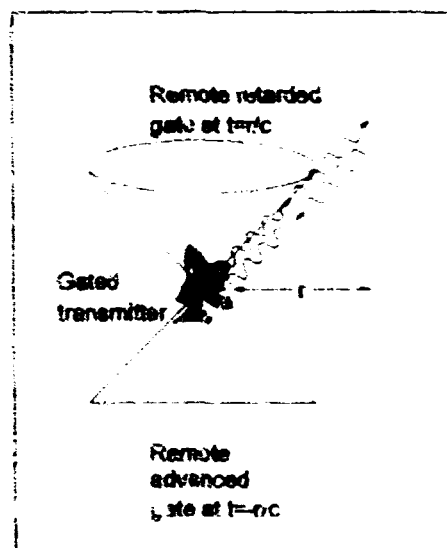

Figure 3. Schematic illustration of the proposed experiment of Heron and Pegg

objectives of the proposed experiments outlined in this paper is to manipulate the future absorption. Bennett also presents a short review of the equivalency between the effects of zero point fluctuations and radiation reaction.

PROPOSED NEW EXPERIMENTAL TEST OF ABSORBER THEORY:

Overview

In the remainder of this paper the proposed experiments will be discussed in detail. Three experiments will be described, but only the first is non-contingent, that is to say the first experiment will be conducting observations testing for possible cosmological consequences of absorber theory. The remaining two experiments are contingent upon the results of the first experiment.

Absorption Astronomy

Figure 4 illustrates what could be described as the standard model of observational astronomy. Detectors functioning as absorbers for retarded radiation emitted in our past light cone determine the past structure of the universe. For the purposes of this paper we will refer to this type of astronomy as "emission astronomy", because it is designed to observe photons emitted in the past. The future light cone is viewed as observationally inaccessible, with the range of speculative ideas describing it being almost embarrassingly large. Possible future light cones include open, closed and flat models of the universe. As the present advances into the future, wave functions are viewed as collapsing into reality. It is generally viewed that as the future moves through the present into the past that only a single future will be observable, but there are models such as the one proposed by Everett (1957) in which the present is not connected to a single future light cone, but rather connects to all possible future light cones.

Figure 4. The standard model of observational astronomy

Consider now the situation shown in figure 5. A source of spontaneous emission, represented here by a light bulb is sitting at the present vertex of a light cone. In absorber theory, a photon can only be emitted from a source if it will ultimately be absorbed. There are 3 example world lines showed in the figure, 2 which terminate on an absorber and 1 which does not. The probability of emission is affected both by the structure of matter along the future world line as well as the ultimate fate of the universe. A universe that collapses into a final singularity might well be expected to absorb all of the free photons in the universe.

The experiment proposed here consists of the construction of an "inverse telescope" together with an "inverse detector". The inverse telescope would be constructed in a similar fashion to an ordinary telescope with the exception that surfaces that are normally coated to absorb stray light would be coated to reflect instead. The inverse detector is more unique. The underlying principle consists of the preparation of an ensemble of excited states (the pump) and then directionally exposing the ensemble to the sky through the telescope. After some exposure time related to the "normal" decay time of the states, the ensemble is probed to look for variations in the background cosmological absorption probability.
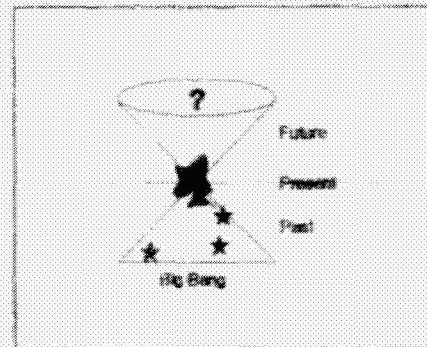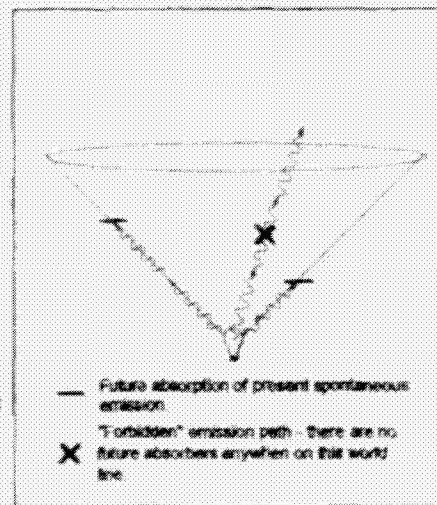

Figure 5. Depiction of a possible mechanism for emission dependency on spatial orientation

Table I. Comparison of detectors for probing past versus future lig it cone

Detector Type	Emission Astronomy	Absorption Astronomy
Biological	Eye	Unknown ???
Intensity	Photo Diode	LED
Position #1	Photographic Film	Phosphorescent Screen
Position #2	CCD	Precharged "Leaky" CCD

Table I presents a comparison of standard "emission astronomy detectors and the corresponding detector for "absorption astronomy". The entry for the biological detector is included to highlight the fact that the type of measurement being performed here does not have a direct analog with any of our normal senses. We are simply not wired to sense events in the future light cone. Under the heading of an intensity detector, a photo diode would be a typical example of a conventional detector. Arriving photons generate electron-hole pairs generating a small potential across the diode leads. In the LED, a forward biased p-n junction moves holes and electrons across the gap which then recombine to emit photons. When the photon emission is suppressed due to the lack of a suitable absorber, recombination is inhibited and a reverse bias develops which reduces the current flowing through the LED. When designing an LED detector for this purpose, it is important to minimize alternate channels which still permit recombination or local absorption of the photons.

Since the inverse telescope is fully capable of imaging, position sensitive detection needs to be included as well. In method #1, a phosphorescent screen is pumped via uniform exposure to bright light and placed in the telescope. After a period of time appropriate to the natural decay time of the phosphorescence, the screen is removed from the telescope and it's residual positional intensity recorded. Variations in the ultimate absorption probability of the photons within the telescopes field of view manifests itself as variations in the residual intensities on the screen. Method #2 takes notice of the predominance of CCD detectors in modern astronomy. A normal CCD detector starts with empty cells and accumulates charge with time as photons generate electron-hole pairs. For absorption astronomy, the CCD begins with all of the cells fully charged and leakage current provides a path for electron-hole recombination and the associated photon emission.

Controlled causality violation

If the first experiment is successful in finding regions of spatial orientation in which photon emission is suppressed from the detectors natural rate, then a 2nd experiment is proposed as outlined in Figure 6. The region contained within the dotted line is essentially the inverse telescope and detector. Here, the inverse telescope is directed at a remote switchable mirror. The mirror is located a distance r from the telescope which is therefore located at time r/c in the mirrors past. The optimal choice of r and the switching rate of the mirror depends largely on the nature of the "forbidden" directions absorption characteristics. For the experiment to exhibit true causality violation, you would like the mirror switching time to be less than r/c. Similarly, the response time of the detector should be such that a time less than r/c is sufficient to produce a significant change in the detector in that time. Switching between the local absorber and the "forbid-
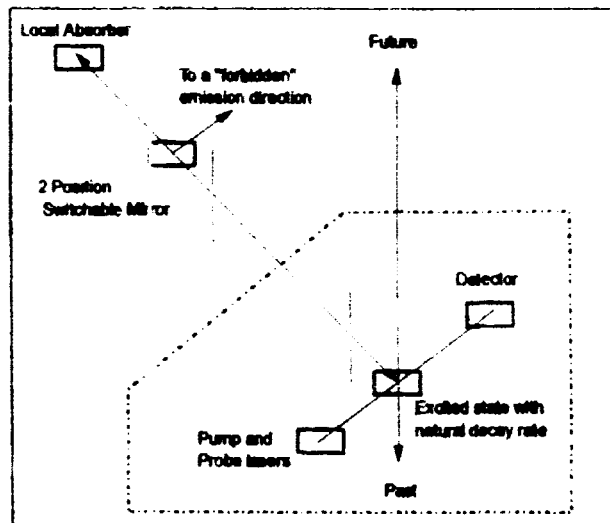

Figure 6. I xperimental setup for controlled causality violation. The pump and probe lasers represent a means of populating an excited state and monitoring it's decay.

den" emission direction is intended to generate a signal in the past that manifests itself as a variation in the decay rate of the excited states.

Instantaneous communication

Figure 7 is a modification of the experiment illustrated in figure 6. Here the resiviour of excited states in the past is coupled to a nearby transmitter that relays the signal via conventional means to a receiver located at a spacelike interval from the signaling mirror.

SUMMARY:

Because we have seen with our eyes for thousands of years the night sky, it would never occur to us to build a physics where the past light cone presents to us a uniform emission background for us to detect. Lacking any direct sense of the future light cone however has led us to do just that with respect to the future. The first experiment outlined in this paper challenges the assumption that the future absorption probability for photons is the same independent of direction. Independent of any other considerations, we argue that the experiment should done for the possible insight to be gained for cosmology and quantum mechanics.
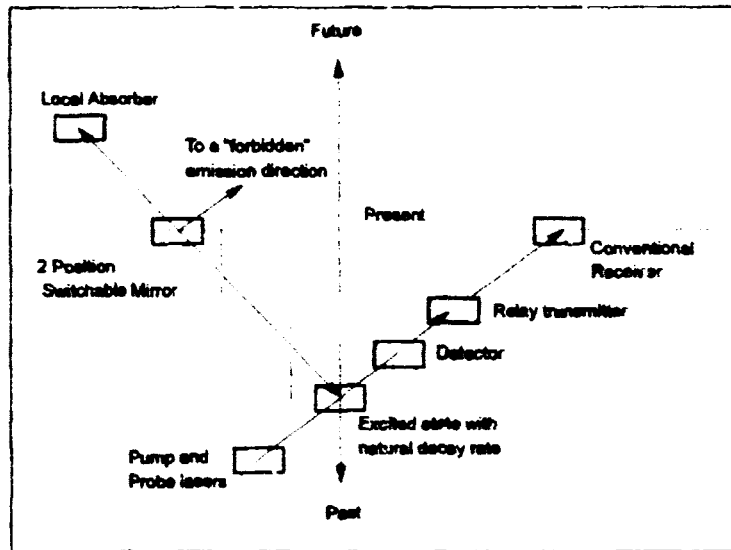

Figure 7. A variation of the 2nd experiment it which a relay has been added to enable spacelike communication.

The universe does not need to have any particular behavior just to satisfy human desires. It is entirely possible that we might not succeeded in finding any dependency upon orientation at any wavelength for spontaneous emission. That is still a data point that model cosmologies have to deal with. If we do succeed in detecting absorption structure, we will have opened up to exploration half of the cosmos that had been previously been hidden. The philosophical impact of exploring and communicating with the future light cone will be as profound as any revolution that has ever occurred.

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NEXT DOCUMENT

DETERMINATION OF THE EXISTENCE OF THE VACUUM STRUCTURE

NASA Breakthrough Propulsion Physics Workshop
Aug. 12-14, 1997

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ABSTRACT

Did the M-M experiment prove there is no aether, or merely that uniform motion relative to the aether cannot be detected? From about 1890 through 1922, this question was of paramount concern to theoretical physicists. Trouton-Noble performed experiments to no avail. The unipolar induction studies of G. P. Pegram, E. H. Kennard, W. F. G. Swann and S. J. Barnett (circa 1908-22) could have solved the problem but for an unfortunate design flaw in measuring the EMF's induced. Had the circuits Barnett used been truly open when he reported the magnetic field under test did not rotate, presence of the aether would have been confirmed. Einstein noted, however, that at the instant Barnett took data, he had actuated a tiny contactor that closed his circuits and rendered his results inconclusive. On the theoretical possibility that the field did rotate and generate an EMF that open circuit testing, if available, would have detected, no credible conclusion could be reached.

The untenable conclusion reached by many was that "there is no aether." Is there in fact no aether? If we are to achieve force field propulsion, the answer to this crucial question must be resolved. The tests being proposed here offer a means of doing so. In the early to mid-50's, sensing an urgent need for a superior alternative to reaction motor propulsion, M.N. Kaplan wondered if the aether's presence could be shown by some means as yet undiscovered. Using unipolar dynamos designed to study system torques, he discovered that although a significant moment could be electromagnetically generated on the rotor, no counter-torque could be made to appear on the rotatably mounted stator. The seat of the system counter-torque therefore had to reside in ambient aether space. These studies led to US Patent 3,390,290, the motorotor, which, when interacting strongly with the aether in torsion, accelerates briskly in rotation. The studies also led to the development of "Structured Space Theory," in which all of the known forces, including gravitation and inertia, are seen to derive from energy density differences in the aether interacting with particle surfaces they cannot penetrate. After professor R. D. Eagleton joined forces with Kaplan in mid-1978, development of structured space theory progressed rapidly. In accordance therewith, force field propulsion should be achievable by generating vectored energy density differences in the aether that interact strongly with the nucleons in the matter being accelerated.

Aether History in Brief

For the benefit of those who know nothing of the once hypothesized aether or who have been led to believe that no aether exists, a brief review is warranted. Before Michelson-Morley, it was generally believed there was an aether medium present.[1] Although little was known of its nature, the records clearly show [2] that Ampere believed the aether composed of positive and negative charges: and Maxwell's "displacement current hypothesis" clearly suggests partial

dissociation of the vacuum structure along potential gradient lines. The outcome of the celebrated Michelson-Morley experiment caused the first serious doubt of the aether's existence to be raised. Until then it had been generally accepted by most that space was filled with an all-pervasive medium that propagated light at 300,000 km/s and supported the natural forces. Three decades transpired during which the Trouton-Noble [3] and the unipolar [4,5,6,7,8,9,10] induction studies failed in their attempts to detect and re-instate the aether. Of particular note is the experiment by S. J. Barnett [4] who believed that with open circuit testing (Fig. 1), he had succeeded in showing that a symmetrically dispersed magnetic field does not rotate in concert with the MMF which produces it. Albert Einstein refuted this claim with the
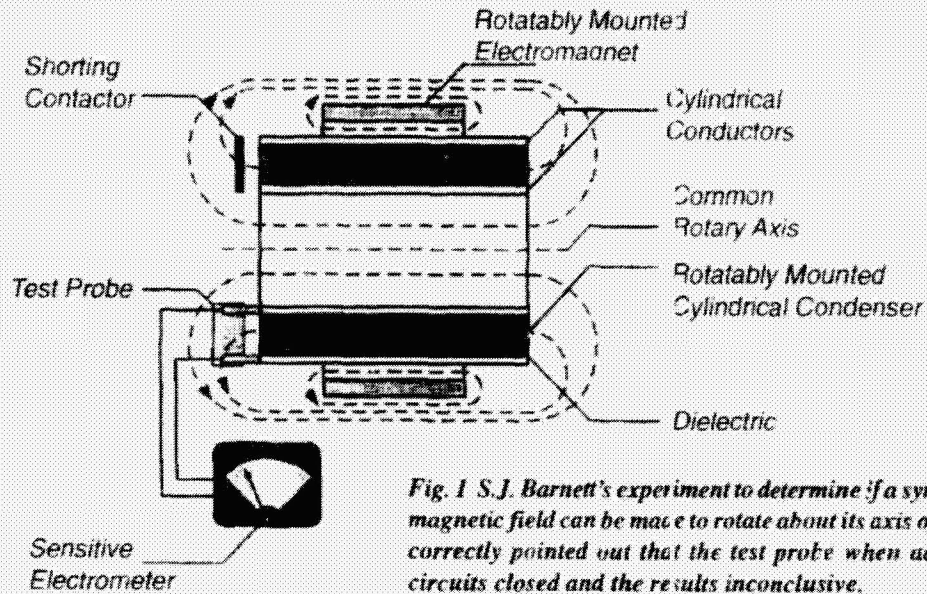

Fig. 1 S.J. Barnett's experiment to determine if a symmetrically dispersed magnetic field can be made to rotate about its axis of symmetry. Einstein correctly pointed out that the test probe when actuated rendered the circuits closed and the results inconclusive.

explanation that a small contactor actuated at the moment data was taken had rendered Barnett's circuits closed. It was well known in theory that there was no way to show the state of rotation of the magnetic fields these studies involved using closed circuits.

By 1920, Einstein [11] still considered an aether necessary for a coherent general relativity to be conceivable, but he couldn't envision how an aether composed of "mechanical" particles might have electromagnetic properties as well. By 1938, he'd declared the problem so great that, "we have to give it up and thus give up the mechanical view (aether) as well." [12]

It can now be shown quite easily that the vacuum has a substantive, functional structure, i.e., an aether. In a recently developed easily reproduced experiment exploiting the fields of synthetic magnetic monopoles (fig. 2), its presence was convincingly confirmed in a demonstration lecture at Caltech. [13,14] The apparatus employed caused Lorentz forces to be generated in and stem from seemingly empty ambient space. The presence of these forces was evidenced as a

Fig. 2 *Hypothetical magnetic monopole inside of and free to turn about common axis with bearing mounted metal tube. In addition to the $f_1 f_2$ couple shown, all current components suffer Lorentz torques in the same sense, thus tending to accelerate the tube in rotation. Note that all Lorentz force components emerge from seemingly empty space.*
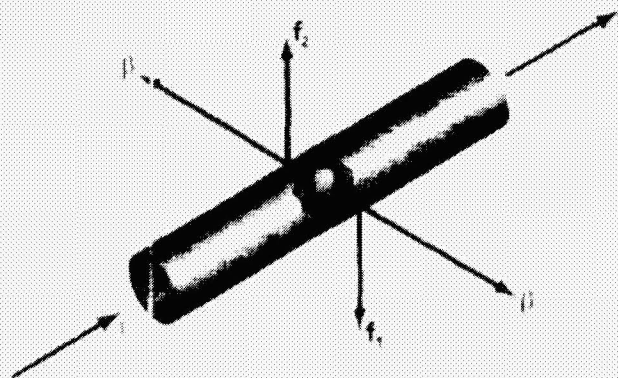
multiplicity of couples co-acting to accelerate a rotatably mounted, current carrying cylindrical tube briskly in rotation (fig. 3). Changing the direction of the current or reversing the monopole field employed caused the rotation observed to be reversed.
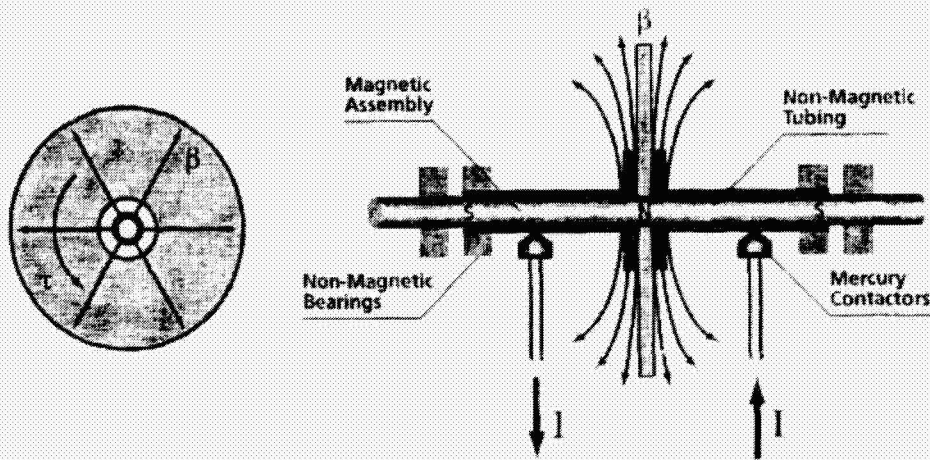
Figure 3 Experiment performed at Caltech in January of 1996 clearly demonstrated Lorentz forces issuing from ambient aether space. When electrically excited, the motorotor accelerated briskly in rotation. When the current, I, or the synthetic magnetic monopole field was reversed, the disk changed direction of rotation with startling abruptness. With no ponderable matter present with which to interact, the motorotor had to be interacting directly with a substantive, stiff magnetized aether.

Fig. 4 All forces must stem from energy sources. As Lorentz forces can be observed to issue from empty space, there is unavailable energy in the vacuum and a medium in which it is stored. By definition, this is the aether medium on which Structured Space Theory is based.
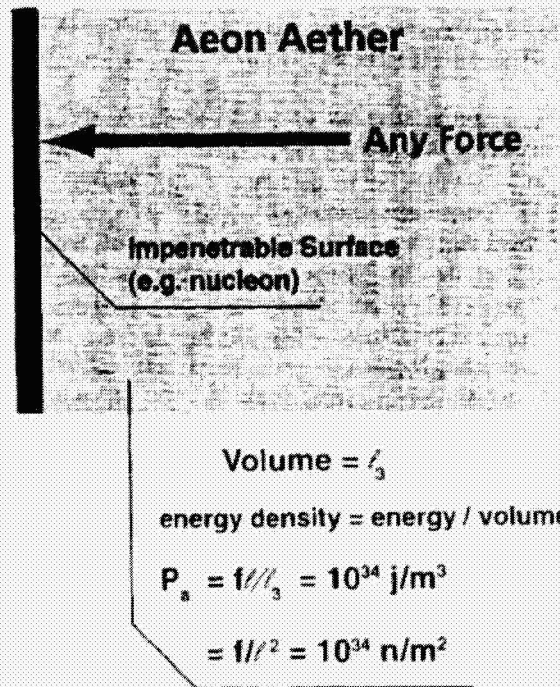
Structured space theory assumes the homogeneous aether (fig. 4) to be a quantized, high-energy density superfluid composed of (+) and (-) "chartrons," nature's smallest charged particles. Packed in closest proximity, (+) and (-) chartron pairs are assumed to exist in the form of massless "aeons" – nature's smallest neutral particles. When partially dissociated, aeons possess mass in the forms of electric and or magnetic field energies. "Void" particles may be described as zero content, zero energy density space; that are symmetrically surrounded by stable, rigid, aggregates of keystone-like aeons. They are heavily stressed by, but are utterly impenetrable to, the ambient aether pressure. They are assumed to have twice the mass of free chartrons. At the most fundamental level, structured space theory assumes all subnuclear particles to be composed of aeons, chartrons, and voids. Matter then derives its mass directly from the stable voids it contains. When the

stabilizing symmetries are "broken" high pressure aether flows into these voids instantaneously, transforming the annihilating particle's void volume, v, into spacetime aether with the attendant release of energy

$$E = p_a v = mc^2$$

Thus it appears the vacuum structure provides for mass-to-energy and energy-to-mass transformations and that without an aether, there would be no matter!

Lorentz forces are resultant reactions to pressures imposed by moving charges (matter) on magnetically strained aether – interactions which produce energy density (pressure) differences in the spacetime structure that are perpendicularly oriented to both the currents, I, and the magnetic field vectors, B (fig. 5). Einstein felt forced to abandon the aether
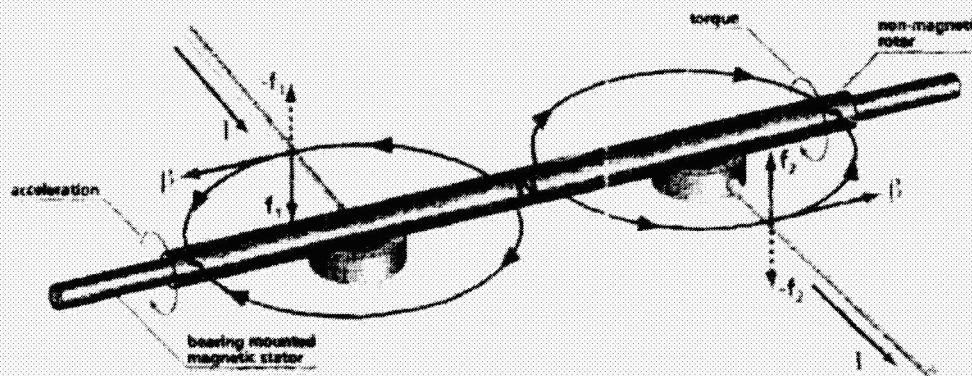

Fig. 5 One of the system of couples. Lorentz forces co-act to accelerate the tube in rotation.

when it appeared impossible to explain these orthogonal relationships – properties without which the aether's presence might never have been discovered experimentally. To react to the forces moving charges impose on magnetized spacetime, Lorentz forces must be supported by energy sources residing in the local vacuum. To a degree, this shows magnetically strained spacetime can be somewhat impenetrable, substantive, and dense.

Contiguous, at an energy density of at least 10^{32} joules per meter^3, aeons comprise an ideal superfluidic aether in which all other particles are immersed, a medium which conserves energy, propagates transverse and spherical waves, and supports all of the natural forces. Energy density is a form of pressure when imposed on surfaces not readily penetrated(fig 4). Can pressure of some kind exist in a deep vacuum? Yes, if the vacuum superfluid is composed of particles so very small that they readily penetrate all known atoms. The spaces between the atomic nuclei of any ponderable matter exceed the dimensions of subnuclear particles by many orders of magnitude. As vacuum chambers and pumps are fabricated of ponderable matter readily penetrated by aeons, no chamber can be evacuated of aeon particles nor can the aeon aether be pumped like ponderable fluids. So how, then, could a medium composed of such small particles interact with matter composed of the atoms they penetrate so readily? Atomic nuclei are thought to be surrounded by electron "clouds" readily penetrated by tiny electrically neutral aeons. As aeons cannot penetrate other aeons or densely packed aeon aggregates, they cannot penetrate atomic nuclei which are, in the main, densely packed aeon aggregates. According to structured space theory, it is the vacuum's energy density that supports the strong nuclear force[15] needed to hold atomic nuclei together.

What then differentiates matter from spacetime aether? The isotropically structured aether is presumed fully packed with as many aeons as can be forced into a given volume with each aeon storing unavailable energy of approximately 10^{-13} J abs. There are no negative energies in structured space theory. As the chartrons and voids in matter displace vacuum structure, the aether's energy density always exceeds that of matter. So in structured space theory, it is the void content thereof that differentiates matter from spacetime. Homogeneous space is structured of identical, highly elastic aeons which, under an energy density, p_a, of at least 10^{32} j/m^3, approach the shapes of dodecahedrally truncated spheres. Matter deviates from this pattern somewhat in the form of stable chartron, aeon, void, aggregates, which directly displace their respective volumes of spacetime. Such displacements produce, in effect, regions of stable, reduced
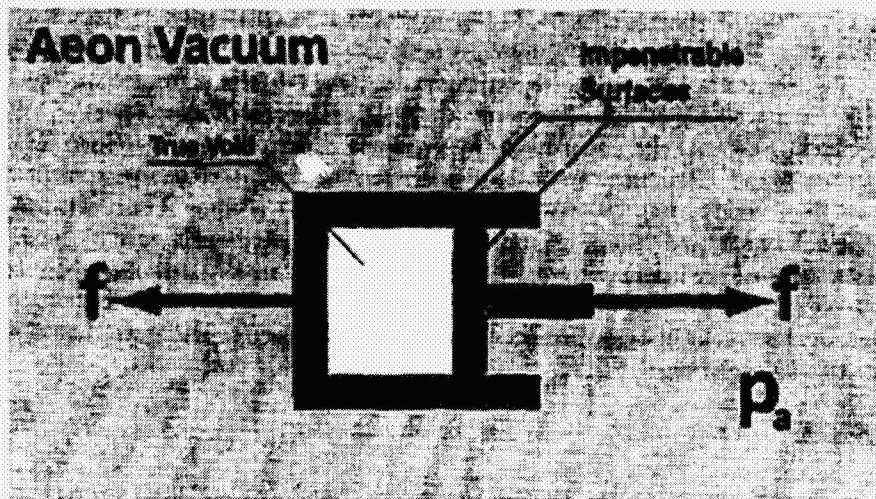
Fig. 6

- **Impenetrable Surfaces = Atomic Nuclei**
- **True Voids = Available Energy**
- **Aeon Vacuum = Unavailable Energy**
- **pa = energy density**

energy density—regions which comprise the source of the physical property, mass.

The energy stored in the vacuum structure is normally unavailable. Thus, the unavailable energy, E, stored in any massless spacetime volume, v, at energy level p_a, is then seen to be:

$$E = p_a v$$

Available energy can also be described as $m_1 c^2$ and $h v_1$. These expressions describe the sinks contained in detectable particles. Equating,

$$E_1 = m_1 c^2 = h v_1$$

So,

$$m_1 c^2 = h v_1 = p_a v_1$$

This implies the aether is the source of all energy which $m_1 c^2$ and $h v_1$ make available. The energy sinks $m_1 c^2$ and $h v_1$ comprise regions of reduced energy density into which the vacuum superfluid rapidly flows when the symmetries involved are broken. The energy made available will be directly proportional to the void volumes, $p_a v_1$, then filled.

It can be argued that all forces derive from pressure differences in the aether that interact with particle cross sections. As this includes gravitational and inertial forces as well, it appears structured space theory provides a physically realistic means for inter-relating all forces, i.e., a coherent approach to the formulation of a valid Unified Field Theory.[13] With regard to gravitation, extremely high frequency, incredibly small variations in nucleon volumes [16] are assumed to cause local spacetime to effectively accelerate in the directions of the undulating nucleons. This appears to explain, mathematically, how mass physically "warps" spacetime. (While evaluating the constants involved in this analysis, the reason the force of gravity is so very small in comparison to the coulomb force was discovered).[13] As local gravitational and inertial accelerations always interact with one and the same nucleon cross-sections (i.e., masses), the forces created by equal accelerations must be equal as well! This appears to be the physical basis for Einstein's principle of equivalence. Note that "energy" mass is proportional to volume whereas "gravitational" and "inertial" masses are proportional to area. This causes no problem because the ratio of a nucleon's gravitational to inertial masses is numerically constant.

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As the aeons of which the aether is composed can and do dissociate, completely or in part, into (+) and (-) chartrons [17] the "mechanical" aether abandoned by Einstein is now seen to possess electromagnetic properties as well. When strained rectilinearly, the aether's aeons store coulomb energy in the form of electric fields; when strained in torsion, however, they store available energy in the form of magnetic moments (lines of force). Electric "lines of force" are gradients which interact with chartron particle cross-sections, causing them to accelerate. Magnetic monopoles have never been detected and in structured space theory they are unneeded. Hypothetically, the field of an isolated "north" monopole might be described as uniformly spaced magnetic "lines of force" directed radially outward from such a particle's center. "North" and "South" monopole fields can be crudely synthesized by contrapolarizing high energy product, high coercive force magnetic materials (rods). As magnetizing forces displace spacetime (aether) in the "lines of force" directions, they generate magnetic energy density differences which would mechanically accelerate synthetic magnetic monopoles exactly like electric lines of force accelerate charges. This is why unlike magnetic "poles" attract each other while like poles repel.

CONCLUSION

The quantum theories emerged in an era during which it was widely believed there was no aether. The QED and QCD theories were invented to explain how action at a distance forces might be transmitted between interacting bodies through the exchange of energy-laden "virtual" particles. In view of the experimental evidence demonstrated at the Caltech lecture,[13] at least to the extent that the aether's presence challenges the need for exchange between interacting particles, some aspects of the quantum theories may need to be modified.

To further bolster proof of the aether's presence, a new experiment (fig. 7) is proposed which will further our understanding of this structure's characteristics. In essence, it would provide means for making true open circuit e.m.f. measurements, technology not available to these early pioneers. Thus, the results obtained will be clear and unambiguous. If no EMFs are generated when only the synthetic magnetic monopole is rotated, the field it produces must remain irrotationally fixed in the vacuum structure. To achieve force field propulsion, all of the aether's magnetic properties should be ascertained. Resolution of the question Barnett and Einstein left open could be crucial.
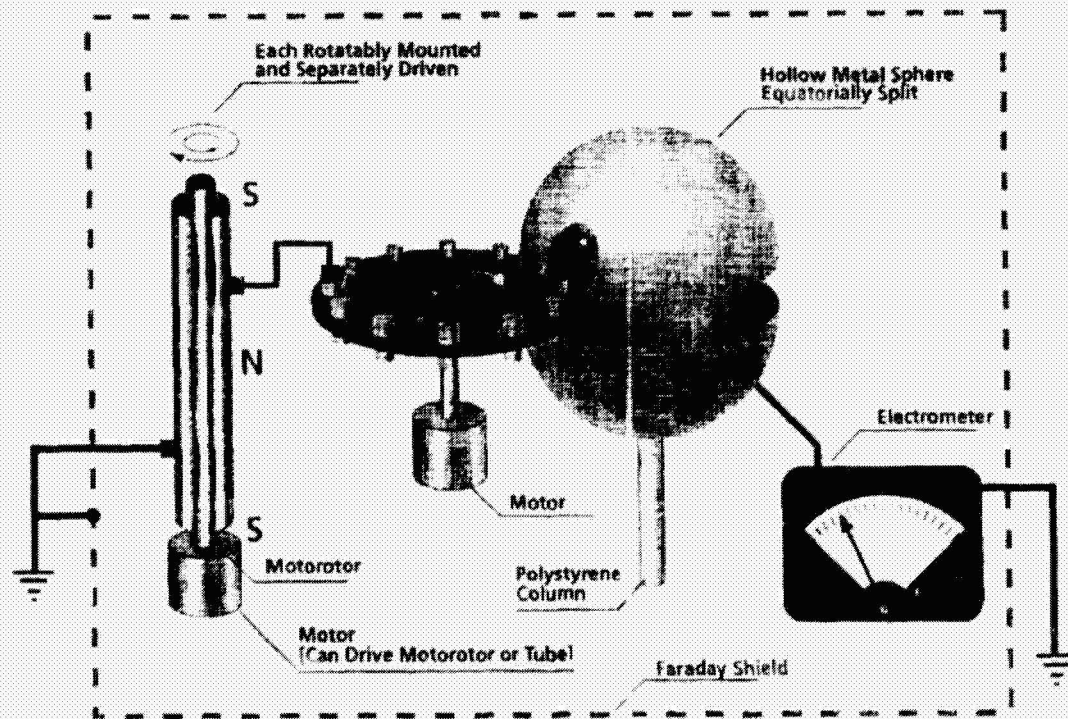
Schematic of Proposed Test

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NEXT DOCUMENT

FORCE FIELD PROPULSION

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ABSTRACT

Early in the century now ending, a concerted effort was made to determine if empty space had physical content, i.e., the once hypothesized aether. No experiment confirming its presence was found at the time, so the aether was relegated to the continued status of an open question. The aether is of current interest because as part of its "Breakthrough Propulsion Physics" program, NASA is seeking to determine if a much superior way to propel spacecraft can be found. Recently, experimental evidence of an aether was reported which appears to make possible precisely the propulsion capability NASA seeks. Force field propulsion must effectively transport energetic particles fore of the "thrust pumps" to regions aft of them. The ambient aether "pressure" is known to be at least 10^{32} newtons/meter^2. As it interacts strongly with nucleons, an infinitesimal wisp of it could easily propel spacecraft. The spaces between nuclei are orders of magnitude greater than the sizes of particles that compose the aether so matter moves freely through spacetime without observable interaction. Propulsion requires energy conversion from potential to vectored "kinetic" form. Inertia is the coupling that makes this conversion possible.

INTRODUCTION

According to aether history, long before the quantum theories emerged, Andre' Marie Ampere[1] clearly envisioned the aether as a combination of the positive and negative "electricities." James Clerk Maxwell effectively enlarged upon Ampere's insight by introducing "displacement" currents to account for a-c conduction in dielectrics. Then in the early 1930's, shortly after P.A.M. Dirac had predicted the existence of "antimatter," C.D. Andersen discovered the positron. Two decades before this physicists had worked fervently, to no avail in their attempts to show the Michelson - Morley results did not preclude the aether's presence.[2] In a companion paper[3], results of a recent experiment were reported which should reestablish the aether's presence. It is now well known that gamma ray photons can create positron - electron pairs out of the vacuum structure near heavy nuclei and conversely, positrons and electron pairs can "annihilate" each other and produce gamma ray photons.[4,5]

In a recent development in theoretical physics[6] called "Structured Space Theory," these facts were effectively correlated by assuming the aether composed of (+) and (-) "chartrons," and "aeons," natures smallest charged and neutral particles, respectively. It would appear the significance of Dirac's and Andersen's contributions escaped Einstein's attention as otherwise, by 1938 in a book he co-authored with Leopold Infeld[7] they would have realized the aether has electromagnetic properties as well as mechanical ones. As the "standard" model does not include an aether, it can neither deal with matter/vacuum interactions nor, by itself, can it contribute to the theoretical or physical development of force field propulsion. Aeons and chartrons provide the spacetime aether with its mechanical and electromagnetic properties, respectively. How they can be exploited to provide the propulsion means sought was suggested nearly four decades ago.[8]

The Motorotor

Shown in **fig.1** is a device called a motorotor. Its current carrying elements and magnetizing force are both contained in an all metal rotor. If rotatably mounted, it accelerates briskly in rotation when energized, like the rotor of an electric motor. The Lorentz forces (couples) which propel it, stem from seemingly empty space **that is magnetized by the rotor.** As with all forces, Lorentz forces must be supported by energy sources. Thus, the magnetized vacuum contains an energetic medium that interacts with the magnetic fields of moving charged particles. Structured Space Theory assumes this energy source is the aether and that it is capable of supporting acceleration fields in excess of 100,000 g's.[*] Although motorotor propulsion is not the capability NASA seeks, it is propulsion derived through a controllable aether/matter interaction.

fig. 1 the "motorotor"

To achieve thrust, not torque, additional phenomena in combination, are needed.
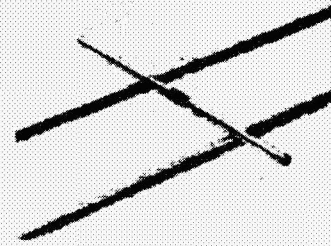
Our present knowledge of physics limits our ability to propel and control spacecraft to Newton's laws of motion (and of universal gravitation). These are mathematical expressions which describe quantitatively "how" free bodies react to applied forces and gravitational fields. They do not explain "why" these laws apply. One stated objective of NASA's "Breakthrough Propulsion Physics Workshop" was to solicit ideas which might answer the question, "how might spacecraft be propelled without expelling onboard mass?" In response to this question, another occurs. Why do Newton's laws apply? The current effort seeks to replace propellants with alternate energy sources together with means for converting such energies directly into vectored kinetic energy. Theoretically, the fields needed to do this might be characterized as a "cross" between gravitation and inertia. The vectored energy density differences needed would have to be derived in a form effectively handled by pumps made of readily available materials. As the aether would permeate any spacecraft so propelled, the "thrust pumps" developed could be installed anywhere inside or outside of the spaceframe.

The Structures of Matter and Spacetime

Basically, structured space theory is a combination of relativity, quantum, and aether theories - a concept which provides, in effect, the basis for a unified view of nature. The vacuum structure interacts strongly[10,11] with matter and endows it with physical properties. The quantum nature of mass and energy derive from the vacuum's corpuscular structure, a high energy density superfluid composed of massless, virtual, neutral particles called aeons, nature's smallest. Although electrically neutral, each aeon contains two contiguous anti-particles, also nature's smallest, one (+) and one (-) chartron. When partially dissociated, aeons possess displacement mass in the forms of electric and/or magnetic field energies. For mathematical convenience, structured space theory treats field-free aeons as if their chartrons somehow penetrate and contain one another, thus cohabiting a single quantum of otherwise void space. Note that aeons cannot penetrate other aeons nor can like chartrons penetrate each other. Void particles are potential "sinks." They may be described as zero content, zero energy density spaces surrounded by stable keystone-like aeon aggregates. Though incredibly stressed, they are not readily penetrated by the ambient aether pressure.

Spherically symmetrical voids have twice as much mass as free chartrons. Matter derives its mass directly from the voids it contains. In structured space theory, all matter is composed of aeons, chartrons, and voids. Without voids, there would be no matter. When matter somehow becomes unstable, the high pressure aether instantaneously transforms the annihilating matter's void volume content - v_i - into spacetime aeons with the attendant release of the energy $p_a v_i$. Matter is composed of neutral atoms which, in turn, are composed of positively charged nuclei and negatively charged electrons. Protons and neutrons, of which atomic nuclei are composed, contain most of the mass found in matter. As aeons can penetrate anything except nucleons, aeon aggregates, and other aeons, the aether interacts strongly with atomic nuclei but readily penetrates the spaces between them. Every detectable particle has mass. These properties engender the fields responsible for the natural forces in nature. What then differentiates matter from the spacetime aether? The homogeneous aether is fully packed with aeons each of which contains an unavailable energy of approx. 10^{13} joules absolute. There are no negative energies in structured space theory. As chartrons and voids in matter displace vacuum structure, the aether's unavailable energy density always exceeds that of matter. So in structured space theory, it is the void content thereof that differentiates matter from spacetime.

der a pressure, p_a, of at least 10^{32} n/m², aeons approach the shapes of dodecahedrally truncated spheres. Matter deviates from this pattern somewhat, taking the various forms of stable chartron, aeon, void aggregates, which displace their respective volumes of spacetime. Such displacements produce, in effect, regions of **stable, reduced energy density** - spaces which comprise the source of the physical property, **mass**.

The sizes of aeons, chartrons, and stable voids are unknown. However, electrons and positrons may be chartrons and if so, aeons would be about 10^{-15} meters in size, about 10^{45} massless aeons would occupy a cubic meter, the aether's energy density would be at least 10^{32} j/m³, and each aeon would possess about 10^{-13} joules of unavailable energy. As the aether cannot penetrate protons and neutrons, their structural integrities would be strongly maintained by an aether pressure of at least 10^{32} n/m².

Note: For light to propagate at 300,000 km/sec, aeons must be contiguous. Electrons and positrons are approximately 10^{-15} meters large and occupy about 10^{-45} m³. As it takes about 1.7×10^{-13} J of available energy to dissociate them, the unavailable energy density of the aether must be about $(1.7 \times 10^{-13} J) / (10^{-45} m^3)$ or 1.7×10^{32} J/m³.

The aether's electromagnetic properties derive from its chartrons. When combined in aeon form, devoid of available energy, chartrons are massless as are the aeons they compose. Detectable matter contains some form of available energy which differentiates it from the ambient vacuum structure. Neither aeons nor the chartrons of which they are composed possess any form of available energy and therefore cannot be detected.

The mechanics of force field propulsion are contained in the physical interface between the matter and spacetime structures outlined. Force field propulsion must be achieved by a physical interaction between the spacecraft's propulsion system and the ambient aether, a pumping process that imparts kinetic energy to the vehicle.

A valid approach to force field propulsion might be for one to determine why reaction motors work. It appears that as the high energy density aether forcefully resists displacement by the forming kinetic energy flow patterns, it also provides an accelerating spacecraft something relatively substantive to push against. While Newton's second law of motion explains how the factors involved vary, it is completely silent as to why these interactions occur. Why, physically, does Newton's second law of motion apply?
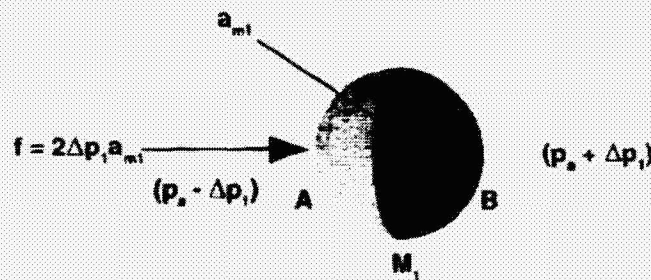

fig. 2 External force f propels M_i

Newton's Second Law of Motion Derived

The key to understanding all forces is to observe that they have energy densities or pressures in common that are imposed on surfaces through which there is little or no energy penetration. Such are the cross-sections of protons and neutrons which compose the nuclei of matter. A free nucleon is represented as M_i in **fig. 2**. In the absence of any net force imposed, M_i is bathed in the aether superfluid at a uniform energy density, p_a. When an external force f is then imposed, motion begins which causes the energy density at B to become $(p_a + \Delta p_i)$ while concurrently, that at A becomes $(p_a - \Delta p_i)$. The resultant force, acting on a_{mi}, M_i's cross-section, will be $2\Delta p_i a_{mi}$, the equal force that opposes f. Letting $a_0 = a_{mi}$

$$f = a_0 (2\Delta p_i) \tag{1}$$

As $a_0 = (3/4)(v_0/r_0)$.

$$f = (3/4)(v_0/r_0)(2\Delta p_i)$$

$$= (3/2)(v_0/r_0)(\Delta p_i) \tag{2}$$

From $m_0 c^2 = p_a v_0$,

$$v_0 = m_0(c^2/p_a).$$

substituting in eq. 2.

$$f = (3/2)(\Delta p_i/p_a)(m_0/r_0)c^2 \tag{3}$$

Letting $t_0 = r_0/c$, then $c^2 = r_0^2/t_0^2$.

Substituting in eq. 3

$$f = m_0(3/2)(\Delta p_i/p_a)(r_0/t_0^2) \tag{4}$$

As $(3/2)(\Delta p_i/p_a)$ is a dimensionless variable and (r_0/t_0^2) is a constant with the dimensions of acceleration, we can write Newton's second law of motion,

$$f = m_0 a \tag{5}$$

Structured space theory assumes the aether is a perfect high energy density superfluid which, except for atomic nuclei, readily penetrates all elements of the periodic table. Where no acceleration is involved, such matter can move through the aether without detectable interaction. Where matter is immersed in aether containing acceleration fields with which it interacts, however, it will be propelled in the field direction. By definition then, the stated propulsion capability sought in NASA's breakthrough propulsion physics effort reduces to the artificial generation, in the aether, of vectored acceleration fields.

In **fig. 3**, there is no external force applied but there has somehow been generated a vectored acceleration field by increasing p_a at B by the amount Δp_i and decreasing p_a at A by Δp_i. As a result, M_i is propelled in the B-A direction as indicated. The acceleration field must be achieved by pumping ambient energy from A to B.

In **fig. 4**, a vectored acceleration field has been generated which is equal to g but directed vertically upward so M_i can hover. To accelerate vertically upward, the intensity of the vectored field must exceed g.

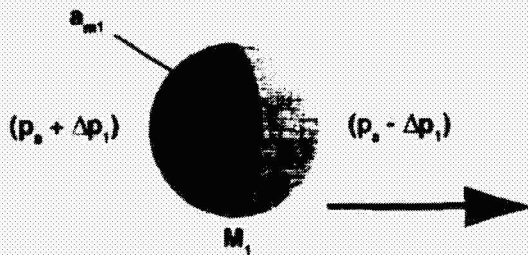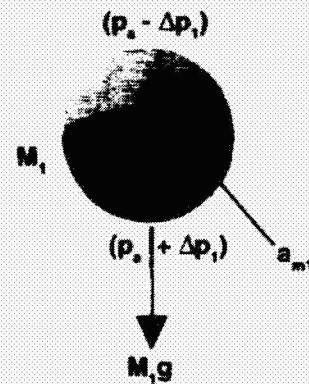*fig. 3 2Δp_i developed in spacetime aether interacts with a_{mi} to propel M_i*

fig. 4 By pumping aether downward so that $2\Delta p_i a_{mi} = M_i g$, M_i hovers weightlessly in zero g field

The energy stored in the vacuum structure is normally unavailable. Thus, the unavailable energy, E, stored in any massless spacetime volume, v, at energy level p_a, is then seen to be

$$E = p_a v. \tag{6}$$

Available energy can be described as $m_i c^2$ and hv_i. These expressions describe the sinks contained in detectable particles such as nucleons and photons. Equating,

$$E = m_i c^2 = hv_i = p_a v_i \tag{7}$$

where v_i represents the aether volume displaced by voids. This suggests the aether is the source of all energy. The energy sinks, $m_i c^2$ and hv_i, comprise regions of reduced energy density into which the vacuum superfluid rapidly flows when the symmetries involved are broken. The energy made available will be directly proportional to the void volumes then filled.

Flow Patterns

In the presence of a force imposed on a body free to accelerate, a pressure difference develops which interacts with the projected cross-section of each of its nucleons to produce a resultant inertial force, equal and opposite to the force imposed. As the body accelerates, the unavailable energy it displaces is transformed into the available kinetic energy flow patterns elsewhere described. Aether interacts strongly with matter and endows it with its inertial properties. Forces are pressures imposed by energetic media on surfaces they cannot readily penetrate. Wherever there is energy, there is a form of pressure. Energy is measured in terms of the work it can do, i.e., the force, f, it can impose on a body while moving it through a finite distance, l. Energy density is measured in terms of work (fl) contained in a given volume, l^3, i.e., $(fl)/l^3$. As this expression reduces to f/l^2, it can be seen that pressure is a form of energy density interacting with a surface, real or virtual, which it cannot readily penetrate. Clearly, pressure can be a measure of energy level. Force fields are energy density gradients in the ambient aether. Any body immersed in a force field with which it interacts will accelerate if free to move.

The aether cannot penetrate moving nucleons so it must flow around them. As illustrated in fig. 5, the vortex flow patterns generated displace aether laterally, and dynamically store the moving nucleon's kinetic energy. As like chartrons cannot penetrate each other, they, too, generate characteristic flow patterns when in motion. And again, the kinetic energies they gain come at the expense of energies stored in the interacting coulomb fields. Energy stored in force fields is thus converted directly into kinetic energy centered in the aether about bodies in motion.
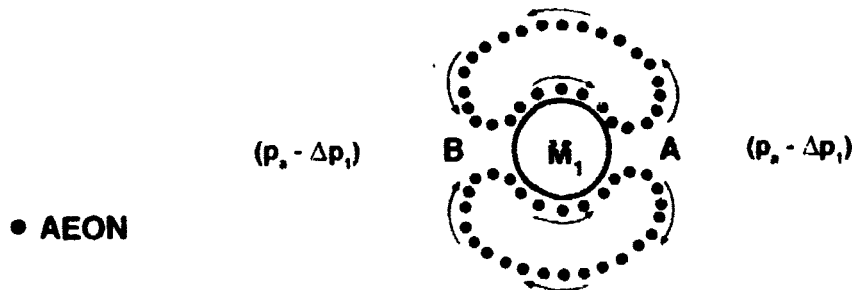

$(P_a - \Delta p_i)$ B M_i A $(P_a - \Delta p_i)$

• AEON

fig. 5 $2\Delta p_i$ created by moving energy from A to B; energy returning from B to A propels M_i

It can be argued that all forces derive from pressure differences in the aether that interact with the various particle cross-sections. As this includes gravitational and inertial forces as well, it appears structured space theory provides a physically realistic means for inter-relating all forces, i.e., a coherent approach to the formula for of a valid unified field theory. Regarding gravitation,[12,13] structured space theory assumes that extremely high frequency, incredibly small variations in nucleon volumes cause local spacetime to effectively accelerate in the direction of the undulating nucleons. This appears to explain, mathematically, how mass physically "warps" spacetime. As local gravitational and

inertial accelerations always interact with one and the same nucleon cross-sections, the forces created by equal accelerations must be equal as well! This may be the physical basis for Einstein's principle of equivalence.[14] Note that "energy" mass is proportional to volume whereas "gravitational" and "inertial" masses are proportional to area. This causes no problem because the ratio of a nucleon's volume to its cross-section is numerically constant.

As the aeons of which it is composed can and do dissociate into (+) and (-) chartrons, completely or in part, the "mechanical" aether abandoned by Einstein is now seen to possess electromagnetic properties as well. When strained rectilinearly, the aether's aeons store coulomb energy in the form of electric fields; when strained in shear, however, they store available energy in the form of magnetic moments. Electric "lines of force" are gradients which interact with charged particle cross'sections, causing them to accelerate. The expression "lines of force" is a misnomer when applied to magnetic fields. Actually, these lines are normals to the planes of magnetic moments. For them to be gradients, magnetic monopoles should have been detected by now. According to classical theory, magnetic fields derive from moving charges. In Structured Space Theory, some solid materials possess retentivity characteristics caused by sheer displacements in their aeon aggregate substructures which remain after the magnetizing forces which produced them are gone. These magnetic fields are not caused by continuing currents. Were this not so, the synthesized magnetic monopoles in motorotors would require there to be potential gradients capable of driving d-c currents in opposing directions concurrently through the same conductors.

Thrust Pumps

Reaction motors work because common, high energy density sources, apply forces to accelerate spacecraft in one direction while applying equal forces to accelerate combustion exhaust particles in the other. In both directions, the interactions involve matter being accelerated relative to the ambient aether. While the kinetic energy imparted to the spacecraft continues with it in the form of the aether flow patterns described, physical losses of the propellant mass and the energy expended in accelerating it cannot be recovered. For obvious reasons, such reaction motors must be mounted in the rear, outside the spacecraft.

Theoretically, thrust pumps should work by effectively generating available energy in the spacetime aether fore of each thrust pump and moving it to space aft thereof where it would be released.

CONCLUSION

As thrust pumps would not pollute the environment or eject anything, they could be mounted inside the spacecraft and interact with the aether there. They could be made available in standard sizes and thrust ratings and all would be controllable by readily available hardware systems. When available, these pumps should be about as efficient as electric motors or generators.

For inhabited vehicles, it may be possible to provide chambers in which a one "g" environment could be maintained. If so, vehicle accelerations exceeding levels passengers could normally endure might become feasible.

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NEXT DOCUMENT

An Alcubierre Drive Using Cosmic String

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Abstract

Configurations of positive and negative mass can be used for propulsion, as proposed by Bondi and Forward, or to create a reactionless "warp" displacement within the constraints of the general theory of relativity, as discussed by Alcubierre. One way to create such a configuration of positive and negative mass might be by use of loops of cosmic string.

1. Cosmic String

"Cosmic string" is a macroscopic one-dimensional "defect" in the geometry of space-time, which is allowed (but not required) by the general theory of relativity. Some theories of cosmology predict that cosmic string may have been formed in the early universe as a relic of the big bang.

A conventional cosmic string is a region surrounded by an angle deficit; that is, a closed circle around a cosmic string contains less than 360° of angle. This can be thought of as a wedge "missing" from the surrounding space; the embedding of the analogous structure in two dimensions is a cone. This results in a space-time which is flat at every point which is not on the one-dimensional string. The string itself has large mass (mass per unit length, μ, typically on the order of Jupiter mass per meter) and positive tension (T). From general relativity, it follows from the geometry that μ and T must be related to the angle deficit ϕ by:

$$\mu = T = \phi/8\pi G \tag{1}$$

Alternately, a cosmic string could be conceived with an angle excess, rather than a deficit. A closed circle around such a string would contain more than 360° of angle, corresponding to a wedge of "extra" space. The embedding of the analogous structure in two dimensions is a fluted-cone. From equation (1), such a string would have negative mass and negative tension, hence, we refer to it as a negative-mass cosmic string. (Negative pressure is the same as positive pressure: for a positive increment of length L, $dE/dL<0$).

Negative mass cosmic string have been discussed in the context of wormhole physics [1], and it has been proposed that such string may have been formed in the early universe [2] However, it should be noted that the question of whether negative mass objects are permitted by field theory is unresolved, and remains a topic of some debate in the physics literature.

Note that cosmic strings should not be confused with "superstrings". Cosmic strings are objects of macroscopic length and mass, subject to analysis by general relativity, while superstrings are objects of microscopic scale (ca 10^{-35} m), and are analyzed using the tools of quantum field theory. Both are one-dimensional objects, but otherwise the two are not related.

2. Cosmic String in Early Universe

It has been proposed that cosmic strings may have existed in the big-bang. Oscillations of cosmic string emit gravitational waves and lose energy; loops of conventional (positive mass) cosmic string would thus tend to shrink toward zero length. Hence, if (positive mass) cosmic string was produced in the beginning of the universe, it is believed to have long since vanished.

Loops of negative mass string also radiate energy in oscillations. However, since loss of energy increases the negative mass, such strings would grow, rather than shrink. This creates a "squiggle" of string surrounded by a shell of gravitational radiation. This process has not been studied. One likely result of the accumulation of angle excess would be a "baby universe" consisting of the negative mass string, coupled to the "ordinary" universe by only a narrow mouth.

3. Creation of Strings

Since angle excess or deficit extends to infinity, a lone string cannot be created, since it cannot match the flat-space boundary condition at infinity.

In principle, though, loops of cosmic string might be created in positive/negative mass pairs. This is a consequence of the fact that topological defects can only be created in pairs. Outside the regions bounded by the strings, any angle deficit must be balanced by angle excess in order to match boundary conditions at infinity

4. Bondi Dipole

A gravitational dipole of positive and negative mass can be used for propulsion. This application has been examined by Bondi [3] and elaborated by Forward [4,5]. One way to create such a dipole might be by use of loops of cosmic string.

A configuration of positive and negative mass can also be used for reactionless "warp" displacement, as discussed by Alcubierre [6]. Again, such a configuration of positive and negative mass might be created from cosmic string.

5. Possible Example of Alcubierre Dipole

An Alcubierre type drive requires four loops of cosmic string, two positive, two negative (figure 1). The negative mass loops vibrate, releasing energy. This lengthens the strings, and creates additional angle excess. The added angle excess "inflates" the surrounding space.

region of travel

negative string;
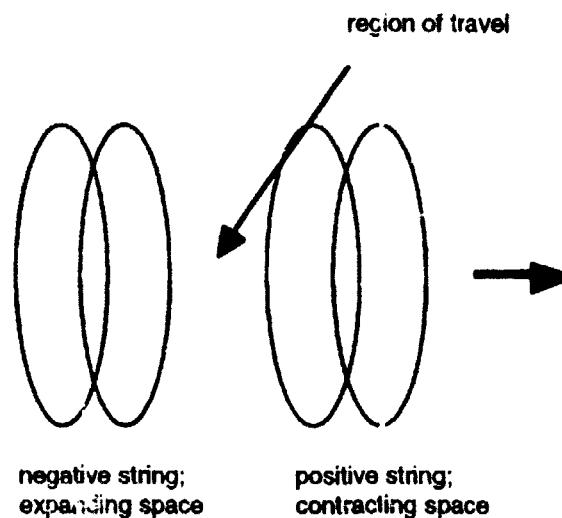expanding space

positive string;
contracting space

Figure 1: positive and negative mass dipole created using loops of positive and negative cosmic string.

The positive mass strings absorb energy. This lengthens the strings, and "contracts" space. In the process, the negative-mass string gains negative mass and the positive-mass string gains positive mass, so the entire system grows with time. However, r: '-- end of the process, the positive and negative mass strings can be canceled against each other, so there is no net accumulation of mass.

For each of the positive- and negative-mass regions, two loc, ... of string are used. This is engineered so that the vibrations of each string can be done in phase, allowing the radiation emitted from the negative mass string to be absorbed by the positive mass string.

6. Engineering Details Remain

Considerable engineering challenges remain unconsidered. How do you make cosmic string? Once made, how can you control it? The magnitude of the masses considered will be extremely high, likely to be more than the mass of Jupiter (positive and negative), and possibly considerably higher, in the stellar mass range. Controlling such masses, and phasing the emission and absorption of energy by each string, presents a considerable challenge.

Likewise, physics details remain. If creation of cosmic-string pairs is not forbidden, it would be expected to occur naturally in the vacuum, releasing energy. Since we do not see this, there must be some barrier to production of cosmic string pairs, perhaps in the form of a yet-unknown selection rule which forbids this occurrence.

7. Conclusions

Cosmic string is a form of negative-mass matter that is not currently known to be forbidden within the context of the general theory of relativity, and that could, in principle, be created from the vacuum in the form of matched loops of positive- and negative-mass loops. Such negative mass artifacts could be used for reactionless propulsion, as discussed by Bondi, Forward, and Alcubierre The engineering challenges, however, are daunting.

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NEXT DOCUMENT

USE OF AFM (ATOMIC FORCE MICROSCOPE) METHODS TO MEASURE VARIATIONS IN VACUUM ENERGY DENSITY AND VACUUM FORCES IN MICROFABRICATED STRUCTURES

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ABSTRACT:

The energy density of the zero-point fluctuations in a region can be investigated by measuring the Casimir force to move a surface in the region. The Atomic Force Microscope (AFM), which is based on a very sensitive microfabricated beam, can be used to measure the Casimir force. Microfabricated structures, made using silicon microfabrication technology, with submicron tolerances should provide advantages in the investigation of Casimir forces and the engineering of surfaces to control vacuum energies.

1. INTRODUCTION

a) Vacuum Energy Density

The measurement of energy density in the vacuum fluctuations of the zero point electromagnetic field is important for several reasons:

1) Vacuum fluctuation phenomena are predicted by Quantum Electrodynamics (QED), which is the most accurately verified theory known to scientists. QED has made predictions of energy levels (e.g. Lamb Shift splitting of 2s-2p levels in the hydrogen atom), magnetic moments (spin-orbit corrections to g-factor), and radiative corrections to scattering cross sections to an accuracy of better than 1 part in 10^8. Thus we have an accurate and well accepted theory which can be used to guide experimental efforts, and to provide a comparison for our experimental results

2) QED predicts an enormous energy density of the vacuum, tens of orders of magnitude greater than the energy density of matter. The ability to transfer energy to the vacuum fluctuations at even a small fraction of this enormous energy density could result in a major scientific and technological breakthrough. In fact, QED predicts an infinite vacuum fluctuation energy density. The energy can be made finite only by invoking a short wavelength cutoff. One very conservative choice for the short wavelength limit is the Compton wavelength of the proton. The resulting energy density is about 10^{28} joules/cc. To appreciate the enormity of this number, note how large it is compared to the chemical energy of a fuel, 10^5 joules/cc, to the energy density of matter, 10^{14} joules/cc, and to the energy density of a nucleus, 10^{24} joules/cc. If the Plank length is taken for a cutoff, as is often suggested, then the vacuum energy density is over 50 orders of magnitude greater!

In formal QED computations, often this divergent portion of the energy density is removed by v. ac's ad hoc mathematical techniques [Brown and Maclay, 1969; Ambjorn and Wolfram, 1983], and only the changes in the energy density of the vacuum fluctuations are computed.

3) There are systems in which the vacuum fluctuation fields can be altered and controlled, which suggests that engineered devices are possible. The most notable example is th. Casimir force, which is the force between two conducting plates in a vacuum that varies as $1/d^4$ and dominates the force when the separation is submicron [Plunien et al, 1986]. This force has been observed experimentally [Lamoreaux, 1997]. The presence of the Casimir force is predicted by QED, which is used to compute the change in the vacuum energy density due to the attenuation of modes because of the conductive plates. The force can be interpreted as arising because of the lower energy density between the plates. In general the vacuum field is altered by the presence of any material that alters the boundary conditions of the electromagnetic field.

4) The Casimir force and other fluctuation phenomena characteristic of the vacuum photon field may be very useful in new engineering applications. Energy can be extracted from the vacuum by letting two plates attract each other by the Casimir force. There is the possibility of revolutionary new technology embodied in microdevices exploiting vacuum fluctuations [Forward 1984; Shrivastava et al 1985]. The applications may be broad in range.

5) Supporting "enabling" technologies have developed that may be very useful in exploiting vacuum fluctuation phenomena, in particular the r solution i. microfabrication technology allows the economical construction of practical devices with submicron accu. c; At the Microfabrication Applications Laboratory (MAL) at the University of Illinois at Chicago we use anisotri .. etching and micromachining of silicon to build electrical, mechanical and electromechanical devices with micron sized dimensions (Peterson 1982). It is with such devices that we expect breakthroughs.

6) Vacuum fluctuation phenomena are very general, and are predicted to occur with all fields, including photon fields, electron-positron fields, meson fields, etc. Certain general results are expected from the study of fluctuation phenomena. The photon field is the proper field to study initially since vacuum fluctuations of the photon field will have experimental consequences that are the most easily observable. This is true because the photon has zero rest mass, consequently the threshold energy to create a photon pair is very low compared to that required to create an electron-positron pair. Useful concepts and devices for photon fields may one day be applied to other fields as technology progresses.

b) Use of the Casimir Force to measure vacuum energy density

Rigorous computations of the change in the vacuum energy density for different geometries have shed some light on the interpretation of the vacuum energy density and the Casimir force. QED calculations have shown that Casimir's model of the force due to vacuum fluctuations was misleading in its simplicity, and that it is probably through serendipity that he obtained the correct result. For example, based on his simplified model, the Casimir force between two conducting surfaces of arbitrary shape would always be attractive, no matter what the specific geometry. However rigorous field theoretic computations predict that both the magnitude and direction of the Casimir force is strongly dependent on the specific geometry, and is repulsive in many cases. The Casimir force on a spherical conducting shell or a cube is outward, not inward [Boyer, 1968; Milton, DeRaad, and Schwinger, 1978]. Table 2 shows the variation in the magnitude and sign of the energy density for several simple geometries.

TABLE 2. CASIMIR FORCE FOR DIFFERENT CONDUCTIVE GEOMETRIES

PARALLEL PLATE	CUBE	SPHERE
-0.0069hc/a⁴	+0.092hc/na⁴	+0.015hc/nr⁴

As the relative dimensions change from a cube into an infinite parallel plate, the force changes from a repulsive force to zero force, to an attractive force[Ambjorn and Wolfram, 1983]. Figure 1 shows a contour plot of the electromagnetic vacuum energy density for a perfectly conducting $a_1 \times a_2 \times a_3$ box. In the region with $a_1 = a_2 = a_3$ (near the origin) the energy density is positive and a maximum for the cubic box. When one dimension, e.g. a_3, becomes equal to about 3.3 ($a_3/a_1 = 3.25$), then the energy density is zero (dark line), i.e. equals the free field density with no surfaces present. If a_3 increases beyond $3.25a_1$, then the energy density becomes negative. The infinite parallel plate Casimir force as computed by Casimir or the Lifshitz equation represents the asymptotic case where both a_3/a_1 and a_2/a_1 are very large. The Casimir force would tend to deform an incompressible spherical "bubble" with conductive walls into a long tube (with the same volume), thereby minimizing the free energy of the system.

The only theoretical predictions that have been verified are for the $1/a^4$ dependence of the Casimir force for parallel plate geometry. Experiments are needed to measure the Casimir force between metals at submicron separations, and for regions with different geometries, with positive and negative energy densities. These experiments will lay the foundation of knowledge required to develop devices engineered to exploit the vacuum fluctuations of the electromagnetic field.

c) Use of Atomic Force Microscope to measure Casimir Forces

Previous experimenters have relied on custom-made instrumentation, with relatively large components to make measurements of the Casimir force in the parallel-plate configuration. With very few attempts made at measuring Casimir forces in other geometric configurations, much of the theory remains unsubstantiated. What makes such measurements more difficult than those of the parallel-plate Casimir force are the extremely small dimensions of Casimir structures required, and the instrumentation challenges associated with proper alignment of such structures during measurements.

The Atomic Force Microscope (AFM) integrates a number of features essential for measurements of Casimir forces in the parallel-plate and in many other configurations. These features include a mechanical force sensor with the necessary sensitivity, capability of detecting the mechanical response of the force sensor, fine-positioning capability with extremely good accuracy, and built-in control electronics necessary to control the separation between the elements carrying the Casimir-active structures.

The force sensor in an AFM is a cantilever beam made using silicon microfabrication technology. The beams are typically several hundred micrometers long and about 30 microns wide. The deflection of the cantilever as it is scanned over a surface is measured by reflecting a laser diode spot off a reflective surface on the cantilever. The diode strikes the surface of a photodiode that is divided into two (or sometimes four) sections. The change in the relative current from the different sections is used to infer the cantilever deflection (Figure 2). Deflections of one nanometer can be readily measured. The AFM can operate is static or contact mode, or in tapping mode in which the p is oscillating. If useful devices could be made with AFM methods (e.g. vacuum energy monitor or motor) the icon microfabrication technology could be used to make the devices.

Using advanced MEMS fabrication technology, AFM cantilevers with atto-newton-per-meter (10-18) spring constants have recently been fabricated at Stanford University. Although such force sensitivities make the AFM cantilever extremely susceptible to thermal noise in the environment, current commercial cantilevers with lower sensitivity are routinely used to measure sub-nano-Newton forces in laboratories.

2. EXPERIMENTAL DESIGN

We have used a commercial AFM (Digital Instruments NanoScope MultiMode(AFM) for measurement of the Casimir force in the parallel plate geometry. To work around the problem of maintaining two flat surfaces parallel, we have used one flat surfaces and one curved surface, which in a small area of a hemisphere approximates a flat surface.

In one of our experiments, the flat surface was that of a metal-coated AFM cantilever without the integrated sharp tip, which in normal AFM cantilevers is used for topographic imaging. In this experiment, the curved surface was that of a ball of mercury, which we deposited on a metal-coated substrate, such as a silicon die.

In the other experiment, the mercury ball was attached to the AFM micro-cantilever. The mercury-loaded cantilever was then held above a metal-coated, flat, smooth surface, such as a die from a polished silicon wafer, or muscovite mica, or highly oriented pyrolytic graphite (HOPG) (Figure 3). We have used cantilevers from 150 to 450 micrometers long and of various materials to control the force constant. The mercury balls are stable on the cantilever tips.

The separation between the surfaces of the Casimir-active structures was varied by raising or lowering either the AFM cantilever or the substrate. Coarse positioning was done using a stepper motor, which moved the AFM cantilever, and fine positioning was done using a piezoelectric element, which in principle can move the substrate with sub-angstrom resolution. Since we did not use any feedback to control the separation, we did not take advantage of the sub-angstrom resolution fine-positioning capability of the AFM.

We performed all our experiments in vacuum, at a pressure of 0.1 atmosphere or less, in a bell jar.

3. PRELIMINARY RESULTS

The simplest measurement type which the AFM offers is the static deflection measurement using the Force-versus-Distance (FD) curve. This is shown for an experiment in which a mercury ball on the end of a cantilever was brought near a polished silicon wafer (Figure 4). The cantilever deflection is plotted along the vertical axis. The abscissa is the separation between the cantilever and the substrate, which is varied by piezoelectrically moving the substrate up and down, which moves the sample closer to and farther away from the AFM cantilever. The points on the far right correspond to the largest separation.

The curvature seen in Figure 4a indicates the presence of a force. In this particular experiment the force proved to be due to the presence of static charges on the surfaces, even though metal-coated substrates and cantilevers were used. After proper electrical connection was made between the surfaces, the flat, slightly tilted, force deflection (FD) curve shown in Figure 4b was obtained. The disappearance of the force causing the curvature indicates that the force was primarily due to static charge. The separation between the surfaces was several microns at the closest approach so the Casimir forces were small.

We suspect that even with the proper "grounding" precautions taken, the contact potential between the Casimir-active structures will contribute a purely electrostatic component to the force measured. Lamoreaux has recently shown that it is necessary to offset this contact potential in Casimir force measurements [Lamoreaux, 1997]. Some commercial AFM's incorporate the necessary hardware to offset this contact potential in an operational mode called "Kelvin Probe Microscopy". Here, the contact potential is detected using a dynamic method involving the AFM cantilever's fundamental resonance frequency, and a potential equal in magnitude to the contact potential and opposite in polarity is applied between the sample and the AFM tip during the imaging. In an experiment of the types we have attempted will have the AFM tip and the sample replaced with the Casimir-active surfaces.

The absolute separation between the surfaces is not known during this experiment, the change of this separation is known. The absolute separation was later determined from the jump-to-contact separation between the surfaces. This was done by modulating the relative separation by a known amount (typically about 1 micrometer) while incrementally reducing the absolute separation by a small fraction of the modulation length. Typically the absolute separation was reduced in increments of 5nm to 50nm. The static deflection showed on the FD curves and became larger with each incremental reduction in the absolute separation. Finally, the static deflection curve showed the jump to contact as the absolute separation was reduced to the point where the force on the cantilever was too large (i.e., the spring constant of the cantilever was too small to hold the surfaces from jumping into contact).

The AFM also offers dynamic measurements of the AFM cantilever's frequency and phase response to an

250

alternating-current drive voltage. This drive voltage is typically applied to a small piezoelectric stack which shakes the AFM cantilever substrate by a small amount. Near the cantilever's resonance frequencies, this motion is amplified by the cantilever and detected by the split photodiode detector. The frequency and the amplitude of the drive signal can be controlled with good accuracy, and the amplitude response and the phase lead (lag) of the cantilever's motion can be measured very accurately at a given frequency. Also, cantilever's response can be monitored at range of frequen ... sweeping the frequency of the drive signal. Attractive forces shift the resonance frequency of the AFM cantilever to lower values [5]. A phase shift corresponds to this frequency shift and both can be measured with the A ... We have repeatedly and reproducibly measured such frequency and phase shifts of the cantilever due to electrostatic interactions.

4. PROPOSED EXPERIMENTS

a) Method to measure energy density in parallelepiped cavities

As discussed in Section 1, the predicted energy density in parallelepiped cavities can vary from positive, to zero, to negative as the ratio of the walls changes. A proposed method of measuring the properties of these fascinating submicron cavities is shown in Figure 4. Using photolithography, we can define small rectangular regions. The depth of these regions can be determined by etching. By removing a sacrificial layer, cantilevers or static membranes are made that serve at the top to each parallelepiped region. Calibration is obtained by using the same type membranes with different depth cavities or no cavity in the silicon. The deflection of the membrane or cantilever is determined using AFM methods.

If the sides are in the correct ratio (about 1:1:3.3) the cantilever or membrane would tend to vibrate due to vacuum energy variations with position. The equilibrium position would correspond to energy density equal to the free field, positive deflections to energy less than free field, and negative deflections to energies greater than free field.

b) Structure to measure energy exchange with the vacuum

Figure 5 shows a mesa structure than could be used to measure the exchange of energy with the vacuum via the Casimir force. The movable platform is designed to be controlled by electrostatic forces from four capacitors on the surface (used to insure parallelism). Gas pressure can be used to balance the Casimir force at separations from 10-100 nm. (See Table 3 for the relative forces). Moving mechanical microsystems with Casimir forces have been modeled [Serry, Walliser, and Maclay, 1995].

TABLE 3: Comparison of Casimir force and electrostatic force for conductive parallel plates. The forces are given as a function of the plate separation "a". The Casimir force is given in N/m^2 and torr. The voltage applied is assumed to be 0.1 volt, and the approximate corresponding electric field is given also.

Separation a nm	Casimir force N/m^2	Casimir force torr	Electrostatic Force N/m^2	Elec. Field V/m
1.0	1.3×10^9	9.8×10^6	7.0×10^3	10^8
10.	1.3×10^5	980.	70.	10^7
100.	13.	0.1	0.70	10^6
1000.	1.3×10^{-3}	9.8×10^{-6}	7.0×10^{-3}	10^5

4. CONCLUSIONS

Atomic Force Microscope (AFM) methods hold promise as a means of exploring Casimir forces. Coupling AFM methods with silicon microfabrication technology may be a realistic approach to vacuum energy measurements and may produce vacuum devices of interest.

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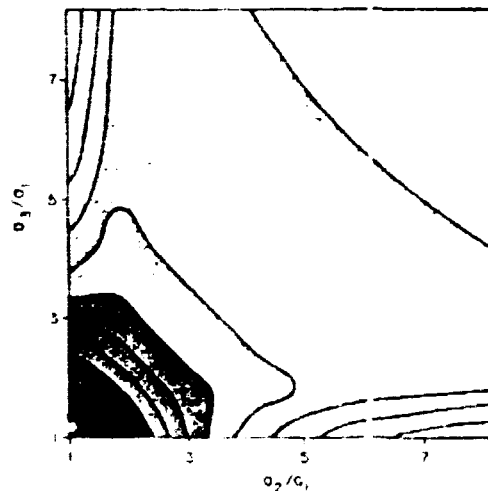
Figure 1 Contour plot for vacuum energy density of a parallelepiped cavity with sides a_1, a_2, and a_3 [Ambjorn and Wolfram, 1983].
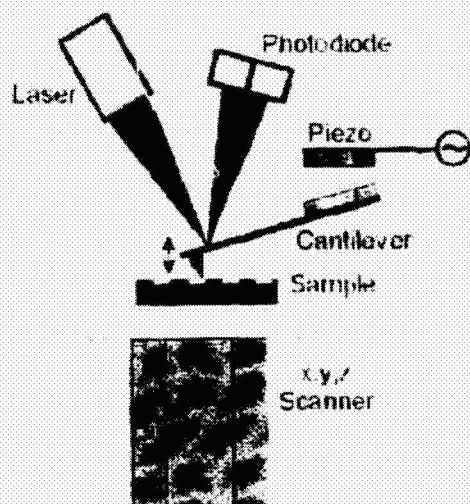
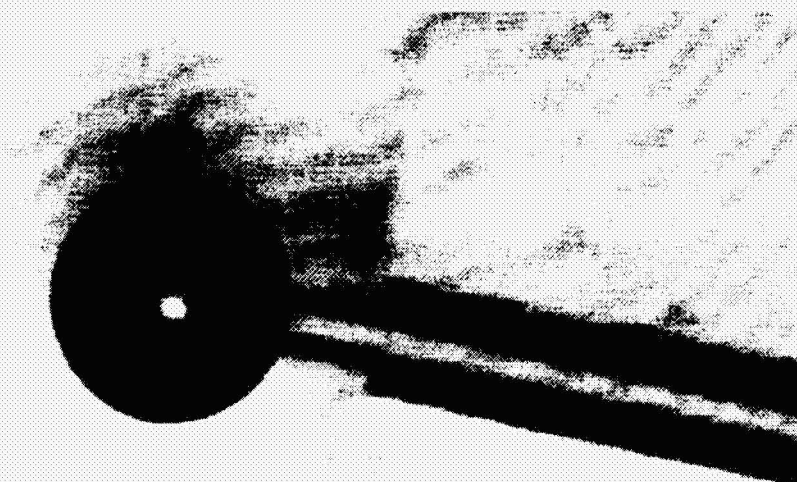Figure 2. Schematic of the operating principle of the Atomic Force Microscope.

Figure 3a. Photograph of a cantilever 225 micrometers long with a 150 micrometer diameter sphere of mercury at the end. The mercury is held in place by depositing a gold layer at the end of the cantilever.
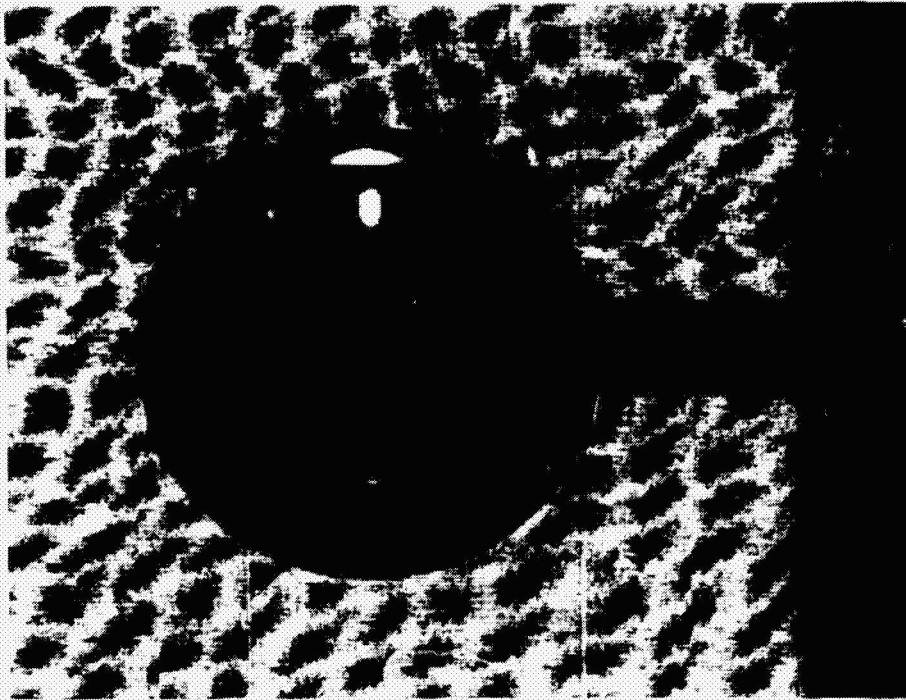
Figure 3b. A 450 micrometer cantilever with a 400 micrometer diameter mercury ball.
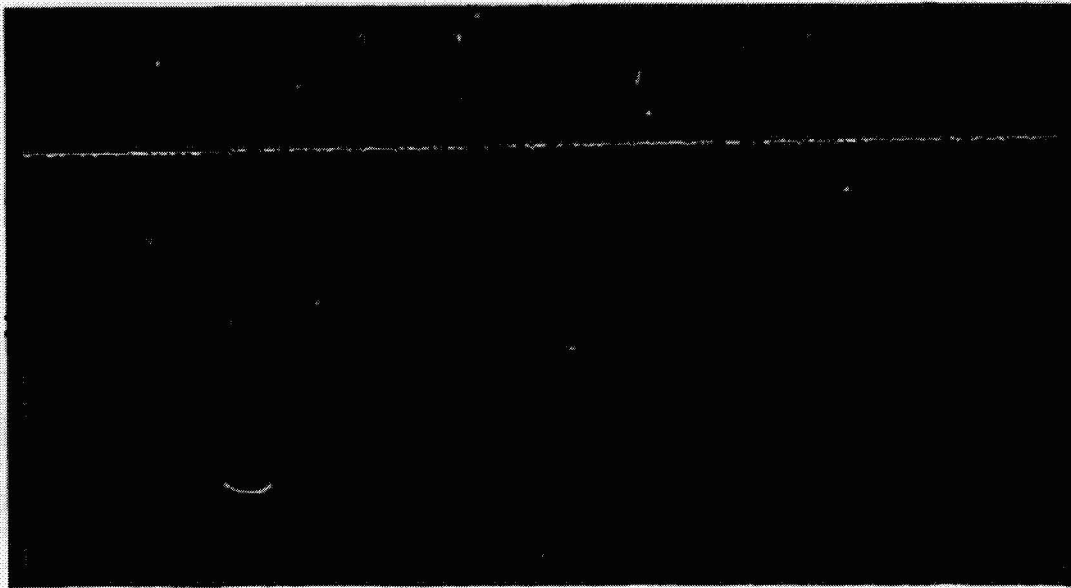

Figure 4a. Force Distance (FD) curve in the presence of excess electrostatic charges. The deflection of the cantilever with a mercury ball is given as a function of the distance of a polished silicon wafer to the cantilever

Figure 4b. Force Distance (FD) curve after the elimination of the electrostatic charges.

Measure Deformation by the AFM

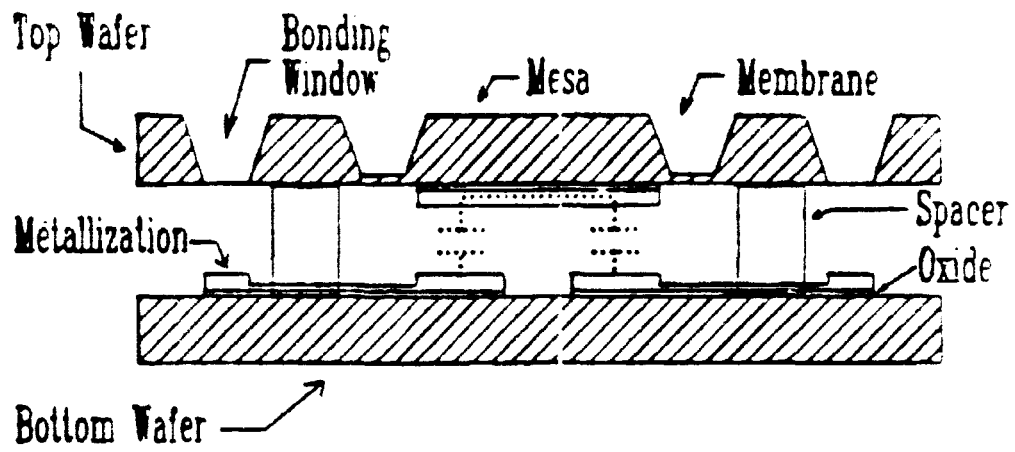Figure 5. Side and top view of a proposed method to measure the energy density of parallelepiped cavities.

Figure 6. Moveable Casimir mesa structure formed from 2 micromachined wafers bonded together.

NEXT DOCUMENT

The Zero-Point Energy (ZPE) Laser and Interstellar Travel

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ABSTRACT:

One conceptual method of utilizing Zero-Point Vacuum Fluctuation Energy (ZPE) in interstellar travel is to utilize the ZPE to "pump" a gas or free-electron laser. Spacecraft acceleration is affected by the radiation pressure of the laser-emitted photons. Waste heat is emitted by laser walls, which must be constructed of low-density, high-melting point material. Deceleration requires either the laser to be operated in reverse or application of a magnetic-field brake or "magsail." Non-relativistic dynamics are derived and used to estimate the travel time to various nearby stars as a function of ZPE-reactor specific mass. Use of "reasonable" values for spacecraft mass, ZPE-reactor power, laser efficiency, wall material and thickness, starship velocity at commencement of ZPE-laser operation and deceleration time reveals that the ZPE-laser can greatly extend the range of a "generation" ship. Very optimistic projections for ZPE-reactor specific mass indicate that one-way travel to the Alpha Centauri system within a human lifetime may not be impossible.

Introduction: A Speculative Possibility

Our universe may have been created from a stabilized quantum-level fluctuation in the universal vacuum that converted "virtual photons" into "real photons". A number of researchers have recently proposed that it may not be impossible for human technology to obtain zero-point energy (ZPE) from the universal vacuum [1-3].

Anomolous heat has been produced in certain hydrogen-loaded electrolytic cells under controlled conditions and repeated by several independent laboratories [4-6]. A possible explanation for this phenomenon is sonoluminescence—sound-driven gas bubbles in water have been observed to emit pulses of ultraviolet radiation with a very high blackbody temperature.

A very provocative (and controversial) theory has recently been proposed that explains sonoluminescence as a "dynamic Casimir effect," in which the rapidly oscillating sound-driven bubble converts virtual vacuum photons to real photons, offering the possibility of universal, "free" energy in the form of ultraviolet photons [7-9].

If confirmed, such an energy source would be a major boon for interplanetary and interstellar space travel. The earliest proposed interstellar ZPE application (to this author's knowledge) was the quantum ramjet [10,11]. In such a craft, interstellar ions are collected as reaction mass by an electromagnetic "ramscoop" [12] and then accelerated by energy obtained from a hypothetical ZPE-reactor. Although the quantum ramjet would hypothetically be capable of relativistic velocities, its performance would in practice be limited by variations in local interstellar medium's density.

While preparing his recent science-fiction novel *Encounter with Tiber* (Warner, NY, 1996), co-authored with John Barnes, Apollo 11 astronaut Dr. Buzz Aldrin challenged this author to develop the concept of a not-impossible very-high performance spacecraft that does not require the enormous expense of antimatter and is free of some of the technical problems of the ramjet.

In response, this author proposed the ZPE photon-drive, in which stabilized vacuum-derived photons are injected into a large laser aboard the spacecraft. The spacecraft is propelled through interstellar space by the radiation pressure of the emitted laser beam. This is a non-nuclear version of the laser propulsion system considered by Matloff and Chiu in 1970 [13].

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Although the very high performance of the Wirtz/Barnes fictional starship does not seem feasible, reasonable assumptions for ZPE-reactor specific mass reveal that the range of the "1000-year ark" is greatly extended over nuclear-pulse or solar-sail versions [14,15]. As shown in the following analysis, very optimistic ZPE-reactor specific-mass assumptions may allow for one-way travel to the nearest stars within a human lifetime.

Preliminary Design Considerations for the ZPE Photon Drive

Figure 1 presents a schematic diagram of the ZPE photon drive concept. Zero-point energy is supplied by reactor R and used to pump gas laser L. Some of the ZPE from R therefore appears in the laser photon stream P; the remainder is radiated as heat energy (RHE) through the walls of the cylindrical laser. Unlike nuclear-propulsion proposals, extensive shielding is presumed to be unnecessary between ZPE reactor system and the human-occupied habitat H. As discussed below, tungsten is assumed to be the laser wall material.

The total mass of the spacecraft is presumed to be in the range $10^6 - 10^7$ kg. This is within an order of magnitude of the mission mass allotments of Forward, Matloff/Mallove, and Vulpetti [16-18]. Laser action could be started from Earth-orbit. Alternatively, a hyperthin solar sail and a close perihelion pass could be used to commence laser operation from an initial velocity (v_0) as high as about 0.003c, where "c" is the speed of light [15,19]. The laser is assumed to operate and provide constant starship acceleration until the spacecraft commences deceleration.

Deceleration at the destination solar system requires two stages. For deceleration from terminal velocity to 0.002-0.003c, a magsail is used to reflect interstellar ions [20]. Final deceleration to planetary velocities utilizes the ZPE-pumped laser firing after the ship is rotated 180 degrees; alternatively, a solar sail is unfurled and directed towards the destination star [21]. The required deceleration time, t_d is estimated as 30 years. (If flight times much longer than those considered here are tolerable, the spacecraft could be rotated 180 degrees at the half-way point and ZPE-pumped laser radiation used for the entire deceleration process.)

Derivation of (Newtonian) ZPE Photon-Drive Kinematics

Except when otherwise noted, all quantities in this analysis are in MKS (SI) units. The discussion of ZPE kinematics begins with the definitions of certain quantities.

M_R = ZPE reactor mass , κ = ZPE reactor specific mass (kw/kg)

P_R = ZPE reactor power (watts) = $1000\kappa M_R$, η = ZPE laser efficiency

P_L = ZPE laser power = ηP_R = $1000\kappa\eta M_R$

P_{wh} = waste heat radiated by ZPE laser = $1000\kappa(1-\eta)M_R$

D_L = laser diameter, L_L = laser length, ρ_L = laser wall density, t_L = laser wall thickness

A_L = laser (cylindrical) area = $\pi D_L L_L$

M_L = laser mass = $A_L \rho_L t_L$ = $\pi D_L L_L \rho_L t_L$ [Note: $A_L = M_L/(\rho_L t_L)$] , M_H = habitat mass

F_{wl} = waste-heat flux radiated laser walls (watts/m^2) = P_{wh}/A_L = $1000\kappa(1-\eta)M_R \rho_L t_L/M_L$

ε = laser wall material emissivity , T = laser wall greybody temperature

σ = Stefan-Boltzmann constant = 5.67×10^{-8} (MKS units) , c = speed of light (3×10^8 m/sec)

t_w = interstellar transfer time, years , v_0 = ship velocity at start of ZPE laser operation, fraction of c

d_w = distance travelled during ZPE-laser operation, light years

t_d = deceleration time, years , v_p = peak starship velocity, fraction of c

The first step in this derivation is to apply the Stefan-Boltzmann Law to the waste heat radiated through the laser wall: $F_{wl} = \varepsilon\sigma T^4$. Substituting and rearranging, the laser mass is expressed (assuming no waste-heat radiation through laser endcaps):

$$M_L = \frac{1000\kappa(1-\eta)}{\varepsilon\sigma T^4} \cdot M_R \rho_L t_L$$

(1)

Applying the standard equation for radiation-pressure acceleration, the non-relativistic spacecraft acceleration (dv/dt) during laser-beam operation is expressed as $P_L/M_s c$, where M_s is the total ship mass. Total ship mass is parameterized $M_s = M_H + M_R + M_L$, where M_H is the habitat mass. If we next define dv_g/dt as the ship acceleration in units of Earth surface gravities (g) or fraction of speed of light ($fsol/year$.

$$\frac{dv_g}{dt} = \frac{1000\,\kappa\eta}{9.8c\left[1 + \frac{1000\,\kappa(1-\eta)}{\varepsilon\sigma T^4}\rho_L t_L + \frac{M_H}{M_s}\right]}$$

g or $fsol/year$. (2)

Elementary kinematics can be applied to derive interstellar transfer time for various interstellar travel distances d_H, for the case of an initial velocity at the start of ZPE laser operation v_0 and a deceleration time of t_d years:

$$t_{gr} = \frac{-v_0 + \sqrt{v_0^2 + 2d_{H}\frac{dv_g}{dt}}}{\frac{dv_g}{dt}} + t_d$$

years. (3)

Finally, the peak starship velocity can be expressed:

$$v_p = \frac{dv_g}{dt}(t_{gr} - t_d) + v_0$$

fsol. (4)

Before proceeding to further design analysis and rigorous calculations using the above formulas, it is instructive to approximately examine the case of a ZPE-laser starship in which the habitat mass and laser mass are together about 30% of the total ship mass. Substituting $M_s = 1.2M_R$, Eq. (2) is replaced by $dv_g/dt = 2.83 \times 10^{-7}\kappa\eta$ (g or $fsol/yr$). For a 50% laser efficiency, starship acceleration is approximately $1.41 \times 10^{-7}\kappa$ (g or $fsol/yr$). For an acceleration of about 0.00014 g, the ZPE-reactor specific mass must be about 1000 kw/kg. An acceleration of about 0.014 g requires a ZPE-reactor specific mass of 10^5 kw/kg.

Laser and ZPE-Reactor Design Considerations

If 5×10^{12} watts are generated by the ZPE reactor and the laser efficiency is 50%, 2.5×10^{12} watts of waste heat must be radiated by the laser walls. If it is assumed that all waste heat is radiated through the cylindrical walls of the laser and none through the laser endcaps (mirrors). In deciding what material to construct the laser walls from, we apply the following criteria:

(1) metallic walls are preferable because we might like to transfer heat from laser interior or ZPE reactor to laser walls;

(2) a high melting point metal is required to minimize laser wall area.

(3) the wall material specific gravity should be as low as possible.

From blackbody-radiation theory [22], it is easily shown that in choosing suitable wall material, we require to minimize the product of wall material specific gravity and the inverse fourth power of the candidate wall material melting point.

Referring to the *Handbook of Chemistry and Physics* [23], candidate laser wall materials include molybdenum, niobium, osmium, rhenium, tantalum, and tungsten. Tungsten is superior in light of the selection process outlined above. This metal has a melting point of about 3670 K and a specific gravity of 19.3.

Maintaining laser wall temperatures at 3500 K, we employ a GEH-15-C radiation calculator (described in Ref. 20) to learn that the laser's cylindrical walls must emit about 8.5×10^6 watt/m^2 as waste heat. (Identical results are obtained by applying the Stefan-Boltzman Law [22]). Assuming that none of the 2.5×10^{12} watts of waste heat is radiated by laser endcaps, the required area of the laser's cylindrical walls is about 3×10^5 m^2.

Assuming (somewhat arbitrarily) that laser length L is 10X laser diameter D, the required (cylindrical) laser dimensions for energy emission are D @ 100 m and L @ 1000 m. If we constrain laser wall mass to 3×10^4 kg, the thickness of the tungsten laser walls will be about 5 microns.

Although metallic laser walls could certainly be thinner than this, the laser mass allotment mentioned could also include heat transferring apparatus. If a 1-3 g solar perihelion maneuver is required to achieve a solar-system escape velocity of about 0.003c before commencement of laser operation, the laser would initially be disassembled and would be constructed after the craft has departed from the solar system.

The volume of the laser cavity is estimated as 8×10^6 m^3, which results in a laser internal power density of about 2×10^5 watt/m^3. This is not dissimilar from the power densities of some early CO_2 lasers [24].

We next assume that the laser gas density is 10^{-5} kg/m^3 (about 10^{-5} of the Earth's ground-level atmospheric density). Since 1 atmosphere pressure @ 1000 Torr [25], the gas pressure in the laser cavity approximates 0.01 Torr. Reference to a laser handbook reveals that many continuous-wave (CW) laser transitions occur at gas pressures not unlike this value [26]. The mass of the gas required to fill the laser cavity is approximately 100 kg, so the spacecraft could carry an ample amount of spare gas.

The design of the ZPE reactor is, at this time, much more speculative than that of the laser. Although the concept is theoretically tantalizing, experimental confirmation has not yet been achieved. Even if an experimental confirmation of ZPE is soon announced, we are still a very long way from the efficient, low-mass and very reliable devices required to propel a long-duration interstellar flight.

Therefore, in the following analysis, a bounded ZPE-reactor specific mass is assumed. The lowest reactor specific mass considered is 100 kw/kg, about the same as an efficient thin-film solar sail in Earth-orbit, oriented normal to the Sun [27]. The highest reactor specific mass considered is 10,000 kw/kg, about the same as very optimistic projections of very advanced, high-power nuclear fission reactors for space application [28].

Conclusions: ZPE Photon-Drive Performance

Using a Symbolic Algebra software package (MathCad^{TM}), Equations (1-4) were solved for a number of ZPE starship configurations. Some results are presented in Table 1, for a 50% laser efficiency, a 5-micron tungsten laser wall thickness, a starship velocity at commencement of laser operation of 0.003c, a 30 year deceleration time, and a habitat mass of 0.1 X ZPE reactor mass.

In all cases, laser mass is small enough so that the acceleration approximation at the end of the Kinematics Section is close to the computed accelerations. Peak velocities for the 10,000 kw/kg case are respectively 0.109c, 0.175c, and 0.203c for travel distances of 4.3, 11.2, and 21 light years respectively. For higher values of reactor specific mass, a relativistic kinematics derivation will be necessary.

Consider, for example, the case of a 2×10^7 kg ZPE-reactor mass and a 2×10^6 kg habitat mass. For a 1000 kw/kg reactor specific mass, the computed laser mass is 2.9×10^5 kg. The total power generated by the reactor is 2×10^{13} watts, about equivalent to the total present-day terrestrial energy consumption. This craft requires 249, 394, and 535 years of travel time to reach destinations 4.4, 11.2, and 21 light years distant. Laser dimensions can be calculated using the results of Sections 3 and 4.

Even lower values of reactor specific mass are useful for extending the range of the "1000-year ark". But the higher values indicate that one-way travel to the nearest stars within a human lifetime may not be impossible, if an efficient and low-mass ZPE reactor can be developed.

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Figure 1. Schematic Diagram of ZPE Photon Drive
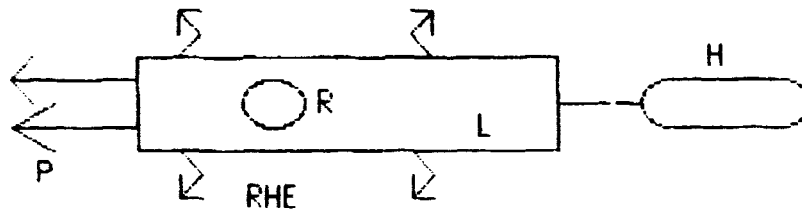
R=ZPE Reactor , L=laser, P=laser photon stream,
RHE=radiated waste heat, H=human space habitat

Table 1. Performance of ZPE-Photon Drive starships

κ (reactor specific mass)	M_L/M_H	Peak Acc	Time to Various Stars		
			α Cent (4.3 l yr)	τ Ceti (11.2 lt yr)	β Hyrd (21 lt yr)
100 kw/kg	0.0014	1.5 E-5 g	607 yr	1056 yr	1496 yr
200	0.0028	3.1E-5	470	790	1104
500	0.0071	7.7E-5	328	532	731
1000	0.014	1.5E-4	249	394	535
2000	0.028	3.0E-4	189	293	393
5000	0.071	7.3E-4	135	202	266
10000	0.14	1.4E-3	107	156	203

The initial velocity for the configuration analyzed is 0.003 c, the tungsten
laser wall thickness is 5 microns, the laser efficiency is 50%, habitat mass is
10% of ZPE reactor mass and a 30-year deceleration time is assumed.

NEXT
DOCUMENT

The Challenge To Create The Space Drive

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ABSTRACT

To travel to our neighboring stars as practically as envisioned by science fiction, breakthroughs in science are required. One of these breakthroughs is to discover a self-contained means of propulsion that requires no propellant. To chart a path toward such a discovery, seven hypothetical space drives are presented to illustrate the specific unsolved challenges and associated research objectives toward this ambition. One research objective is to discover a means to asymmetrically interact with the electromagnetic fluctuations of the vacuum. Another is to develop a physics that describes inertia, gravity, or the properties of spacetime as a function of electromagnetics that leads to using electromagnetic technology for inducing propulsive forces. Another is to determine if negative mass exists or if its properties can be synthesized. An alternative approach that covers the possibility that negative mass might not exist is to develop a formalism of Mach's Principle or reformulate ether concepts to lay a foundation for addressing reaction forces and conservation of momentum with space drives.

INTRODUCTION

New theories have emerged suggesting that gravitational and inertial forces are caused by interactions with the electromagnetic fluctuations of the vacuum. [1,2] There have also been studies suggesting experimental tests for mass-altering affects [3], and a theory suggesting a "warp drive." [4] With the emergence of such new possibilities, it may be time to revisit the notion of creating the visionary "space drive." Space drive, as defined here, is an idealized form of propulsion where the fundamental properties of matter and spacetime are used to create propulsive forces anywhere in space without having to carry and expel a reaction mass. Such an achievement would revolutionize space travel as it would circumvent the present constraint of requiring propellant. Without such a discovery, human interstellar exploration may not be possible. [5]

One of the missing prerequisites to achieving this breakthrough is having a starting point for the research; a description of the specific problems to be solved. Without this first step of the Scientific Method there is no framework against which to assess, augment, and apply emerging science to the goal of creating a space drive. To provide such a starting point, a variety of hypothetical space drives are presented and analyzed to identify the specific problems that have to be solved to make such schemes plausible.

PROBLEM FORMULATION METHOD

A NASA precedent for systematically seeking revolutionary capabilities is the "Horizon Mission Methodology." [6] This method forces paradigm shifts beyond extrapolations of existing technologies by using *impossible* hypothetical mission goals to solicit new solutions. By setting impossible goals, the common practice of limiting visions to extrapolations of existing solutions is prevented. This method forces one to look beyond existing methods and specify the technologies and sciences that are genuinely needed to solve the problem, whether the solutions exist yet or not.

The theme of the Horizon Mission Methodology is followed here. The "impossible" goal targeted in this exercise is to create a space drive. In the spirit of the Horizon Methodology, the envisioned propulsion methods can entertain the possibility of physics yet to be discovered. However, to ensure that the envisioned methods are consistent with firmly established physics, the analysis imposes the constraints of conservation of momentum and energy, and requires that observed natural phenomena are not contradicted. From imposing these constraints, the characteristics needed to make space drives plausible can be identified.

Seven different hypothetical propulsion concepts were created for thi; exercise. These concepts were envisioned by considering analogies to collision forces and interactions with fields to produce net forces.

HYPOTHETICAL COLLISION SAILS

One means to produce force is collisions. Conventional rocket prop ilsion is fundamentally based on the collisions between the propellant and the rocket. These collisions thrust the rocket in one direction and the propellant in the other.

To entertain the analogy of collision forces for a space drive, consider the supposition that space contains a background of some form of isotropic medium that is constantly impinging on all sides of a vehicle. This medium could be a collection of randomly moving particles or electromagnetic waves, either of which possess momentum. If the collisions on the front of a vehicle could be lessened and/or the collisions on the back enhanced, a net propulsive force would result. Three variations of such a hypothetical collision-sail are illustrated in Fig. 1 through 3. In all these illustrations, the rectangle represents a cross sectional element of the sail and the wavy lines represent impinging waves of the isotropic radiative medium. The large arrow indicates the direction of acceleration.

For any of these concepts to work, there must be a real background medium in space. This medium must have a sufficiently large energy or mass density, must exist equally and isotropically across all space, and there must be a controllable means to alter the collisions with this medium to propel the vehicle. A high energy or mass density is required to provide sufficient radiation pressure or reaction momentum within a reasonable sail area. The requirement that the medium exist equally and isotropically across all space is to ensure that the propulsion device will work anywhere and in any direction in space. The requirement that there must be a controllable means to alter the collisions ensures that a controllable propulsive effect can be created.

The supposition that space contains an isotropic medium is reasonable. Space contains electromagnetic fluctuations of the vacuum, also called the Zero Point Fluctuations (ZPF) [7], Cosmic Background Radiation (CBR) [8], free hydrogen (protons) [9], the theoretically suggested virtual pairs [10] and possibly even dark matter. [11] Whether any of these media have all the characteristics needed to be used as a propulsive medium remains a subject for future research.

Regarding conservation of momentum, this condition can be satisfied by using the medium as the reaction
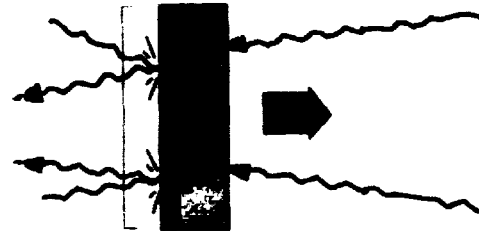
Fig 1 Hypothetical Differential Sail
Analogous to the principles of an ideal radiometer vane, a net dif erence in radiation pressure exists across the reflecting and absorbing sides.
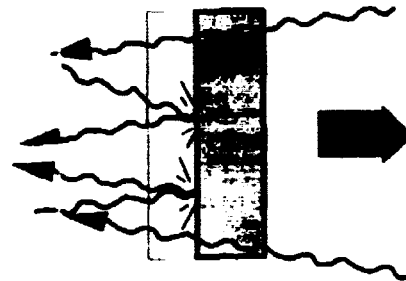
Fig. 2 Hypothetical Diode Sail
Analogous to a diode or one-way mirror, space radiation passes through one direction and reflects from the other creating a net difference in radiation pressure.
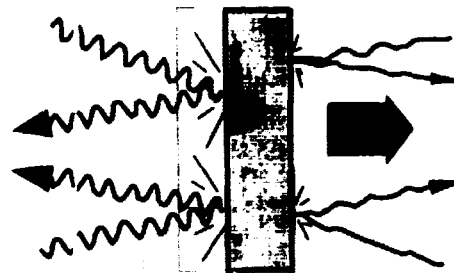
Fig. 3 Hypothetical Induction Sail
Analogous to creating a pressure gradient in a fluid, the energy density of the impinging radiation is raised behind the sail and lowered in front of the sail to create a net difference in radiation pressure across the sail.

mass. Any net momentum imparted to the vehicle must be equal and opposite to the momentum change imparted to the medium.

Regarding conservation of energy, this condition can be satisfied by imposing the constraint that whatever propulsive method or phenomenon is used, the total system energy before and after the propulsive effect is equal. This includes the energy state of the surrounding medium, the energy state of any energy sources on the vehicle, the kinetic energy imparted to the vehicle, and any loss mechanisms.

HYPOTHETICAL FIELD DRIVES

In addition to producing forces with collisions, forces can be produced from interactions between matter and fields. Gravitational fields accelerate masses and electric fields accelerate charges. To entertain the analogy of using field interactions to create a space drive, it is necessary to assume that there is some way for a vehicle to induce a field around itself that will in turn accelerate itself. Field drive concepts are more complex and more speculative than collision sail drives. A description of the critical issues follows.

Even if there was a device on a vehicle that could induce a force-producing field, there is still the question of whether such a field would accelerate the vehicle. A typical expectation is that the induced forces would just act between the vehicle's field-inducing device and the rest of the vehicle, like blowing in your own sails, or trying to move a car by pushing on it from the inside. In such cases all the forces act internally and there would be no net motion of the vehicle. For reference, this issue can be called the "net external force requirement."

The net external force requirement is closely related to conservation of momentum. Conservation of momentum requires that the momentum imparted to the vehicle must be equal and opposite to the momentum imparted to a reaction mass. In the case of a field drive, there is no *obvious* reaction mass for the vehicle to push against.

Similarly to conservation of momentum is the issue of conservation of energy. This issue can be satisfied by imposing the constraint that whatever propulsive method or phenomenon is used, the energy required to create the effect is equal to the kinetic energy imparted to the vehicle and to whatever constitutes its reaction mass, plus any inefficiency losses. In addition, there is also the issue of controllability, insuring that the force-producing effect can be turned on and off at will.

A closely related aspect to controllability is sustainability. Sustainability refers to the ability to continue the propulsive effect throughout the vehicle's motion. This implies that the force inducing effect must work in both an inertial frame and an accelerated frame. It also requires that the force-producing field is carried along with or propagated with the vehicle, or at least can be induced again after the vehicle has been set in motion.

In the spirit of the "Horizon Methodology", it is assumed a priori that space drives are possible. By doing so and then by addressing the critical issues, the required physical characteristics of matter and space to make such propulsion methods plausible can be identified. Future research can then determine whether these conditions can be created with the phenomena that are known to exist, or at least indicate what other phenomena to search for.

Four hypothetical field drives, "Diametric Drive," "Pitch Drive," "Bias Drive," and "Disjunction Drive," are presented next and illustrated in Fig. 4 through 7. These concepts were envisioned by examining the characteristics that describe a field or how matter reacts to a field, and then assuming it is possible to modify a given characteristic of this relation. The Diametric Drive works with field sources, the Pitch Drive with the field itself, the Bias Drive with the properties of the space that contain the field, and the Disjunction Drive with the properties of matter that create and react to a field.

A common theme to all of these is that an *asymmetric* field is induced such that a gradient is located at the center of the vehicle, or more specifically at the center of whatever part of the vehicle will experience a reaction force from the field. An asymmetric field is required so that a net force is created on the vehicle.

These concepts are presented in the context of using mass and gravitational properties. A more thorough treatise would also have to address using space media and electromagnetic phenomena.

Diametric Drive

This first type of hypothetical field propulsion, as illustrated in Fig. 4, considers the possibility of creating a local gradient by the juxtaposition of diametrically opposed field sources across the vehicle. This is directly analogous to the "negative mass" propulsion suggested by Bondi[12], Winterberg[13] and Forward.[14] The diametric drive can also be considered analogous to creating a pressure source and sink in a space medium as suggested previously with the Induction Sail.

Negative mass propulsion is not a new concept. It has already been shown that is theoretically possible to create a continuously propulsive effect by the juxtaposition of negative and positive mass[12] and that such a scheme does not violate conservation of momentum or energy.[14] A crucial assumption to the success of this concept is that negative mass has negative *inertia*.

Fig. 4   Hypothetical Diametric Drive

Qualitatively, this concept can be illustrated by the following equation:

$$V = (-m)\left(\frac{-G}{\sqrt{(x+d)^2+y^2}} \right) + (+m)\left(\frac{G}{\sqrt{(x-d)^2+y^2}} \right)$$

(1)

where V is the gravitational scalar potential for the combined system, shown as a surface plot over an x-y plane in figure 4 (singularities have been truncated for clarity). The first term is the gravitational potential for the negative mass, $-m$, the second for the positive mass, $+m$. In both cases, G is Newton's gravitational constant. The negative mass is located a distance, d, along the x axis behind the origin and the positive mass is located a distance, d, in front of the origin. The origin is taken to be the midpoint between the two masses along the x axis.

By taking the gradient of the scalar potential caused by the negative mass at the location of the positive mass, and of the positive mass at the location of the negative mass, the accelerations for each mass can be calculated;

$$a_{-m} = \frac{-G(-m)}{(2d)^2}$$

(2a)

for the negative mass which is in the positive x direction, and

$$a_{+m} = \frac{G(+m)}{(2d)^2}$$

(2b)

for the positive mass which is also in the positive x direction. Their combined interactions result in a sustained acceleration of both masses in the same direction. This result is also obtained by Forward using an alternative analysis.[14]
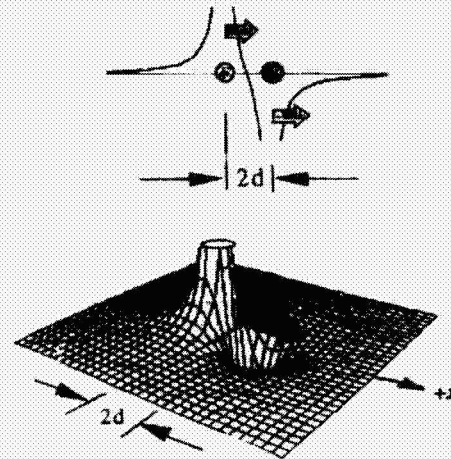
Pitch Drive

This second type of hypothetical field mechanism, as illustrated in Fig. 5, entertains the possibility that somehow a localized slope in scalar potential is induced across the vehicle which causes forces on the vehicle. In contrast to the diametric drive presented earlier, it is assumed that such a slope can be created without the presence of a pair of point sources. It is not yet known if and how such an effect can be created.

Qualitatively, this can be illustrated by the following equation:

$$V = \left(\frac{-Gm}{r}\right) + \left(-xAe^{-r^2}\right) \qquad (3)$$

Fig. 5   Hypothetical Pitch Drive

where V is the gravitational scalar potential for the combined system, shown as a surface plot over an x-y plane in figure 5, which is equal to the superposition of the potentials from the vehicle and the induced pitch effect. The term for the vehicle's gravitational potential is the familiar Newton's gravitational potential where r is the distance from the source mass ($r^2 = x^2 + y^2$ for the x - y plane). The origin is taken to be at the center of the vehicle. To entertain the possibility of a Pitch Drive, a localized gradient in the scalar gravitational potential is superimposed across the symmetric gravitational potential already present from the vehicle's mass. This induced pitch effect is represented by a magnitude, A (units of acceleration), with a negative slope in the positive x direction, and is localized by a Gaussian distribution, e^{-r^2}, over the distance, r, centered at the origin. This localizing equation was arbitrarily chosen for illustration purposes only.

By taking the gradient of the scalar potential at the location of the vehicle, specifically the derivative of V with respect to r of the induced pitch effect at r=0, the acceleration for the vehicle is determined to be equal to A, and acts in the positive x direction.

Bias Drive

The third type of hypothetical field mechanism, as illustrated in Fig. 6, entertains the possibility that the vehicle alters the properties of space itself, such as the gravitational constant, G, to create a local propulsive gradient. By modifying Newton's constant to have a localized asymmetric bias, a local gradient similar to the Pitch Drive mechanism results.

Qualitatively, this concept can be illustrated by the following equation:

$$V = \left(xBe^{-r^2} + 1\right)\left(-G\frac{m}{r}\right) \qquad (4)$$

Fig. 6   Hypothetical Bias Drive

where V is the gravitational scalar potential plotted over an x-y plane, shown as a surface plot in Figure 6. This scalar potential is described by the familiar Newton's gravitational potential on the right which is multiplied by a spatially asymmetric modifier on the left. The spatially asymmetric modifier is represented by a magnitude, B (units of inverse distance), multiplied by x, to give a positive slope in the positive x direction, and is localized by a
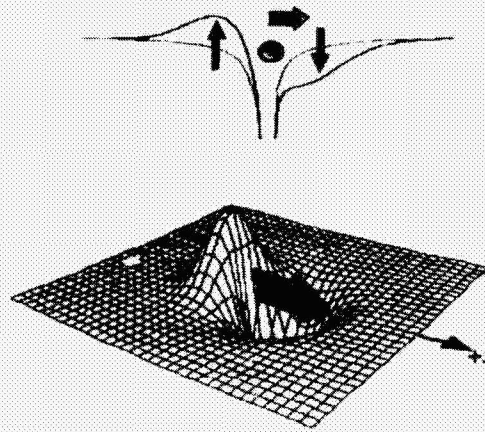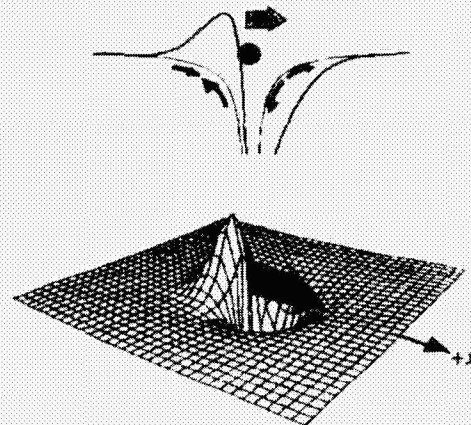
Gaussian distribution as with the Pitch Drive. The "+1" identity term is necessary to return the Newtonian gravitational potential to its original form at large distances (r>>0). Unfortunately, it is not possible to present a qualitative representation for the resulting acceleration for this hypothetical example since the gradient of this scalar potential produces a singularity at the origin.

A similar concept by Alcubierre [4] suggests creating a propulsive effect by asymmetrically altering spacetime itself. Alcubierre theorized that by expanding spacetime behind the vehicle and contracting spacetime in front of the vehicle, faster-than-light travel would be possible without violating general relativity. The net effect is that this "warped" space and the region within it would propel itself "with an arbitrarily large speed." Observers outside this "warp" would see it move faster than the speed of light. Observers inside this "warp" would feel no acceleration as they move at warp speed. Although a sub-light-speed space drive would constitute a sufficiently important breakthrough, the possibility that a space drive may also enable faster-than-light transport is intriguing. The feasibility of this "warp drive" theory is an open issue.

Disjunction Drive

The fourth type of hypothetical field drive, as illustrated in Fig. 7, entertains the possibility that the source of a field and that which reacts to a field can be separated. By displacing them in space, the reactant is shifted to a point where the field has a slope, thus producing reaction forces between the source and the reactant. It is assumed that the source and reactant are held apart by some sort of rigid device.

Obviously, a critical issue of this scheme is whether the field's source is a separate entity from that which reacts to a field. This perspective is similar to that used in the analysis of the properties of negative mass. [12] In the course of examining the nature of hypothesized negative mass, three different masses can be distinguished: the "source mass," "reactant mass," and "inertial mass." Although these distinctions were made to classically analyze the behavior of negative mass,

Fig. 7 Hypothetical Disjunction Drive

they do invite speculation. Could either a "source" or "reactant" mass be mimicked through some coupling between gravity, electromagnetism and spacetime? If so, the propulsive effect suggested above may be possible. This is unknown at this time.

Qualitatively, this concept can be illustrated by the following equations:

$$V = \frac{-Gm_s}{\sqrt{(x-d)^2 + y^2}}$$

(5)

where V is the gravitational scalar potential plotted over an x-y plane as a surface plot in figure 7 which is equal to the familiar Newton's gravitational potential of the *source* mass, m_s, which is a distance, d, along the x axis, from the reactant mass. The source mass is defined to have the property that it only causes a field, but does not react to one. The reactant mass is defined to react to the presence of a field but not to cause one. Thus, there is no force on the source mass from the reactant mass.
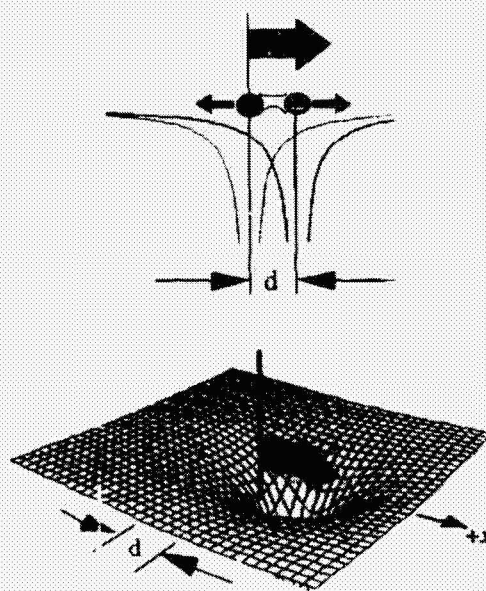
To illustrate how this concept works, examine the sum of the resulting forces:

$$\Sigma \text{ forces} = \frac{Gm_s m_R}{d^2} + m_{Si}a + m_{Ri}a$$

(6)

The first term of the sum is the gravitational force from the source mass, m_S, acting on the reactant mass, m_R. By definition, there is no force created on the source mass from the reactant mass, and hence, no term for that force in this equation. However, to entertain the possibility that the source and the reactant mass have inertial mass, terms are included for the reaction forces due to these inertiae. These reaction forces are the second and third terms in the summation, where m_{Si} is the inertia of the source mass and m_{Ri} is the inertia of the reactant mass. Since it is assumed that the masses are rigidly connected by whatever device has pulled them apart, the acceleration, a, is the same for both masses. Solving for the acceleration gives:

$$a = \left(\frac{G}{d^2} \right) \left(\frac{m_S\, m_R}{m_{Si} + m_{Ri}} \right)$$

(7)

which acts in the positive x direction.

Although existing evidence strongly suggests that the source, reactant, and inertial mass properties are inseparable, any future evidence to the contrary would have revolutionary implication to this propulsion application.

REMAINING RESEARCH

There are a variety of unexplored paths toward discovering the physics for a space drive. To explore the collision sail concepts it would be useful to seek any means to interact asymmetrically with the media that are known to exist in space. In particular, the medium of the electromagnetic fluctuations of the vacuum, also called the ZPF, is a promising candidate because of its high energy density, estimated to be as high as 10^{114} Joules per cubic meter. [3] A recent experiment to reexamine the Casimir force, which is an empirical artifact of this energy density, found agreement with the theory at the level of 5%. [15]

Multiple research paths exist to further explore field drive concepts. First, the concept of negative mass, with its inherent negative inertia, could be further explored. Another research path that covers the possibility that negative mass cannot exist, is to develop a formalism of Mach's Principle or reformulate ether concepts to provide an alternative means to satisfy momentum conservation for field drives. Such formulations would also have to address how to impart reaction forces against space itself. A more general approach that may even encompass these other two approaches is to develop a physics that describes inertia, gravity, or the properties of spacetime as a function of electromagnetics that leads to using electromagnetic technology for inducing propulsive forces.

Regarding the physics of negative mass, it is not know whether negative mass exists or if it is even theoretically allowed, but methods have been suggested to search for evidence of negative mass in the context of searching for astronomical evidence of wormholes. [16] If negative mass is found to exist and if methods can be eventually engineered to collect and handle negative mass, it seems reasonable that a propulsive effect could be engineered as previously discussed with the Diametric Drive. If negative mass does not exist naturally, it is still possible, in the spirit of the Horizon Methodology, to consider the alternative of artificially synthesizing negative mass effects using some as-yet-undiscovered physics, perhaps using a form of gravity-electromagnetic coupling.

The idea of discovering some gravity-electromagnetic coupling goes beyond the idea of mimicking negative mass. If there is any way to modify gravity, inertia, or the properties of spacetime using electromagnetics, it may be possible to mimic negative mass to create a gravitational dipole, induce gravitational or electromagnetic fields to create a Pitch Drive, or modify other properties of space to create a Bias Drive.

The idea of using one phenomenon to control another is not new. Electric fields are used to create magnetic fields.

By knowing the specifics of how these phenomena are coupled, it is possible to engineer such effects. In the case of a space drive it is desired to create an acceleration-inducing field using some phenomenon like electromagnetics that can be readily controlled.

Electromagnetism is suggested as the control phenomenon for two reasons: electromagnetism is a phenomenon for which we are technologically proficient, and it is known that gravity, spacetime, and electromagnetism are coupled phenomena. In the formalism of general relativity this coupling s described in terms of how mass warps the spacetime against which electromagnetism is measured. In simple terms this has the consequence that gravity appears to bend light, red-shift light, and slow time. These observations and the general relativistic formalism that describes them are experimentally supported. [9] Although gravity's effects on electromagnetism and spacetime have been observed, the reverse possibility, of using electromagnetism to affect gravity, inertia, or spacetime is unknown. To explore this possibility, it would be advantageous to have a formulation that describes these observed couplings as a function of electromagnetics.

Electromagnetism is also suggested as a target phenomenon for space drive research because of the ZPF. The ZPF is an electromagnetic phenomenon. Discovering any way to react asymmetrically with the ZPF would likely create a space drive. ZPF has also been theorized to be an underlying phenomenon to inertia and gravity [1,2], and experiments have been suggested to test these theories and to test other related speculations on the relation between the ZPF and mass properties. [3] It should be noted that these theories were not written in the context of propulsion and do not provide *direct* clues for how to electromagnetically manipulate inertia or gravity. Also, these theories are still too new to have either been confirmed or discounted. Despite such uncertainties these theories provide new, alternative approaches to search for breakthrough propulsion physics.

Inherent to all the propulsive mechanisms discussed above is the need to generate an asymmetric field, one that results in a *net* acceleration of the vehicle. One way to search for such asymmetric effects is to search for nonlinear or non-conserved effects. If, for example, there exists some characteristic coupling between electromagnetism, spacetime, inertia, or gravity that behaves nonlinearly, has some hysteresis, or is non-conserved (analogous to friction) it may be possible to create net forces from imbalanced, cyclic perturbations of this effect.

To illustrate this possibility, consider the analogy of an irregularly oscillating mass affixed to a cart that is initially at rest on the floor. When the mass moves slowly in one direction its reaction forces are not sufficient to overcome the static coefficient of friction between the cart and the floor and the cart remains still. When the mass moves quickly in the other direction its reaction forces are sufficient to overcome the static coefficient of friction, and the cart rolls. Repeating this cycle results in a net motion of the car. If there are any field properties of space that have such a characteristic non-conserved interaction analogous to friction, then it may be possible to create an analogous propulsive effect in space.

A more conventional example which better illustrates the possibilities of nonlinear propulsion, is a method suggested by Landis. [17] This concept outlines a technique for changing the orbits of satellites without using propellant, and does so using conventional physics. It uses tethers on a satellite to take advantage of the nonlinear nature of a gravitational well. If the orbiting satellite extends a tether toward Earth and another tether away from earth, the imbalanced reactions will create a net force toward the Earth. This is because the downward force on the near-Earth tether increases more than the outward force on the outer tether as the tethers are deployed. By alternately deploying and retracting long tethers at different points during the orbit (apogee and perigee), an orbiting satellite can change its orbital altitude or eccentricity.

Another approach is to revisit the field properties of space itself in search of evidence of imbalanced forces. One experiment to explore this possibility is where a homopolar motor is used to illustrate a paradox of apparently imbalanced magnetic reaction forces. [18] Another is from experimental observations of unipolar induction that explores the relation between magnetic fields and the surrounding space. [19]

To further explore the propulsive implications of any of these imbalanced force concepts, it is necessary to fully address the law of conservation of momentum. In the case of the tether example discussed above, the Earth acts as the reaction mass to conserve momentum. In the case of negative mass propulsion, conservation of momentum is

satisfied by taking advantage of the negative inertia of negative mass. [14] With the remaining field drives, however, research will be required to determine how the surrounding space can be use i satisfy conservation of momentum.

One approach to conserve momentum is to consider space itself as the reaction mass. This approach evokes the old idea of an "ether." To be strictly consistent with empirical evidence, such as the Michelson-Morely experiment, any further research to revisit the idea of an ether would have to impose the condition that an ether is electromagnetically Lorentz invariant. Note that this condition is a characteristic of the ZPF. [7]

An alternative to considering space as the reaction mass is to further develop Mach's Principle. Mach's Principle asserts that surrounding matter gives rise to inertial frames, and that the inertial frames are somehow connected to the surrounding matter. [9] Mach wrote that although he felt a connection to the surrounding matter was required for the property of inertia to be detected '' he also admitted that such a treatment was not necessary to satisfactorily describe the laws of motion. [20] To search for new, additional laws of motion to explore the goal of field drives, however, if may be useful to revisit Mach's Principle more literally. Specifically, to be useful for propulsion physics, a formalism of Mach's Principle is required that provides a means to transmit reaction forces to surrounding matter. This implies developing a quantitative description for how the surrounding matter creates an inertial frame, and how pushing against that frame with a space drive is actually pushing against the distant surrounding matter.

It is also possible to consider the very structure of spacetime itself as a candidate for propulsive interactions. If it were possible, for example, to create asymmetries in the very properties of spacetime which give rise to inertial frames, it may be possible to create net inertial forces. This is similar to the "warp drive" suggested by Alcubierre. [4]

It is also conceivable that other research approaches exist. To further explore any of these possibilities, it would be useful to have a succinct problem statement to guide the evaluation and application of emerging science to the goal of creating a space drive. Such a problem statement is offered next.

PROBLEM STATEMENT

The critical issues for both the sail and field drives have been compiled into the problem statement offered below. Simply put, a space drive requires some controllable and sustainable means to create asymmetric forces on the vehicle without expelling a reaction mass, and some means to satisfy conservation laws in the process. Regardless of which concept is explored, the following criteria must be satisfied.

(1) A mechanism must exist to interact with a property of space, matter, or energy which satisfies these conditions:
    (a) must be able to induce an unidirectional acceleration of the vehicle.
    (b) must be controllable.
    (c) must be sustainable as the vehicle moves.
    (d) must be effective enough to propel the vehicle.
    (e) must satisfy conservation of momentum.
    (f) must satisfy conservation of energy.
(2.1) If properties of *matter* or *energy* are used for the propulsive effect, this matter or energy...
    (a) must have properties that enable conservation of momentum in the propulsive process.
    (b) must exist in a form that can be controllably collected, carried, and positioned on the vehicle, or be controllably created on the vehicle.
    (c) must exist in sufficiently high quantities to create a sufficient propulsive effect.
(2.2) If properties of *space* are used for the propulsive effect, these properties...
    (a) must provide an equivalent reaction mass to conserve momentum.
    (b) must be tangible; must be able to be detected and interacted with.
    (c) must exist across all space and in all directions.
    (d) must have a sufficiently high equivalent mass density within the span of the vehicle to be used as a propulsive reaction mass.
    (e) must have characteristics that enable the propulsive effect to be sustained once the vehicle is in motion.
(3) The physics proposed for the propulsive mechanism and for the properties of space, matter, or energy used for the propulsive effect must be completely consistent with empirical observations.

CONCLUSIONS

Prior to the emergence of new theories suggesting connections between gravity, inertia, and the electromagnetic fluctuations of the vacuum, and the recent "warp drive" theory, the prospects for creating a space drive have seemed too far in the future to provide near term research opportunities. Now with these emerging theories, new research approaches exist. To provide a framework for taking advantage of these emerging theories and progressing science toward the goal of a space drive, a problem statement was needed and is now offered in this paper. Regarding the prospects for breakthroughs, consider the following quotes from past experts. These quotes were copied from Anderson's article on the Horizon Methodology.[6]

"Heavier than air flying machines are impossible." "Radio has no future." "X-rays are a hoax."

- William Thomson (Lord Kelvin)
President of London's Royal Society (1895-1904).

"There is no likelihood man can ever tap the power of the atom."

- Robert Millikan,
Nobel Prize in Physics (1923).

"The secrets of flight will not be mastered within our lifetime.. not within a thousand years."

- Wilbur Wright (1901).

ACKNOWLEDGMENTS

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NEXT DOCUMENT

Vacuum Fluctuations, Connectivity and Superluminal Physics for Interstellar Travel

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Abstract:

This paper argues that scientific speculation on the possibility of practical superluminal transport leads down quite restrictive paths of thought. A machine that can globally exceed the speed of light must be able to actively modify the spacetime metric in its locality in order to avoid the tachyonic causality violation in Minkowski space. Although metric warps sufficient for transport seem to require unphysically large amounts of negative energy within General Relativity, the potentially even larger content of virtual energy in the EM zero-point fluctuations (ZPF) is pointed out. Otherwise, to work around the energy dilemma, there must exist a small-scale structure to spacetime that can be manipulated locally with reasonable energy expenditure. The idea is proposed that quantum noise of some sort prevents the reconnection of elementary spacetime paths and a consequent topological collapse, or reversion to a less structured state, of spacetime itself. This is a generalization of an interpretation, based on Boyer's stochastic electrodynamics, that ZPF keeps the world from atomic collapse. The transport machine then operates as an inchworm in spacetime by temporarily forcing an above equilibrium connection of paths between locally spacelike separated regions. EM field configurations analogous to those used in some resonance experiments are suggested as possible tools. The connection of paths between normally spacelike separated regions having a different energy level of the vacuum may possibly lead to the direct extraction of energy at the expense of spacetime structure.

Introduction

Hopefully, Dr. Richard van der Riet Woolley's famous quote[1], "Space travel is utter bilge", emphatically repeated by him in response to President Eisenhower's announcement of the US satellite program just one year before Sputnik I, will be shown not to apply to practical interstellar or intergalactic travel as well. However, this speculative paper makes no attempt to predict the future. Instead, the purpose here is to provide food for scientific thought by supposing that such travel is possible and asking the question of how can that be? Retaining only the most basic and well established generalities regarding spacetime structure, the above assumption then drives one down rather selective paths of thought. These paths then naturally suggest hypothesis of a microscopic structure that should have observable consequences in nature.

Minkowski space and continuous Lorentz transformations are accepted as a well established and a locally valid macroscopic approximation wherever spacetime curvature is not too great. The physical spacetime, however, is well known to contain the f^3 spectrum[2] of the zero-point fluctuations (ZPF) of the vacuum electromagnetic (EM) field. Therefore, it may be necessary to replace the Minkowski spacetime and its continuous Lorentz group with a discrete spacetime in order to cut off this otherwise unbounded f^3 spectrum. Besides ZPF, other forms of 'quantum noise', such as fluctuations of the vacuum with respect to particle-antiparticle pairs, similarly hint of a deep substructure that has a potential discreteness built into it. Globally, spacetime is assumed to be well described by a metric manifold structure, where the metric has the usual signature and satisfies either the usual Einstein-Hilbert or perhaps someone else's field equations.

Globally superluminal space-time machines are not mere tachyons

Practicality of travel to the stars is taken to mean that round trip time for journeys to the local stars, or even to the nearest galaxies, as measured back home, is at most some reasonable number of years. Thus the scenario of

heroically drifting in a spaceship for generations is excluded as being impractical. This implies that the transport machine must be capable of a global speed that is truly enormous from the viewpoint of the back-home observers. And it also leads to a violation of the common sense of macroscopic causality in Minkowski space, presented in introductory physics texts and repeated below.

Test particles that exceed the speed of light c, as seen by an inertial observer, are forbidden by the basics of Lorentz transforms in combination with the common sense of time-ordering. Let E_1 and E_2 be the events of departure from point 1 and arrival at point 2, respectively, of such a test particle. An observer who sees E_1 and E_2 to be spatially fixed a distance d apart will assign $t_2 > t_1$. Since $d/(t_2-t_1) > c$ for this particle, another inertial observer can be found such that he sees $t_2' < t_1'$, which amounts to a blatant violation of causality.

This simple argument against tachyonic particles in Minkowski space has great force. There is a way, and possibly the only way, to avoid a crucial causality violation at the start: the transport machine must somehow modify spacetime geometry away from Minkowski. And for the sake of practicality, one should suppose this modification to be relatively local about the transport machine. To put it differently, this hypothetical machine must be surrounded by a metric field-like distortion such that, regardless of the observer, the synchronism of his clocks that happen to be in the vicinity of E_1 and E_2 is sufficiently disturbed to avoid a causality violation. This fast machine thus can not behave as a simple test particle, with no effect on the background metric. Instead, it must be in the 'warp drive'[3] class and is, in that sense, a space-time machine of some sort, i.e., a machine that actively modifies the spacetime geometry in its locality. Such machines have been argued by Alcubierre to have impressive advantages, deriving from the use of a dynamic spacetime within general relativity. The round trip time can in principle be very short, as measured by both the ship clocks and the clocks back home. And within the ship itself, the occupants are not subject to violent tidal forces because presumably a relatively flat spacetime can be maintained there and the ship remains essentially at rest in its comoving frame; thus the term 'warp bubble' is sometimes used. Further, causality seems not to be violated, because closed timelike curves can be avoided. If feasible, such features would make this a 'dream machine' of transport, indeed.

Not to build bridges to the stars

Traversable, large-scale wormholes may conceivably exist, with throats perhaps near a large gravitating body, as suggested by some authors, that could serve as short cuts to otherwise distant parts of the universe.[4] Wormholes, if they exist at all[5], may have serious difficulties related to traversability, stability and navigability. Moreover, a wormhole is not likely to connect to where one wants to go and the location of its far end would not be known in advance. Brute forcing a large wormhole into being is surely ruled out, simply by the enormous amounts of energy required. For example, magnetic fields far in excess of 10^6 T would be required to produce a significant spacetime curvature due to the field energy[6], but no method is presently known that could sustain such enormous fields. The Alcubierre warp bubble has similarly been criticized[7] on the grounds that an "unphysical amount of negative energy", of the order of 10^{72} joules, is needed to maintain an extremely thin-walled, 100 m diameter bubble moving with speed c. This criticism is based on an inequality from quantum field theory combined with standard general relativity and other assumptions. If the engines of this drive can no muster the energy required for speeds in excess of c, then the drive slows down and becomes less interesting.

The idea that the magnitude and seemingly unphysical negativity of the required energy presents an insuperable barrier to a general warp drive, can be challenged and certainly deserves further study, since alternatives[8] to the Einstein-Hilbert equations have been proposed. Or there may be more subtle work-arounds in regard to the source, nature and gathering of the energy. Enormous energies do indeed occur when evaluating the total spatial density, $8\pi^2 \hbar f_c^4 / c^3$, of energy in the EM zero-point spectrum, where f_c is a cutoff frequency. The f_c is thought to be derived from the Planck time, and depending on whose formula for f_c is used, energy densities in excess of 10^{100} J/m^3 can be obtained; for example, the Sakharov cutoff $f_c = [c^5/(2hG)]^{1/2} = 5.2 \times 10^{42}$ sec^{-1} gives 2.3×10^{113} J/m^3. This energy is considered as virtual, since it is not normally tappable for work, but is not physically nonsense just for its magnitude. However, does the warp drive necessarily need tappable energy? The spacetime connectivity scheme

proposed below suggests no more than a minute tappability of this energy sea and gives no insight on how to control large variations, but it could be a step in the right direction.

Is the mechanism already there for the taking?

The consensus of the literature to date is clearly that truly enormous amounts of energy are needed to create shortcut paths in spacetime geometry. And even the quite local metric distortion of a warp type drive would seem to require impractical amounts of energy, if that distortion has to be fed through an energy-momentum tensor coupled to say Einstein's field equations. Forcing the distortion this way is practical nonsense. To avoid the enormous energy requirements, consider the possibility that the elements for creating a desired metric distortion already exist as fundamental building blocks of spacetime itself, that need only be harnessed for the purpose. In other words, these are rearrangable segments of paths of the small scale structure of spacetime. The establishment of a path linking two spacetime points is interpreted to mean that these points then either wholly or partially lose their distinctness or separation. Enormous energies may still be involved in the same sense as the existence of the zero-point energy of the electromagnetic field. But there may not be a requirement for macroscopically wholly tappable energy on a large scale. From this point of view, the creation of a macroscopic metric distortion is carried out through a process of reconnection to induce a reversion of spacetime to a more primitive state and is, in a way, a destructive process. Regardless of how fanciful and speculative all this may sound, the principle of causality plus the argument for the feasibility of geometric transport (e.g., the warp-drive bubble) leads into this current of thought. Effects simulating a macroscopic metric distortion, as needed for transport, must be energetically not too hard to come by and the process must involve spacetime elements which are exceedingly small. A speculative idea regarding the nature of such elements is proposed below.

And is the world supported by quantum noise?

In papers on stochastic electrodynamics Boyer[2] and Puthoff[9] argue that on the scale of the Bohr orbit, an electron begins to be significantly buffeted by the random forces of the electromagnetic field zero-point fluctuations. And hence these forces make it difficult for the electron to localize into the nucleus, ending in atomic collapse. These authors go on to show that the size of the orbit, the quantization of angular momentum and other properties predicted by quantum mechanics are also correctly predicted by the stochastic electrodynamics. Not that quantum mechanics is wrong, but the interaction of charged particles with ZPF is an alternative and physically more intuitive explanation of some quantum mechanical effects.

The Boyer and Puthoff papers support the interpretation that the EM zero-point fluctuation 'quantum noise' is what keeps the world from an atomic collapse. To generalize this idea, consider the proposal that quantum noise of some sort is what keeps spacetime itself from a topological collapse and a reversion to a less structured state. This proposition suggests that spacetime points themselves are generated by a kind of entity, or 'quantum of action', and naturally prefer to get connected. But it appears to an observer that the paths are torn apart by some sort of quantum noise. The establishment of a path, or a series of paths, would presumably be interpreted macroscopically as a sudden connection, or coalescing, of normally spacelike separated points. There is a resemblance here to the much more developed idea by R. Penrose[10] on the generation of spacetime by the correlation of elemental 'spins', but the action here of noise and paths is different. The mathematically precise description of the proposed generators and the action of noise on paths, if the idea is indeed fruitful, may of course turn out to be as different as the quantum description is from stochastic electrodynamics.

The speculation above is motivated only by its obvious relation to the notion of the space-time machine that can at most rearrange a local, microscopic structure. The paths only need be induced to locally connect for a (very?) short time and the machine then operates like an inchworm in spacetime, digging out a path in front and closing it behind. Since the only known manipulable fields are electromagnetic, perhaps a cooperative alignment of paths could be induced by a superposition of sufficiently intense steady and high frequency electromagnetic fields: a resonance of the vacuum itself. Other methods are difficult to suggest, until this idea of a dynamic connectivity is

further developed and related to the more precise notions of a macroscopic metric, the quantum mechanical time-energy uncertainty constraint, etc..

Energy from spacetime a dividend to consider

The realization that energy can be extracted from spacetime itself[1-] dates, in principle, from the time of discovery of the EM zero-point energy and the Casimir force. Indeed, this force may be a contributor to fusion level temperatures in tiny, collapsing bubbles, as evidenced by the radiation observed in sonoluminescence experiments. The Casimir coagulation of particles requires disposable matter or else the operation is in a storage battery mode[12], and is presently not a candidate for useful levels of power. On the other hand, the idea that energy can be extracted continuously from space with over-unity efficiency is mostly relegated to nonsense by mainstream physics, because there is neither a manifest source above the energy zero level of local space, as defined by the vacuum fluctuation 'sea', nor an empty level below the zero level and efforts to induce a coherency, or reduction of entropy, in this sea will surely suffer the fate of the Maxwell demon.

Consider, however, the possibility that the local zero level is not zero everywhere with respect to spacetime locations. Such a nontrivial scenario may be a consequence of the fact that the universe is evolving. Normally there is no way to connect arbitrary points of spacetime with causal curves in order to exploit differences in the local zero levels of energy associated with evolution. The above described short circuiting of normally spacelike separated points may also bring together different zero levels, causing some photons to spill over and be available for useful work. Since the space-time machine operates over a small spacetime volume, such a spill would not be expected to be enormous, yet could be practically significant. The source of the energy released is here the slight degeneration, or collapse, of the spacetime structure itself. One can assume that such a disturbance would be compensated by the propagation of a gravitational wave or a wave in the zero-point energy sea. This model provides at least a rational starting point for a more serious study of the source of such energy that works around what appears as a gross violation of thermodynamics. As a grand scale example of this idea, the energy released by matter falling into a black hole could be ascribed to a certain amount of collapse of spacetime structure.

With this sort of a spacetime model in mind, it may be worth while to search for and examine phenomena in nature that appear to be anomalously energetic. The so called ball lightning plasmoid could very well contain EM field superpositions of the sort mentioned above (i.e., steady, toroidal magnetic field plus plasma oscillations), even though just atmospheric pressure can not contain steady magnetic fields of any great intensity. Among the presently existing, man made devices that may also be worth a look with respect to the ideas presented here, are the Methernitha machines[13]. These well known, but rarely accessible for study, machines are claimed to be multikilowatt level, steady extractors of energy from space that use no external power. It is easy to relegate these claims to the crackpot fringe or fraud, except that the known structure of these machines and the reports of witnesses do seem to admit the presence of interesting combinations of intense EM fields.

Summary

The supposition that superluminal transport is feasible restricts the candidate drives to the metric warp type, in order to avoid causality violations in Minkowski space. Studies within General Relativity have shown that unphysically large amounts of energy are likely to be needed to maintain the necessary metric distortion , for both large-scale wormholes and the Alcubierre warp drive. In addition, these energies are negative, which implies exotic matter in the standard theories of spacetime geometry. In the speculative scheme presented here, the reconnection of spacetime paths and consequent topological collapse of the world is prevented by quantum noise. Then this negativity merely means that the space-time machine is put into an energy level below that of the normal vacuum, as a consequence of the local spacetime connectivity manipulation that suddenly coalesces spacelike separated regions. The vacuum of such regions may well have an energy differential due to evolution of the universe. Even so, there is still no obvious way that the relatively local alteration of connectivity could produce the enormous energy differentials predicted for warp drives by classical theory. If indeed the alteration of paths idea is

a key to fast transport, then either the metric distortion so induced somehow differs from the classical model, or else there exists a more subtle work-around. Success could depend on the discontinuous character of the making and breaking of the paths or on quantum effects. Electromagnetic fields come to mind immediately as candidate tools for connectivity manipulation. A superposition of intense steady and high frequency fields is suggested as a first cut, as such combinations produce results in resonance experiments.

The connectivity manipulation idea could also serve as a basis for a closer look at one or two of the so-called free energy machines that have been claimed to steadily extract kilowatt level power from space. If such a machine has actually been realized, then surely nothing short of a new concept about the structure of spacetime will do to get around the apparent blatant violation of thermodynamics. When there is neither a reservoir of energy around to drain nor an empty level below that of the local vacuum, then the source must be the spacetime structure itself. In closing, the standalone Swiss Methernitha M-L Converter appears to admit a field configuration of the type mentioned above and likewise may the naturally occurring ball lightning plasmoid.

Acknowledgments

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NEXT DOCUMENT

Search for Effects of an Electrostatic Potential on Clocks in the Frame of Reference of a Charged Particle

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ABSTRACT:

We propose a Nuclear Magnetic Resonance experiment tomeasure the influence of electric potentials on clocks in the rest frame of a charged particle. The motivation for these experiments rests on a theory that describes classical electrodynamics within the framework of (Psuedo)Riemannian geometry including Torsion. The first of two definitive papers describing the theory has already been published [1]; the second is in review[2]. This is tantamount to claiming that a classically unified theory has been developed that correctly imbeds Classical Electrodynamics in the geometry of Einstein's field equations incorporating propagating torsion. Metric solutions to the field equations of the theory result in the correct electromagnetic potentials appearing in the metric tensor for several cases including: spherical gravity plus spherical electrostatic field, the line charge electric field and the uniform magnetic field. The latter two solutions are exact. Solutions have been chekeed with "Mathematica".

From the solutions, an experimental prediction is made that electric potentials influence proper time much the same as gravitational potentials. The effect is expected to generate a line shift on the order of 6 ppm and broadening for a sharp proton resonance in the presence of a 10kV electric field and a 5T magnetic Larmor field. If the temporal effect is verified, then it is likely there exist solutions that couple to space and thus to gravity, either explaining existing effects or predicting new ones.

INTRODUCTION:

The present work is a highly condensed summary of a theory that is shown to correctly represent both gravity and electromagnetism classically within a Pseudo-Riemannian geometry. It is grounded upon a new connection [Ringermacher, 1994] which derives from an electrodynamic torsion acting upon charged particles in an electromagnetic field. The geometry is that seen by a charged particle and depends upon the electromagnetic potential at the particle location within a space-time that can include gravity. The present theory applies to weak fields and therefore does not couple the two fields. Present gravity experiments remain unaffected and the correct electromagnetic potentials derive from metrical solutions of the field equations. Thus both the Einstein equations and the Maxwell equations are satisfied by the metric solutions.

It is shown, however, that pure electromagnetic geometry should produce efffects similar to those of gravity. These effects are resolved within the particle reference frame since that represents the simplest solution. The result is a consistent field theory with solutions and an experimental prediction[2].

In ref.[1] a new connection is derived from first principles but can be found effectively from introducing an electrodynamic torsion. The same connection was found by Schrödinger[3] but not identified or recognized as such - indeed he discarded the antisymmetic part of his connection(pure torsion) since it did not contribute to the motion.

This torsion, given by

$$\tilde{\Gamma}^{\lambda}_{[\mu\nu]} = \frac{\kappa}{2} u^{\lambda} F_{\mu\nu} ,$$

(1)

does not alone contribute to the Lorentz motion of a charged particle. Its properly symmetrized contribution to the connection (eqn. 2 below) does, however. The pure torsion, eqn. (1) alone, was shown to be the source of the well-known Thomas Precession term in the "classical spin" equation of motion. It cannot be physically ignored. It can be said that the connection is fully determined by the metric tensor and the torsion as seen in eqn.(2). J. Vargas [4] has independently found the same torsion tensor from a Differential Forms approach.

The electrodynamic connection is:

$$\tilde{\Gamma}^{\lambda}_{\mu\nu} = \Gamma^{\lambda}_{\mu\nu} + \kappa \Lambda^{\lambda}_{\mu\nu}$$

(2)

$$\Gamma^{\lambda}_{\mu\nu} = -\frac{1}{2} g^{\alpha\lambda} (\partial_{\mu} g_{\nu\alpha} + \partial_{\nu} g_{\mu\alpha} - \partial_{\alpha} g_{\nu\mu})$$

$$\Lambda^{\lambda}_{\mu\nu} = \frac{1}{2} g^{\alpha\lambda} (u_{\mu} F_{\nu\alpha} + u_{\nu} F_{\mu\alpha} - u_{\alpha} F_{\nu\mu})$$

$$F_{\lambda\mu} = A_{\mu\lambda} - A_{\lambda\mu}$$

$$u^{\lambda} = \text{test particle 4-velocity}$$

where $\kappa = -e/mc^2$

Torsion is traditionally identified with angular momentum which, it seems, has not borne phy ical fruit in the present context. The present work departs from tradition and clearly identifies it with electromagnetic objects.

In a second paper[2], the new Einstein tensor is developed from that connection. This follows the work of J. Schouten exactly. The new Einstein tensor has both charged and "displacement" currents as sources. The electromagnetic energy density is ignored as contributing only higher order massive effects on the geometry in comparison to the new current terms. Solutions of the new field equations are presented that yield the classical electromagnetic potentials together with gravitational potentials in the appropriate cases. These solutions include: (1) spherical electric plus gravitational field; (2) cylindical line charge field and (3), cylindrical uniform magnetic field

RIEMANN AND EINSTEIN TENSORS WITH TORSION:

The Riemann tensor is given by:

$$\tilde{R}^{t}_{\mu\nu\sigma} = R^{t}_{\mu\nu\sigma} + \kappa \frac{g^{\sigma\tau}}{2} (u_{\iota} F_{\mu\tau,\sigma} - u_{\iota} F_{\nu\tau;\sigma} + u_{\iota} f_{\nu\sigma} - u_{\sigma} F_{\mu\tau,\nu} - u_{\iota} F_{\sigma\tau;\nu} - u_{\iota} F_{\mu\sigma,\nu})$$

(3)

This Riemann tensor satisfies the following Cyclic Identity upon alternating indices :

$$\tilde{R}^{t}_{[\mu\nu\sigma]} = \kappa u^{t} (F_{\mu\nu,\sigma} + F_{\nu\sigma,\mu} + F_{\sigma\mu,\nu})$$

(4)

In deriving (3), covariant differentiation was passed through 4-velocities. Thus the identity (4) implicitly assumes this. Eqn. (4) can be derived from a Differential forms approach, as shown in Appendix A, without

this assumption. The Einstein tensor is given by:

$$\tilde{\epsilon}_{\mu\nu} = \epsilon_{\mu\nu} + \frac{\kappa}{2}(u_\mu F^\tau_{\nu,\tau} + u_\nu F^\tau_{\mu,\tau} + u^\tau F_{\mu\nu,\tau} - 2u^\tau F_{\mu\tau,\nu} - 2g_{\mu\nu}u^\tau F^\sigma_{\tau\sigma})$$

(5)

The Einstein tensor separates into symmetric and antisymmetric parts(eq.6). The symmetric part provides the metrical field equation while its conservation yields the Maxwell source equations as our second field equation. The antisymmetric part yields the homogeneous Maxwell equations as a solution for arbitrary u since it must vanish. Eq. (4) also yields the homogeneous Maxwell equations.

$$\tilde{\epsilon}_{(\mu\nu)} = \epsilon_{\mu\nu} - \frac{\kappa}{2}u^\sigma(F_{\nu\sigma,\mu} + F_{\mu\sigma,\nu} - g_{\nu\sigma}F^\tau_{\mu,\tau} - g_{\mu\sigma}F^\tau_{\nu,\tau} + 2g_{\mu\nu}F^\tau_{\sigma,\tau})$$

(6)

$$\tilde{\epsilon}_{[\mu\nu]} = \frac{\kappa}{2}u^\sigma(F_{\mu\nu\sigma} + F_{\nu\sigma\mu} + F_{\sigma\mu\nu})$$

where, $F^\tau_{\mu\tau} = -J_\mu$

Following Schrodinger, the Einstein tensor on the right of eq.(6) is taken to vanish since this is purely gravitational and the electromagnetic field is assumed to contribute a negligible energy density compared to the massive source for this solution. This leaves E-tilda on the left with no apparent structure except as determined by its electromagnetic torsion effects on the right. Since we have shown that this tensor is symmetric and pseudo-Riemannian we assert that its structure will be that of the usual Einstein tensor but that it now is a more general function of a metric tensor that includes the effects of electromagnetic torsion. We can drop the tilda notation since and g-tildas on the right will only contribute in second order. This leads us to the new Einstein equation.

FIELD EQUATIONS AND SOLUTIONS:

The governing equations are chosen to be (for vanishing charge current sources):

$$\epsilon_{\mu\nu} = -\frac{\kappa}{2}u^\sigma(F_{\nu\sigma\mu} + F_{\mu\sigma\nu})$$

$$F^{\mu\tau}_{,\tau} = 0$$

$$F_{\mu\nu\sigma} + F_{\nu\sigma\mu} + F_{\sigma\mu\nu} = 0$$

(7)

These equations are functions not only of the metric and electromagnetic fields but also of the test particle 4-velocity. The dependence on the 4-velocity is not unexpected since in classical correspondence the velocity-dependent Lorentz force must be accounted for and the connection describes precisely those forces. This has been a bone of contention, but this is a classical theory and that is life. The test charge rest frame is chosen for simplicity in the solutions.

Conservation of the Einstein tensor yields exactly the wave equation for the EM field and thus Maxwell's source equations.

$$\epsilon_{\mu\nu,}{}^\nu = -\frac{\kappa}{2}u^\sigma(F_{\mu\sigma\nu}{}^\nu + J_{\kappa\sigma} - J_{\sigma\mu})$$

(8)

This vanishes identically since it can be shown that the wave eq. is

$$F_{\mu\sigma\nu}{}^\nu = J_{\sigma\mu} - J_{\mu\sigma}$$

and thus the new Einstein tensor is conserved.

Solutions for the three cases described above are:

(1) SPHERICAL GRAVITY PLUS ELECTRIC FIELD

The spherical interval is:

$$ds^2 = e^{\nu}dt^2 - e^{\lambda}dr^2 - r^2 d\theta^2 - r^2 \sin^2\theta\, d\phi^2$$

We ignore QM terms for our "zero coupling approximation" to find solutions:

$$e^{\nu} = 1 - \frac{2M}{r} - \frac{2\kappa Q}{r} \qquad e^{\lambda} = \left(1 - \frac{2M}{r}\right)^{-1}$$

$$E = \frac{Q}{r^2}$$

(9)

(2) LINE CHARGE ELECTRIC FIELD

The cylindrical interval is given by:

$$ds^2 = e^{\nu}dt^2 - e^{\lambda}dr^2 - r^2 d\phi^2 - dz^2$$

The solutions are:

$$e^{\lambda} = 1$$

(10)

$$e^{\nu} = e^{4\kappa\Lambda\ln(r/R)} \approx (1 + 4\kappa\Lambda\ln\frac{r}{R})$$

$$E = \frac{2\Lambda}{r}$$

We have taken $\kappa\Lambda \ll 1$. R is a constant of integration. Λ is the line charge density. The temporal metric coefficient fits the standard electric potential form, $1 - 2\kappa\Phi_{el}$, analogous to the gravitational form, $1 + 2\Phi_g$, which was also the case for the spherical electric field solution. Φ_{el} here is precisely the line charge potential.

(3) CYLINDRICAL UNIFORM MAGNETIC FIELD

For this case, the classic Rotating Frame metric was found to be an exact solution of the new Einstein equation. It can be stated that the magnetic field is equivalent to a rotating spatial frame. The interval is given by:

$$ds^2 = \left(1 - \omega^2 r^2\right)dt^2 - dr^2 - r^2 d\phi^2 - 2\omega r^2 d\phi\, dt - dz^2$$

The solutions are:

$$g_{00} = 1 + 2\kappa\, \vec{v}\cdot\vec{A} \ = 1 + \kappa\, \vec{r}\cdot\left(\vec{v}\times\vec{B}\right) = \left(1 - \omega^2 r^2\right)$$

(11)

$$g_{02} = \kappa B r^2$$

$$F_{01_{unit}} = \left(\vec{v}\times\vec{B}\right)_r = \omega B r \qquad F_{12_{unit}} = -B$$

$\omega = -\kappa B$ is the cyclotron frequency for the orbit. EM field solutions are shown here with respect to standard

unit vector . B is a constant, the magnetic field. Note that the solutions are given with respect to standard "unit vectors". The solutions as found from the theory are with respect to "base vectors". The relation between unit and base vectors is given by:

$$F_{\mu\nu_{base}} = \sqrt{\left| g_{\mu\mu}\, g_{\nu\nu} \right|}\ F_{\mu\nu_{unit}} \quad \text{(not summed)}$$

Thus, for example, in the magnetic solution:

$$F_{12_{base}} = -Br \qquad F_{01_{base}} = \omega Br$$

MATHEMATICAL ISSUES:

In order to obtain the above results covariant derivatives were passed through the 4- velocities. The motivation for this, other than it greatly simplifies the work and gives physically correct results, is that the 4-velocity is a parallel vector field on the curve (geodesics) hence invariant to order κ in the field equations on the right. This was not a rigorous assumption at the time, just a compelling one. I have included a rigorous proof that 4-velocities effectively pass through covariant differentiation with respect to the coordinates in the Appendix using a Differential Forms approach. The proof derives the fundamental Identity (eqn. 3) that Riemann satisfies and clearly shows that the four velocities fall out "as though they are constant". It therefore asserted in this work that differentiation can pass through the 4-velocities . A full rigorous approach might use a Finsler Space context(J. Vargas uses such an approach in his works) in which the 4-velocities are independent variables. But that is beyond the scope of the present work.

AN EXPERIMENTAL PREDICTION:

The theory suggests that a particle of charge e, and mass m, immersed in a suitable electric field but unshielded and supported will see, in its rest frame, a time differing from the proper time of an external observer arising from the electrostatic potential at that location. Since we have an exact solution for a line charge electric field, it is appropriate to use this field for a test. Let us suppose that we have a distribution of test charges, for example free protons (q=+e), between two concentric cylindrical electrodes, an inner cylinder of radius R_1 and an outer cylinder of radius R_2 . We further suppose we are able to create a situation in which the protons are momentarily at rest or at least moving slowly while experiencing an intense electric field. For example, they may be immersed in a dielectric medium, but must be at least momentarily ionized with electrons stripped and removed to the positive electrode. The relation between proper time elements at any two positions r_1 and r_2 within the dielectric is given from the theory by:

$$\frac{d\tau(r_1)}{d\tau(r_2)} = 1 + 2\kappa\Lambda \ln\left[\frac{r_1}{r_2} \right]$$

(12)

where κ = -e/m and Λ is the line charge density. The second term is the classical line charge potential appearing in the g_{00} solution of our Einstein Equations This equation is exactly analogous to that for the gravitational red shift. The negative electrode is the zero potential reference for the free proton.

If we choose r_1 as the center electrode R_1 , then the laboratory time is defined throughout by $r_2 = R_1$, where we may define the zero potential at the negative electrode at R_1 . We thus have a time effect depending on κ = +e/m for the proton in its proper frame. One possible clock for such a test is Nuclear Magnetic Resonance. A proton placed in an intense electric field within a radio-frequency transverse field "H_1" coil aligned orthogonally to a uniform magnetic field, H_0, is resonant at the Larmor frequency, $\omega = \gamma\, H_0$, where the

gyromagnetic ratio, γ, for the proton spin is proportional to e/m We thus have a natural clock. From eq.
(12) we expect the proton's clock frequency to depend on its position with respect to the zero potential electrode
as:

$$\omega(r) = \omega(R_j)\left[1 + 2\kappa\Lambda \ln\left(\frac{R_j}{r}\right) \right]$$

(13)

The Larmor field distribution is then given by:

$$H(r) = H(r_j)\left[1 + 2\kappa\Lambda \ln\left(\frac{R_j}{r}\right) \right]$$

(14)

From this it is straightforward to calculate the NMR lineshape and shift that will result when the electric field is
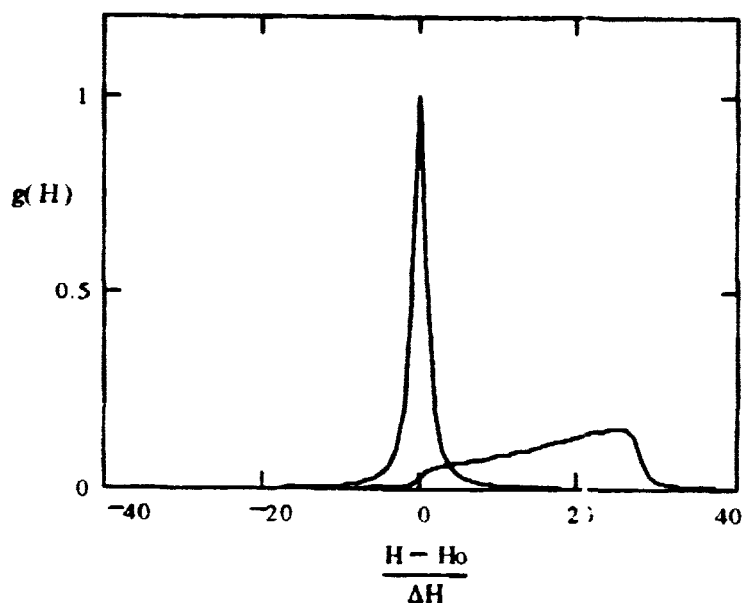turned on as compared to the field off. Figure 1 shows the result of this calculation for $R_1/R_2=0.50$.

Fig. 1   Normalized NMR lineshape as a function of magnetic field for electric field off
(sharp line) and on (broadened). ΔH is the line half-width.

With the E-field off, all the protons resonate simultaneously at the Larmor frequency and a sharp sweep field
line will result - it's width assumed to be broadened by the H₀- ield inhomogeneity and local fields. With
the electric field on, protons at different potential points will cor tribute to the signal at different times in the
sweep thus further broadening and shifting the line while reducin ; the line intensity. We assume the the natural
width is much less than the electric broadening. Pulsed methods nay be necessary to provide for protons
momentarily at rest. Under ideal circumstances, for a free proton in a 5T magnetic field with a 10kV/cm electric
field and electrons completely removed to the boundaries, a line shift and broadening of approximately six parts
per million is expected.

SUMMARY AND CONCLUSIONS:

We have shown that classical electrodynamics, neglecting radiative effects, can be embedded in a geometric framework in a self consistent way through the solutions of the field equations for the appropriate metrical and electromagnetic field variables. In the process, Maxwell's equations fall out naturally from conservation and symmetry requirements. From these solutions, not only are the correct electromagnetic fields found for a spherical electric field plus gravity, a line charge electric field and a uniform magnetic field, but also the expected electromagnetic potentials appear in the metric tensor alongside gravitational potentials. The procedure by which this is accomplished is partly grounded in Schrödinger's affine theory through a new "electrodynamic connection".

All that we have shown here is consistent with what is currently observed. Coexisting electric and gravitational fields act independently, within the scope of present measurements, on charged test particles, yet appear to share similar geometries. A classical neutral particle can pass with impunity through an electromagnetic field suggesting that electromagnetic fields do not influence the global geometry. In a sense we have a "relativity of geometry" since test charges with different κ experience correspondingly scaled geometries in their rest frames. Indeed, electromagnetic forces are velocity-dependent which stems from the nature of the Lorentz transformation .

Finally, it should be stressed that we have made several simplifications. We have only included order κ terms from the start. We have ignored the energy-momentum tensor . For the electric field solution we chose the rest frame and assumed spherical symmetry which is not strictly correct . We also ignored weak coupling terms.

APPENDIX A:

The curvature 2-form for a differentiable manifold X_n referred to local coordinates x^ν endowed with a general nonsymmetric connection is given by:

$$\Omega^\iota_{.\mu} = \frac{1}{2} R^\iota_{.\mu\nu\sigma} dx^\nu \wedge dx^\sigma$$

(A1)

The torsion 2-form is given by:

$$\Omega^\iota = \frac{1}{2} S^\iota_{.\nu\sigma} dx^\nu \wedge dx^\sigma$$

(A2)

where,

$$\tilde{\Gamma}^\iota_{[\mu\sigma]} \equiv S^\iota_{.\mu\sigma} = \frac{\kappa}{2} u^\iota F_{\mu\sigma}$$

(A3)

is the torsion tensor of this work. This torsion, although a direct product of a vector field on a curve in X_n with a tensor field on X_n is nevertheless valid with regard to defining a differentiable manifold since each field is itself differentiable on its domain. It can be shown that the exterior covariant derivative of the torsion 2-form is related to the curvature 2-form from the well known result (5):

$$D\Omega^\iota = -\Omega^\iota_{.\lambda} \wedge dx^\lambda$$

(A4)

The crucial point of this result is that with differential forms, the covariant derivative is the absolute derivative,

so that partial covariant derivatives, relevant in coordinate representations, need not be considered at all at this point.

Now the vector u^ϵ in general is the sum of a geodesic gravitational component and an electromagnetic contribution of order κ. We can ignore the electromagnetic contribution to the geometry since it will enter the field equations as order κ^2. Thus, since u^ϵ is then a vector on a geodesic, we may conclude without hesitation or question that

$$Du^\epsilon = 0$$

(A5)

We now expand (A4) using the above results to find:

$$DS^\epsilon_{\nu\sigma} \wedge dx^\nu \wedge dx^\sigma = \frac{1}{2} R^\epsilon_{\sigma\lambda\nu} dx^\lambda \wedge dx^\nu \wedge dx^\sigma$$

$$\kappa u^\epsilon DF_{\nu\sigma} \wedge dx^\nu \wedge dx^\sigma = R^\epsilon_{\sigma\lambda\nu} dx^\lambda \wedge dx^\nu \wedge dx^\sigma$$

(A6)

Now utilizing the covariant partial on the spatial field F yields:

$$\kappa u^\epsilon F_{\nu\sigma\lambda} dx^\lambda \wedge dx^\nu \wedge dx^\sigma = R^\epsilon_{\sigma\lambda\nu} dx^\lambda \wedge dx^\nu \wedge dx^\sigma$$

(A7)

In component form this becomes precisely the equation, (4) above,

$$\kappa u^\epsilon (F_{\lambda\nu,\sigma} + F_{\nu\sigma\lambda} + F_{\sigma\lambda,\nu}) = \widetilde{R}^\epsilon_{(\lambda\nu\sigma)}$$

(A8)

Thus Eq (3) is a valid result and the fact that the partial covariant derivative passes through u^ϵ is an artifact of the component representation of a possible Differential Forms approach to this theory. I choose to adhere to the component approach and adopt the rule that *covariant partial differentiation with respect to local coordinates,* x^ν, *in* X_n *will pass through vector fields defined on a geodesi in* X_n.

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Laboratory Scale Vacuum Energy Extraction
Modeled on Weak Nuclear Force Reactions
in a Spinning Black Hole System

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ABSTRACT

A spinning black hole with accreting disk of matter and axially directed jet(s) of ejecta may promote a catalytic process of vacuum energy extraction by weak nuclear force reactions. This process would have profound cosmological implications and offers rationale for a luminosity mechanism in jets, anti-matter emission in jets, disrupted regions in jets, and some deep space gamma emission peaks.

Innovative interpretations of three known quantum level effects each offer rationale for laboratory scale matter/spacetime interaction using nuclear magnetic resonance techniques. The natural model of putative vacuum energy extraction represented by a spinning black hole may potentially be mimicked in a laboratory setting by exploiting the solar neutrino flux, using off-the-shelf equipment, in the near-term, with no major design challenges, and at relatively low cost.

SPACETIME GEOMETRY

At first look a perfect vacuum appears to be nothing at all. However, this largest (by far) of the three components of our universe is a void with very real properties. In Max Born's words, (1962), "In itself the four dimensional spacetime continuum is structureless. It is only the mutual relations of world points disclosed by experiment which impress a geometry with a definite metric on it."

To this structureless Einsteinian spacetime geometry may be added a directional arrow of time defined by our notions of entropy increase and causal order. Gravity is the one different force in that it distorts the directional metric to influence the kinematics of those world points which so impress. in other words, "... gravity shapes the arena in which it acts." (Hawking and Penrose, 1996).

Finally, on the smallest scale of the vacuum, virtual particle production, distribution, range and annihilation dance to discordant causal tempos of mass and uncertainty, correlation and charge, (Gribbin, 1984). Examined finely, this vacuum is dimensional and directional, and continual and causal, and hectic, and metric, and really quite energetic. Hardly "nothing at all"!

GEOMETRY OF A BLACK HOLE

Consider now a black hole in spacetime. This is the corpse of a massive star catastrophically collapsed to within its Schwarzschild limit when pressure from nuclear fires no longer resist its self imposed spacetime curvature. The hole's gravitational mass overwhelmingly determines the metric of spacetime surrounding its event horizon. This, together with the hole's angular momentum and net electric charge, influences the kinematics which order accreting material into a death spiral ending at the event horizon -- or boost into new life along an axially directed jet of ejecta perhaps a thousand light years in length. (Thorne, 1994).

As accreting matter approaches the distorted spacetime near the event horizon it experiences slowed time rate-of-passage. In this region, weak nuclear force coupling increases due to uncertainty relation influence on virtual particle production and range around accreting nuclei. Additionally, accreting massless particles approaching the distorted spacetime region experience gravitational and time blueshifting of their energy and frequency.
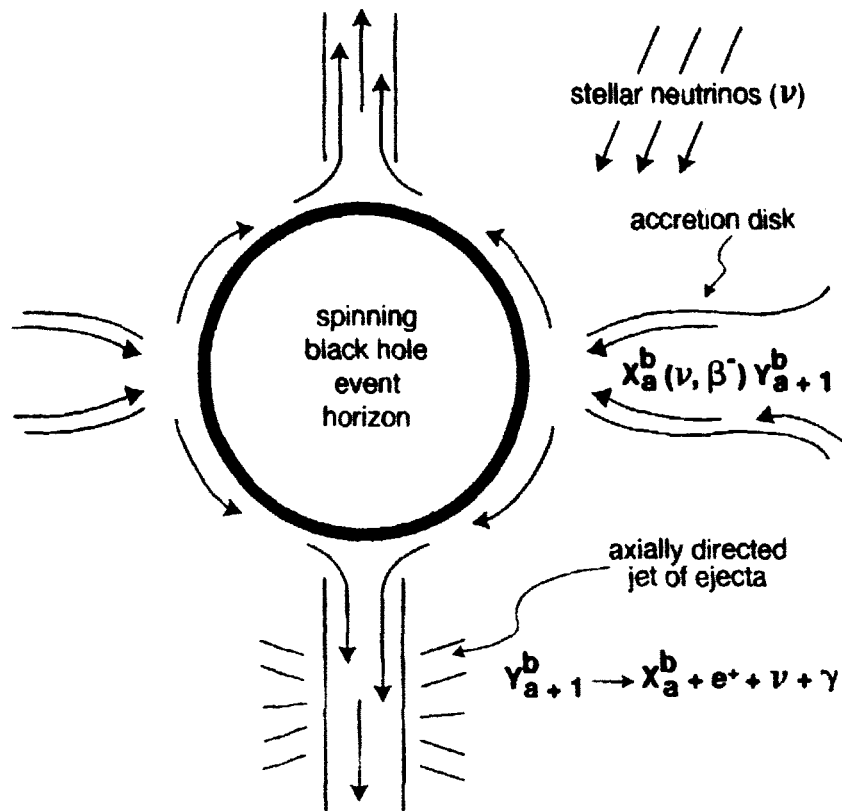
As an example, consider that virtual particle production and range of intermediate vector bosons increase around accreting nuclei near the event horizon while incident ste lar neutrinos exhibit blueshift of their apparent kinetic energy. Together these effects should promote induced beta⁻ reactions in those accreting nuclei.

FIGURE 1 Induced Beta⁻ Decay in a Slowed Time Region
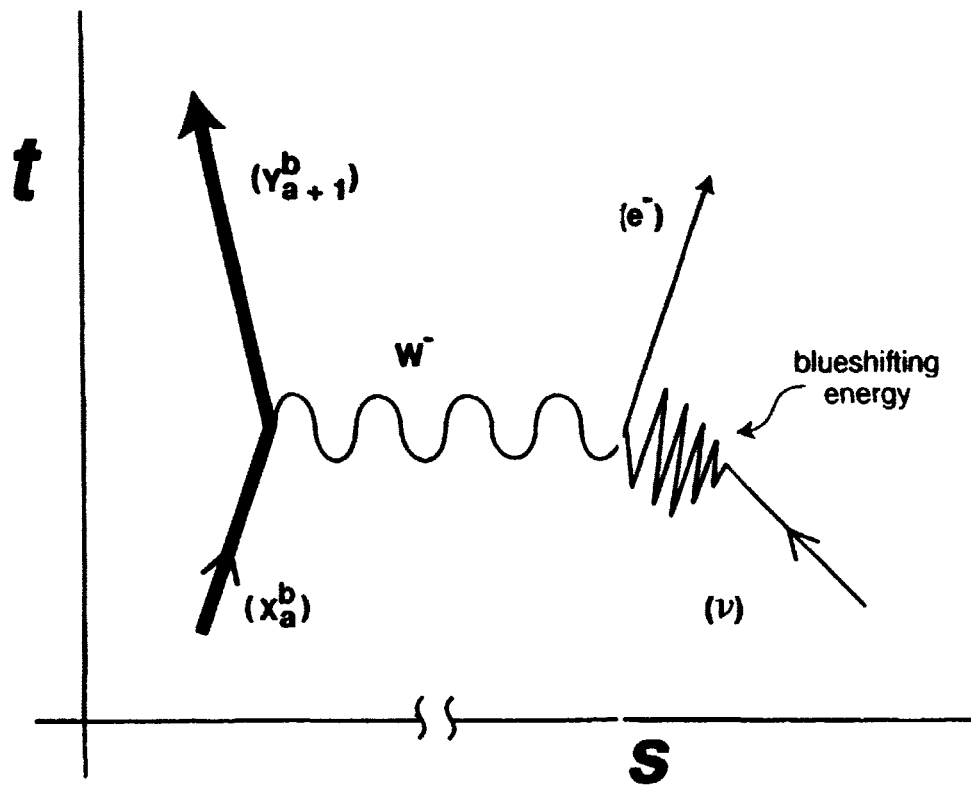
In figure 1 an intermediate vector boson mediates the weak nuclear force reaction between a nucleus and a blueshifting neutrino near the event horizon of a black hole, X^b_a $\nu,\beta^-) Y^b_{a+1}$. Uncertainty relation influence in a slowed time region extends virtual "W" particle lifetimes, allow ng them to range far beyond their normal 10^{-15} cm distance from the nucleus. This essentially increases the cros s sectional target area for neutrino interaction at the same time that gravitational and time blueshifting increases apparent neutrino kinetic energy.

FIGURE 2 Weak Force Reactions in a Spinning Black Hole System

stellar neutrinos (ν)

accretion disk

spinning
black hole
event
horizon

$X^b_a (\nu, \beta^-) Y^b_{a+1}$

axially directed
jet of ejecta

$Y^b_{a+1} \rightarrow X^b_a + e^+ + \nu + \gamma$

In figure 2, some of the proton rich and unstable nuclides survive to be ejected from the system in a jet due to natural half-lives and to time dilation influence on natural half-lives near the event horizon. The decay products of subsequent beta$^+$ reactions include positron and neutrino emission plus secondary gamma emission from nuclear transition states and from positron/electron annihilation. This gamma signature may be modified by relativistic effects from near light speed velocities in entrained matter in the jet, or by Compton scattering of gamma photons to longer wavelengths through gamma/electron collisions.

Disrupted regions in jets might be caused by instabilities attributable to concentrated internal beta$^+$ and gamma radiation pressure initiated by neutrino bursts from collapsing stellar cores. Jets then visually exhibit an historical record of far distant supernovae while producing a short lived and distinctive gamma emission peak for each such event.

The blueshift of apparent neutrino energy on entering a distorted spacetime region may validly be interpreted by an observer also situated near the event horizon as a borrowing of energy from the vacuum. This borrowed energy is "trapped," or locked into an accreting nucleus by the weak nuclear force reaction and then carried away from the event horizon by that nucleus in a jet. Therefore a balance sheet accounting of energies into and out of this putative black hole luminosity mechanism suggests a catalytic conversion of spacetime energy into radiant and kinetic energy with profound cosmological implications.

Consider a neutrino of 0.42 MeV energy commonly produced in the $_1$H,p fusion reaction in stars. As its apparent energy blueshifts near the event horizon of a black hole it may enter into the following reaction, Al^{27} (ν, β^-) Si^{27}. After transport away from the event horizon in a jet, Si^{27} releases on average 4.8 MeV through its beta$^+$ decay products while returning to its original Al^{27} identity. (Nuclides and Isotopes, 1989). This catalytic tenfold energy surplus is energy drained from the vacuum.

GEOMETRY OF SELECTED QUANTUM LEVEL EFFECTS

Replacing the black hole in the process described above with a laboratory scale matter/spacetime interaction mechanism similarly able to distort time in the local region surrounding atomic nuclei might allow catalytic vacuum energy extraction here at home. Those matter/spacetime interaction mechanisms commonly cited in the literature include ultradense forms of matter, exotic forms of matter, megatesla electromagnetic fields, and applications of relativistic velocities. These might be found in theoretical exploitation of collapsed stellar bodies in deep space, in laboratory exploitation of the "Casimir" effect, in attempts to manipulate charged virtual particle pair distribution and annihilation in the vacuum, or in theoretical "Tipler" machines. However, none of these would seem to offer near-time doable laboratory approaches to vacuum energy extraction with practical (positive net return) results.

Innovative interpretations of three quantum level effects each hold promise for a more practical matter/ spacetime interaction mechanism. For example, maximum violation of weak nuclear force parity conservation may be viewed in a Standard Model light as disappearance of weak force "charge" into the vacuum upon a reversal of massive particle spin handedness, (Georgi, 1981). This acceptance or return of weak force charge by the vacuum based on particle chirality may be interpreted as a sort of matter/spacetime interaction mechanism distinct from those commonly cited in the literature, and nuclear spin manipulations are easily accomplished in a laboratory setting using nuclear magnetic resonance techniques.

A second quantum level effect having potential for matter/spacetime interaction may be visualized in Flatland. A Flatland resident cannot manipulate a two dimensional chiral outline in any way which can produce its enantiomorph. However, a three dimensional Solidlander can easily turn over a two dimensional outline in his third spatial dimension to produce the enantiomorph, (Gardner, 1964). The Flatlander watching this extradimensional inversion, since he cannot look "up," would see only a quantum transition with no intermediate state of orientation.

A three dimensional chiral particle, such as a left hand spin proton, may be similarly inverted in a fourth spatial dimension, if such exists in Nature. This would produce its enantiomorph, a right hand spin proton. This extradimensional inversion will now appear to a Solidlander observer as a quantum transition. For us, massive particle inversions in a postulated fourth spatial dimension are identical in appearance to quantum spin flips. This represents a sort of matter/spacetime interaction mechanism distinct from those commonly cited in the literature, and quantum spin manipulations are easily accomplished in a laboratory setting using nuclear magnetic resonance techniques.

Finally, phase entanglement has been shown by the Clauser/Freedman and Alain Aspect experiments testing Bell's Theorem to strongly and non-locally correlate polarization angles between photons created in a common quantum event. This connection has been described by Herbert, (1985), as "unmitigated" (by distance), "unmediated" (by any known particle or force), and "immediate" (simultaneous anywhere in the universe). It is here assumed that phase entanglement can be assigned as a (testable) property of spacetime.

Massive particles created in a common quantum event are also non-locally, though perhaps not strongly correlated in their spin orientations, the massive particle analog to wave polarization angles. For example, beta⁻ reactions may enrich a working fluid in phase entangled proton/electron partners. Such a working fluid may be produced by neutron bombardment of a magnesium isotope, Mg^{26} (n,β^-) Al^{27}.

Electrons formed in these beta⁻ events and eventually bound in atomic orbitals may now be spin aligned in a stationary magnetic field – and electron cloud alignments then influence nuclear alignment to "spin up" or "spin down" states. The phase entanglement enriched and spin aligned working fluid can next have a magnetic resonance tuned radio frequency field applied to nuclei while electron partners continue to be held spin invariant on at least one axis by the stationary magnetic field. When the resulting "irresistible" proton spin flips meet their "immovable" electron spin partners, the assigned spacetime phase entanglement property between them may "twist" to distort spacetime in the working fluid. This enforced geometric distortion of an assigned spacetime property represents a potential matter/spacetime interaction mechanism distinct from those

commonly cited in the literature, and the quantum spin manipulations are easily accomplished in a laboratory setting using these nuclear magnetic resonance techniques.

MIMICKING BLACK HOLE GEOMETRY IN THE LAB

All three of the quantum level matter/spacetime interaction mechanisms proposed above depend upon opposingly chiral nuclear spin orientation manipulations. All three mechanisms may be tested in a spinning nuclear magnetic resonance apparatus in which a ring of working fluid is held in a magnetic field rotating with and therefore stationary to the fluid. This field quantizes the fluid and orders its nuclei into spin up or spin down states, with one state dominating depending on polarization of the magnetic field.

Application of a scanning radio frequency field, properly tuned for isotopic make up of the fluid and for magnetic field strength, interacts with nuclei through photon absorption to cause quantum spin flips. When the nucleus later emits the absorbed photon, (resonance), it returns to its original spin orientation. The relative proportion of spin up to spin down populations upon initial alignment defines a thermal equilibrium state for the working fluid as a whole. (Chandrakumar and Subramanian, 1987).

Since the testing program here proposed is concerned not with resonance return signals, but with demonstration of spacetime distortion caused by nuclear spin manipulations, the Z axis of the spinning ring would be aligned with the solar neutrino flux. Nuclear spin up and spin down states then present opposingly chiral aspects to incident neutrinos to take advantage of weak force parity violation temperament. Similarly, spinning the ring cyclically reverses random off-alignment-spin nuclear aspects across the X-Y plane to give a uniform probability of interaction for the fluid overall. Any spacetime distortion produced in the local region surrounding working fluid nuclei could be expected to induce beta⁻ reactions through uncertainty relation influence and blueshifting energies – just as in the spacetime distorted region near a black hole in space.

The first goal of a laboratory experiment would be to maximize the number of quantum spin flips in order to locally overwhelm some natural equilibrium state between weak nuclear force "charge" and the vacuum, or to maximize the number of quantum particle inversions locally crowded into a postulated fourth spatial dimension, or to maximize the number of "twists" introduced in the assigned phase entanglement spacetime property of an appropriate working fluid. For all three rationales the stationary magnetic field would be as strong as possible to maximally skew aligned spin populations to a single dominant orientation, while the scanning radio frequency field would be applied at intensity to suddenly and massively invert thermal equilibrium in the fluid. Hopefully this results in sufficient distortion of local spacetime geometry to induce neutrino/matter interaction in nuclei chirally aligned with the solar flux.

Success in the testing program for any one of the three quantum level rationales would thus be indicated by induced beta⁻ decay reactions. For all three mechanisms success then also results in enrichment of the working fluid by more phase entangled beta⁻ partner particles. Assuming that phase entanglement is appropriately assigned as a spacetime property, then the potential for a runaway reaction is evident for any of the three test regimens.

Given induced beta⁻ reactions in the working fluid, removal of proton rich and unstable nuclei along an axial pathway then completes the mime with black hole geometry and allows release of spacetime energy to the environment as radiant and kinetic energy. In the lab, however, this working fluid may be returned to the NMR ring to give a closed loop of catalytic vacuum energy extraction. Perhaps a central black hole with its jets and galaxy of stars and gas clouds attendant for is a grand sort of gravitationally bound closed loop too.

The proposed test regimen uses known technology and virtually off-the-shelf equipment so planning, assembly and start up should be possible on a near-term basis for at least two of the three matter/spacetime interaction rationales. Preparation and timing for test of a phase entanglement enriched fluid will take longer and require standard health physics safeguards in the lab. No major design challenges would seem to present except for consideration of the "runaway" reaction possibility. This might dictate a hydrogen atmosphere surrounding the test apparatus and/or very high threshold and very short lived reverse beta half-life structural materials for the test apparatus such as silicon and its oxide. (Nuclides and Isotopes, 1989).

Cost of the proposed empirical regimen would not be exorbitant if equipment availability and experiment feasibility are considered in comparison to test regimens for those matter/spacetime interaction mechanisms more commonly cited in the literature. Any near-term alternative approach offering practical results and not fatally violating physical laws is worth a try considering the scale of potential returns in many fields accruing from a successful experimental outcome.

WHENCE THE ENERGY?

The Big Bang theory of cosmology posits the universe of all things as originating in a beginning point source. It is philosophically uncomforting to think of the three components of our universe as coexisting in separate forms in a singularity. Matter, energy, and spacetime may all have been homogeneous universe "stuff" at some level of organization dating back to the one primordial singularity. If so, then not just matter and energy are interchangeable; matter, energy, and spacetime are all interchangeable under at least one set of admittedly extreme conditions.

So whence the energy gained in the $beta^-$/$beta^+$ cycles discussed in this paper? It would not seem to come from spacetime within the event horizon of a black hole The theoretical event boundary isolates "inside" from "rest of the universe" rather convincingly, and of course there is no isolated gravitational well upon which to draw in the proposed empirical test. An event horizon's surface area anyway represents the total entropy of a black hole, and by extension it represents the total number of past histories that the hole could ever have had in coming to rest at a single point in space and time, (Hawking and Penrose, 1996). To reduce the hole's "irreducible" mass energy would in essence be to resurrect entropy and revise history. Further, for a $beta^-$/$beta^+$ cycle draining energy from a black hole's interior, unlike the claim made for Hawking radiation, there would seem to be no way to satisfy the Hawking/Bekenstein relation that dS_{hole} plus $dS_{universe}$ must always be greater than or equal to zero, (Thorne, 1986).

A quite different argument holds that a black hole's spin angular momentum, a quantity known to be extractable, yet cannot be used to justify energy gained with the weak force reaction cycle. Simply put, the weak force cycle's energy surplus should still hold for a nucleus pass ng near the event horizon of a non-rotating black hole and subsequently escaping its gravitational trap ballistically.

Energy gain in the $beta^-$/$beta^+$ cycle would thus seem to come from distorted spacetime surrounding the event horizon of a black hole and from the distorted spacetime surrounding atomic nuclei in the laboratory ring. This violates no entropy law since the source of energy is not counted as energy or as entropy while still resident in its spacetime form outside of an event horizon. Conversion of vacuum energy to radiant energy, essentially adding "new" energy to a universe then slightly depleted in spacetime, can only leave dS_{hole} plus $dS_{universe}$ unchanged now and increased later.

It is important to note that a majority of nuclei undergoing beta decay in a black hole's accretion disk probably are captured by the hole – so the hole too increases in its irreducible mass energy as a result of this and from blueshift of any other particle energies as particles fall to their final entrapment. Black holes must therefore swallow spacetime as they swallow matter and energy – as well as convert spacetime into new energy for the universe – if the arguments presented in this paper hold true under critical review and empirical test.

If so, then black holes in space may increase the universal store of mass energy enough to one day slow to a cusp cosmological expansion through process of vacuum energy conversion. This process will be done on Earth as in the heavens. For by mimicking black hole geometry in a laboratory setting and exploiting weak nuclear force reactions we too will convert spacetime into radiant energy for the great benefit of mankind.

"For since the creation of the world
God's invisible qualities –
his eternal power and divine nature –
have been clearly seen,
being understood from what has been made... "
(Romans 1:20, NIV).

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NEXT DOCUMENT

Anomalous Weight Behavior in YBa$_2$Cu$_3$O$_7$ Compounds at Low Temperature

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ABSTRACT

YBa$_2$Cu$_3$O$_7$ high temperature superconductor samples were weighed on an electronic balance during a warming cycle beginning at 77°K. The experiment was configured so that the YBa$_2$Cu$_3$O$_7$ material was weighed along with a magnet, a target mass, and liquid Nitrogen coolant. The weights were captured during Nitrogen evaporation. Results indicated unexpected variations in the system weight that appear as a function of temperature and possibly other parameters.

I. INTRODUCTION

Dr. Eugene Podkletnov reports[1,2] an experiment wherein a rotating, supercooled YBa$_2$Cu$_3$O$_{7-x}$ disk apparently acts as a shield between the Earth's gravitational field and a Silicon Dioxide sample suspended from the arm of an electronic balance. Sample weight changes are reported ranging from .05% to .3% depending on the velocity of rotation of the superconductor. During the period of time the weight effects were recorded the superconductor had a temperature range between 20K to 70K. The superconductor was suspended over a toroidal solenoid and was in a state of levitation due to the Meissner Effect. A varying magnetic field was placed around the superconductor and the frequency was varied between 50 HZ and 10^6 HZ. The greatest weight change occurred at the highest frequency. However, the weight reductions apparently occurred even when the rotating field was turned off and the superconductor stopped rotating. Further anomalous weight behavior was reported[2] using Podkletnov's experimental design, but with significant simplifications.

The experimental designs reported to date have basically followed the Podkletnov approach. That is using a weight suspended over the top of the superconductor (SC), and the weight being connected to a balance. Essentially we can view the weight and the SC as two separate systems. In such an experimental arrangement determining if "gravitational shielding" is at work as opposed to an action-reaction force, such as magnetic or electric fields, is very difficult. Therefore, the experimental approach described herein creates a system in which the action-reaction components cancel each other.

The experimental question is whether the YBa$_2$Cu$_3$O$_7$ SC material acts as a gravitational shield in that mass situated above the SC loses weight while the SC is in the supercooled state. It must be noted that very little theory exists[4,5,6,7] that predicts a gravitational interaction with SC's at the macroscopic level. Most assuredly no engineering formulas exist that aid in system design.

II. EXPERIMENTAL DESIGN

The experimental approach reported herein has two phases:

Phase 1. The determination of weight anomalies in a system consisting of magnet, coolant, SC, and target mass.

Phase 2. The determination of whether variations in the target mass produces a proportionate variation in system weight.

Figure (1) shows the test model used in phase 1. It consists of a 50 cc plastic prescription medicine bottle. A rare earth Cobalt disk magnet (approximately .5 Tesla, Edmund Scientific part number C52, 867) is attached 1.9 cm below a 2.54 cm-by-.31 cm SC (Edmund Scientific part number C37, 446) disk. The magnet is held in place by sytrofoam and plastic resin is used as a platform for the SC. A small plastic bead is used to provide air space between the SC and the resin surface. The SC, bead, and resin platform are glued together. A number 2 rubber stopper is glued to the bottle's cap to act as a target. This target mass is approximately 10 grams. Four .5 cm holes are drilled in the bottle just above the top surface of the SC. These holes allow liquid Nitrogen(LN2) to enter and act as the coolant during the weighing. The bottle plus magnet, SC, target, and LN2 will be heretofore designated as the *system*. Not having any engineering guidelines for the construction of this test model, the criticality of the dimensions provided are uncertain.

The experimental methodology is merely to cool the SC to $77^\circ K$ using an LN2 bath. Some LN2 enters the bottle through the holes. The system is then placed on a sensitive digital electronic balance. In the case of this experiment a Sartorius Model 1207-MP is used. It has a readability of .1 mg and it updates its reading every second. The balance has glass sliding doors at the top and both sides, so the mode. can be completely enclosed for more accurate weighing. A six-ounce styrofoam cup separates the balance's pan from the system. This distance seems sufficient to prevent the magnet from interacting with the balance's electro-mechanics. However, balances are subject to magnetic influences and this is an area of noise that could not be completely eliminated with certainty.

As the system sits on the balance the LN2 is evaporating and, therefore, mass is leaving the system and the balance reads a continual weight decrease over time. The balance's digital readout was videotaped during the full span of time that LN2 is evaporating and beyond to assure that weights are gathered after the SC warms passed its critical temperature, T_c, of approximately $90^\circ K$. The video camera uses 8mm tape and contains a time and date stamp so the time down to 1-second intervals can be recorded along with the weight readings. T_c can vary by several degrees from one piece of $YBa_2Cu_3O_7$ to another. The exact value of T_c was not determined during the course of these experiments. The LN2 in the system appeared completely evaporated after about 2 minutes.

After each weighing cycle the videotaped readings are transcribed to an Microsoft Excel Version 5 spreadsheet. Both the time and the corresponding weight are placed on the spreadsheet. The graphs contained herein were generated using Excel. The raw data plots are presented along with a 4-point average plot. The 4-point average serves to smoothe out the low level noise, but does not disguise the anomalous weight behavior.

The test model in Figure (2) was used for Phase 2 testing. The magnet and SC are the same as in Phase 1. The magnet, however, is glued directly to the SC, and then this complex is glued to the bottom of the bottle. A nylon bolt is attached to the bottle's cap. 2.38 cm X .31 cm rubber washers are then bolted in as required to vary the weight. To add more weight two brass washers are used in place of the washers. This arrangement creates a rigid, but modifiable target.

III.   PREDICTED RESULTS

In this experimental design, if the SC acts as a gravitational shield, then the system should display a gain in weight as it warms passed T_c. This gain in weight is expected because when the test model is placed on the balance, it is already in the supercooled state and, therefore, shielding should be occurring. In essence the system is lighter when it is placed on the balanced and in theory we would assume it would gain weight as T_c is passed. The weight vs. time curve should show an abrupt slope change at the point of transition and then a continuation with the previous slope characterized by evaporating LN2.

IV.   PHASE 1 RESULTS

Four(4) trials were performed during phase 1. Two trials were with the SC. The third and fourth trials used rubber and brass controls respectively instead of a SC; yet, no other feature were changed in the system.

Trial 1 results are shown in Figure (3). Using the gravitational mass scale as shown we can see a high degree of linearity in the evaporation curve until a sharp slope change occurs at around 46 seconds. This linearity is apparent down to the centigram level. The sharp slope change is unusual, but can be easily explained as being the point in which the LN2 has completely evaporated and the balance's sampling rate is not fine enough to catch transitional points.

Nothing particularly unexpected appears in the weight vs. time curve. But, the linearity allows us to perform some statistical analysis that could reveal effects to a much lower level. First, we make the assumption that T_c occurs somewhere between 0 and 45 seconds. Second, we estimate the actual evaporation curve as given in Figure (3), by fitting a line to the actual data. This is done simply by using the slope intercept formula with the first weight at time 0 and the second weight at time 45. The intercept is the point with the weight corresponding to time zero(0).

We know that a curve in two dimensions can be represented by the following formula:

$w(t) = l(t) + n(t)$, where w is weight, l is the linear part of the curve, n is the nonlinear, and t is time.

Therefore, $n(t) = w(t) - l(t)$.

Letting $l(t)$ be the linear estimate, $n(t)$ represents the nonlinear behavior of $w(t)$ with respect to this line of estimation. $n(t)$ measures the deviation of weight from the linear. If $l(t)$ is very close to $w(t)$, then $n(t)$ will display very minute variations in the weight.

$n(t)$ is plotted in Figure (4). Note the linearity is so tight between $l(t)$ and $w(t)$ that $n(t)$'s scale ranges only 20 mg. We can easily see effects at the mg level. We can see the obvious 5 mg increase in weight beginning at about 16 seconds. The target mass weighed about 10 grams. Hence, we observe a .05% weight increase. This percentage is what Podkletnov noted as the lower level of observations he had made in his initial work.[1] This increase seems to evolve over a period of about 8 seconds. Then a sharp decent occurs to the original slope of the "pre-event" curve.

The same experiment was repeated in trial 2 to see if the results could be replicated. Figure (5) shows again the high linearity during the first 45 seconds. Figure (6) uses the linear estimation technique as in trial 1. Note the appearance of the weight increase beginning at about 25 seconds and continuing to about 33 seconds, an 8-second cycle. Also, this weight increase is again at about the .05% level. The fact that it occurs later in the warming period is an interesting variation from trial 1. Also, the concavity of the chart is concave down, rather than up as in trial 1.

One of the significant challenges in this experimental arena is finding the right combination of controls to narrow the possible explanations for the results seen in trials 1 and 2. Possibly the curves merely display the normal evaporation behavior of LN2. Or, possibly the magnet is interacting with the balance. Some insight can be gained by using a control sample material instead of the SC. Hence, trials 3 and 4 used rubber and brass respectively.

Figure (7) shows the evaporation curve for rubber. Note the linearity again, so we were immediately able to apply the linear estimate technique and plot the results shown in Figure 8. At the same mg scale as in previous trials no obvious and anomalous weight effects are observed.

The experiment was repeated using a brass control sample in trial 4. The weight vs. time curve is shown in Figure (9). The results here are a bit more nonlinear. However, we still applied the same linear estimation technique where the results are displayed in Figure (10). Again, we see no obvious weight anomalies.

V. PHASE 2 RESULTS

Recall that in Phase 2 the test model was redesigned. The major change was actually putting the magnet much closer to the SC. This had the effect of increasing the local magnetic field entering the SC by a factor of over 1000. The Sample SC has a critical magnetic field much lower than .5 tesla. Therefore, the SC was being over-saturated

by the magnetic field. The SC, therefore, could not achieve superconductivity. Over-saturating the SC was not intentional and it was discovered during the Phase 2 experimental calibrations and in conversations with the SC's manufacturer. The calibration performed was merely checking the presence of the Meissner Effect at LN2 temperature, 77°K. The Meissner Effect was never achieved with this configuration.

However, the trials performed in Phase 2 offered some interesting and surprising effects. In trial 1 of Phase 2 we use a 13 gram target weight. Note the subtle slope aberration at around 17 seconds in the weight vs. time curve, Figure (11). The slope decreases for a short burst then continues on with its previous slope. Using the linear estimation, Figure (12), we see that at the 17-second point what might be interpreted as a very subtle increase in weight, but this could be merely judged as noise. Figure (11) shows an obvious decrease in slope, which would indicate a small increase in system weight. Of course, these anomalies could easily be relegated to noise effects. Figure (13) displays a bar chart of the slopes from 7 seconds to 27 seconds of the trial run. The slope is simply Weight$_i$ - Weight$_{i+1}$. Note that at 17 seconds the slope is markedly less than all others in the group. This decrease in slope can be explained by a system weight increase of .05% to approximately .1%.

Trial 2 increases the target mass to 27 grams using two brass washers. Figure (14) shows the weight vs. time curve and again we see the slope anomaly appear at 16 seconds. The linear estimation curve is shown in Figure (15) and the increase is clearly seen at the 16-second point, representing a weight increase of approximately .05% to .1% of the target weight. Doubling the target weight seems to produce a proportionate increase in system weight during warming.

VI. ANALYSIS OF THE EXPERIMENT

The experimental data to date is very difficult to interpret. To assume that gravitational effects are at work is premature. Other possibilities exist and will be discussed below.

1. Thermal conductivity changes in the superconductor.
If the thermal conductivity of the superconductor changes around the critical temperature, then we would see changes in the LN2 evaporation rate, which could account for some of the observed results. However, these effects could be ruled out because the thermal conductivity of this particular type of SC actually begins to increase at T$_c$ and peaks at about 50° K.[5] The increase is small from approximately 3.5 to 4.0 watts/meter/ K degree. The conductivity is very flat up to around 150°K. So, the smallness of the change in thermal conductivity is not expected to produce the observed results. Yet, even more is the fact that the thermal conductivity increases. This would cause the evaporation rate to increase, not decrease. Therefore, such a change in thermal conductivity would be observed as a decrease in system weight, not an increase.

2. Thermal State Changes.
One of the most probable causes of the weight anomalies is the profound changes that occur in the SC's specific heat around its critical temperature. These thermal changes are particularly pronounced when the SC is in a mixed state, which is induced by the external magnetic fields. If the SC behaves the same as other high temperature superconductors in a magnetic field, then at some point near the critical temperature, the specific heat should show a high amplitude spike. Under such circumstances the evaporation rate of the LN2 would increase. Such an event could easily explain the behavior of the evaporation curves. Unfortunately, the effects of the thermal state changes could not be confirmed.

3. External magnetic fields.
Such fields are the most viable candidates for the observed results and the most difficult to rule out. The experimental surroundings were not shielded against electromagnetic fields. The fact that the rubber and brass trials showed none of the effects observed with the SC trials, indicates that the magnet attached to the system did not contribute by itself to the anomalous effects. However, the controls do not rule out magnetic effects brought on by the superconducting material, even though the SC does not achieve superconductivity in Phase 2. The observation that the proportion of weight increase remains constant even as the target weight is doubled also indirectly

diminishes the external magnetic field possibility, and contributes some validity to a gravitational shielding explanation. However, further testing is necessary to rule out external field influences.

4. Effects within the Electronic Balance.

These effects are good candidates and must be ruled out by repeating the experiment using other equipment. The assumption in these experiments is that effects within the balance would occur at random points and would not occur in the same places or in the same way during successive trials. Therefore, balance effects would not explain the repeatable results obtained in these experiments.

5. Random Noise.

We can quickly rule out random effects because of the fact that the experimental behavior showed consistent and similar results during each trial execution.

6. Atmospheric effects.

Because LN2 is evaporating inside the closed balance chamber, significant thermal effects are occurring. Convection currents would be prevalent and the balance may be effected by the temperature changes. The assumption in these experiments is that atmospheric effects would behave in a random manner and would show up differently during the experimental replications. However, ideally this experiment could be greatly improved by performing it in a vacuum.

7. Rapid condensation of water vapor.

These effects are assumed to behave randomly.

VI. HYPOTHESIS

To provide a hypothesis as to the cause of these observed phenomena is tempting. The effects seen by varying the target mass appears to point to a gravitational connection. However, the fact that in the experiment superconduction was prevented by an over-saturating magnetic field would lead one to guess that the material displays some temperature dependent critical points in its own gravitational interaction, which are possibly independent of the electronic effects causing superconduction. The critical temperature for the gravitational interaction may be somewhat different than that of superconduction. No viable theory at presents explains or predicts the phenomena observed in these experiments. Obviously a great deal more work is required with rigorous examination and replication within the scientific community.

Since these effects were observed at the macroscopic level, a useful endeavor might be to describe the phenomena using a Newtonian perspective. Minimally we observed in these experiments a weight anomaly at the .05% level. Let:

$$Force = GM_1 M_{target}/R^2$$
where $G = 6.67 \times 10^{-11}$ nt-m^2/kg^2,
M_1 = mass of the Earth at 5.98×10^{24} kg,
R = the radius of the Earth at 6.37×10^6 meters,
M_{target} = the mass of the experimental target. .01 kg for the first set of trials.
$GM_1/R^2 = 9.86$ using the values provided.

Hence, the force between the target mass and the earth is
$$9.86 \times .01 = .0986 \text{ nts.}$$

The anomaly appeared as a decrease in weight of .05%, or 4.93×10^{-5} nts.[9] The question now arises regarding what is really changing to produce the weight anomaly: target mass, Earth mass, the gravitational field, or some other parameter(s). To assume that the masses have changed would immediately open additional questions regarding whether inertial mass changed equally. Is the Principle of Equivalence violated? Another perspective would be to assume that the gravitational field is altered locally above the SC and the masses are left unchanged. This would imply the gravitational constant G changes at some point around the SC's critical temperature.

G has dimension Length(L)^3/(Mass(M) x Time(T)^2). If we assume that mass does not change, then we are left with length and/or time. For simplicity sake, assume that time does not change. Therefore, we can argue that if the field constant G changes, it is a result of a change in length measure. Or, we can establish a very restricted form of relativity within the domain of superconductivity.

Since all variables, except length, are considered invariant under a transformation that occurs at the SC's critical temperature(T_c), we can immediately write a relation between reference frames above and below T_c.

L'/L = (F'/F)$^{1/3}$, where L' and F' are the length and force measures as observed below T_c. In the case of trial 1 with a 10 gram target mass, F'/F = .999995. Therefore, L'/L = .9 $\cdot$9998. Or, L' = .999998L.

We can use the information determined above as a form of boundary condition in determining a metric transformation equation. The behavior of the weight in these experiments can be described as shown in Figure (16). Note the step near the critical temperature of approximately 90°K. We know that superconducting materials behave electrically as shown in the figure in that electrical resistance also drops to zero as a step. The following equation is a good representation of the experimental behavior:

(1) $L = L_0 \cdot \beta \cdot (1 - T^n/T_c^n)$, -1

where T is the temperature in degrees Kelvin. T_c is the critical temperature. ß is the appropriate scale factor determined by boundary conditions. n is a real number that is determined by the bandwidth around T_c. n and ß need to be determined experimentally because they seem to be material dependent. In Figure (16) for this discussion we let ß = .999998, T_c = 90K, and n = 10. n does not need to be a whole number.

Using Equation (1) we can begin asking questions similar to those related to Special Relativity. What do observers in one reference frame see happening to events occurring in another reference frame? In the case of these experiments we are speculating that the reference frames are related as a function of temperature, such as Equation (1). The laws of physics transform invariantly because Equation (1) merely behaves as a constant in derivatives of L and L' with respect to time. The distance metric also preserves its form, so Maxwell's Equations and General Relativity transform invariantly. The conclusion of this speculation is the observers in the above-T_c frame will see measured differences in physical phenomena, such as weight, occurring in the below-T_c frame.

VII.   CONCLUSIONS

A great deal more work is required to determine the validity of this anomalous weight behavior. The observed effects in this report and in others have been very small, but definitely on the macroscopic level and they are detectable with simple apparatus. Most high school laboratories could repeat the experiments described in this report. Replication of the experiment described in these pages is encouraged, but the following avenues of research also need further investigation:

*   Test the effect of cascading magnets and SC's above one another. Would this increase the anomalous effects?
*   Different configurations of magnetic fields, both static and varying need to be examined.
*   Different types of SC materials need to be tested, such as Bismuth compounds and other varieties of high temperature SC's. Not all SC materials may behave as the one in these experiments.
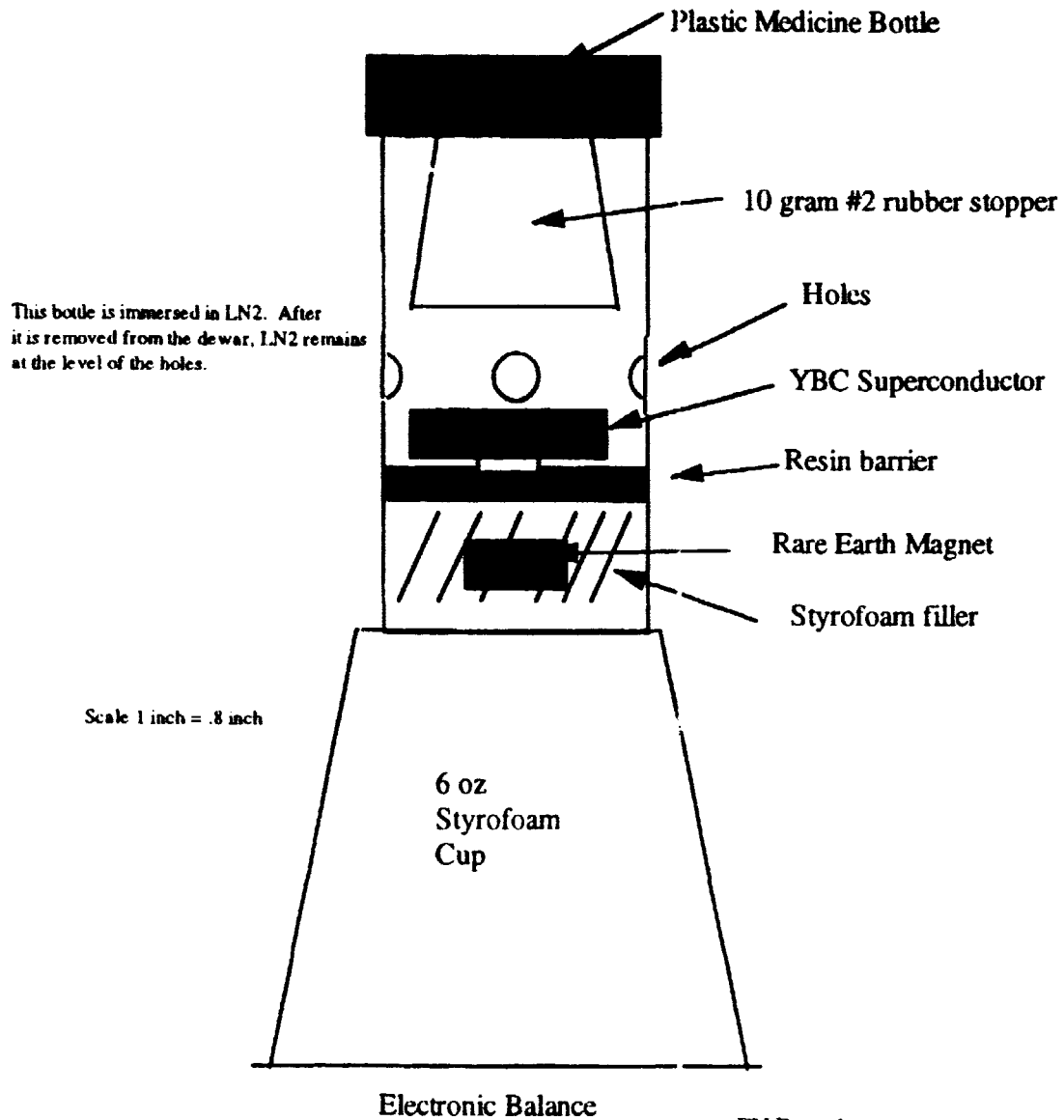*   Further tests need to be made using increasing target mass.

VIII.   ACKNOWLEDGMENTS

not only been encouraging and has helped me calibrate what possible theoretical basis exists for the observed behavior. I appreciate the help that Dr. David Noever has provided me during these difficult experimental trials. He has been willing and interested in looking at the results and helping with trying to narrow the various reasons for the anomalies. I am extremely grateful to Michael Adamson from NASA Ames Research Center for helping me with the laboratory equipment. He was very cooperative during the strange hours of these experiments. Lastly, I appreciate the comments received from Phillip Carpenter of the Department of Energy, Oak Ridge Operations relative to the experiment and this report.

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[2]E. Podkletnov, "*Weak gravitational shielding properties of composite bulk $YBa\_2Cu\_3O\_[7-x]$ superconductor below 70 K under electro-magnetic field*", report MSU-chem 95, improved version. Los Alamos preprint cond-mat/9701074 (http://xxx.lanl.gov).

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[4]Modanese, G., and John H. Schnurer, *Possible Quantum Gravity Effects in a Bose Condensate Under Variable E. M. Field*, Dipartimento di Fisica dell'Univerita, Gruppo Collegato di Trento, University Report, UTF-391/96, pp. 1-30, (1996)...

[5]G. Modanese, "*Theoretical analysis of a reported weak gravitational shielding effect*", Europhys. Lett. vol. 35 (1996), p. 413.

[6]*Effects of a gravitomagnetic field on pure superconductors*. N. Li and D. G. Torr. Physical Review D. 15 January 1990. Volume 43. Number 2.

[7]D.G. Torr and Ning Li, "*Gravitoelectric-Electric Coupling via Superconductivity*", Found. Phys. Lett. vol. 6 (1993), p. 371.

[8]*Physical Properties of High Temperature Superconductors I*. Donald M. Ginsberg. World Scientific Publishing Co. New York. 1989. Page 19.

[9]Weight and mass are used interchangeably throughout this paper. We consider them related through a constant.

Figure 1.
Test Object or Gravity Shielding Experiment
Phase 1 Model

Plastic Medicine Bottle

10 gram #2 rubber stopper

This bottle is immersed in LN2. After
it is removed from the dewar, LN2 remains
at the level of the holes.

Holes

YBC Superconductor

Resin barrier

Rare Earth Magnet

Styrofoam filler

Scale 1 inch = .8 inch

6 oz
Styrofoam
Cup

Electronic Balance

FN Rounds
4/2/97

Figure 2.
Test Object or Gravity Shielding Experiment
Phase 2Model

Nylon Bolt
to hold weights.

Plastic Medicine Bottle. Cap
mass equals 1.8 grams.

Rubber target masses.
5 at 2.2 grams each for
Trail 1. Two brass washers
used for Trial 2, with total
target mass of 27 grams.

This bottle is immersed in LN2. After
it is removed from the dewar, LN2 remains
at the level of the holes.

Holes

YBC Superconductor
and Rare Earth Magnet
glued together. Glued
to bottom of bottle.

Scale 1 inch = .8 inch

6 oz
Styrofoam
Cup

Electronic Balance

FN Rounds
4/2/97

Figure 3: Weight vs. Time Trial 1. The evaporation curve is highly linear up to about 46 seconds. The slope breaks sharply then becomes linear again when the LN2 is completely evaporated.
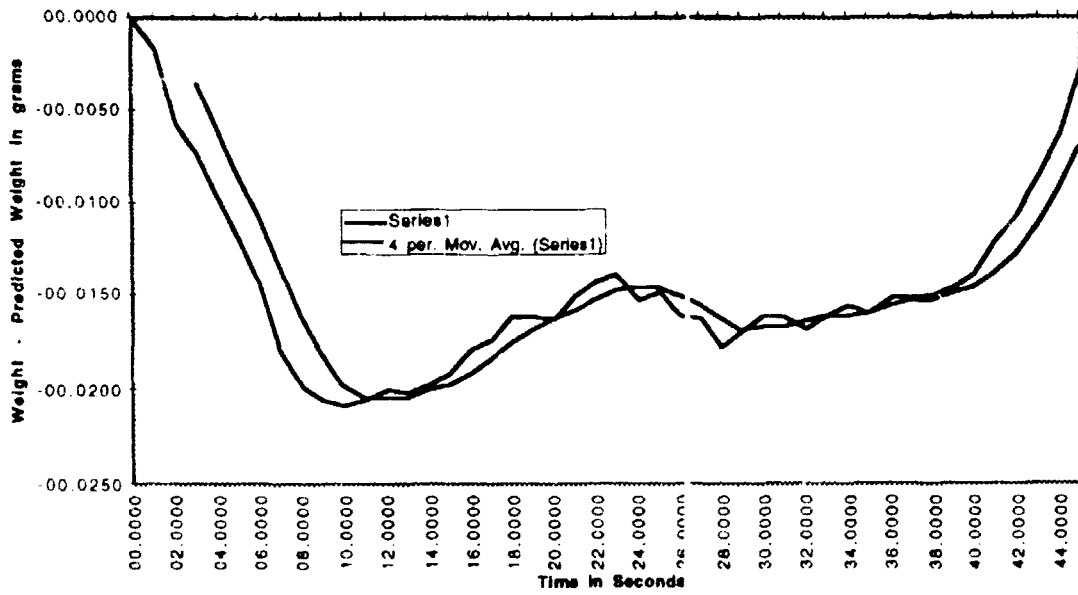
Figure 4. Weight - Predicted Weight for Trial 1, 10-gram target. Note the prominent weight increase beginning at about 16 seconds. Approximate system weight increase equals .05% of target weight.
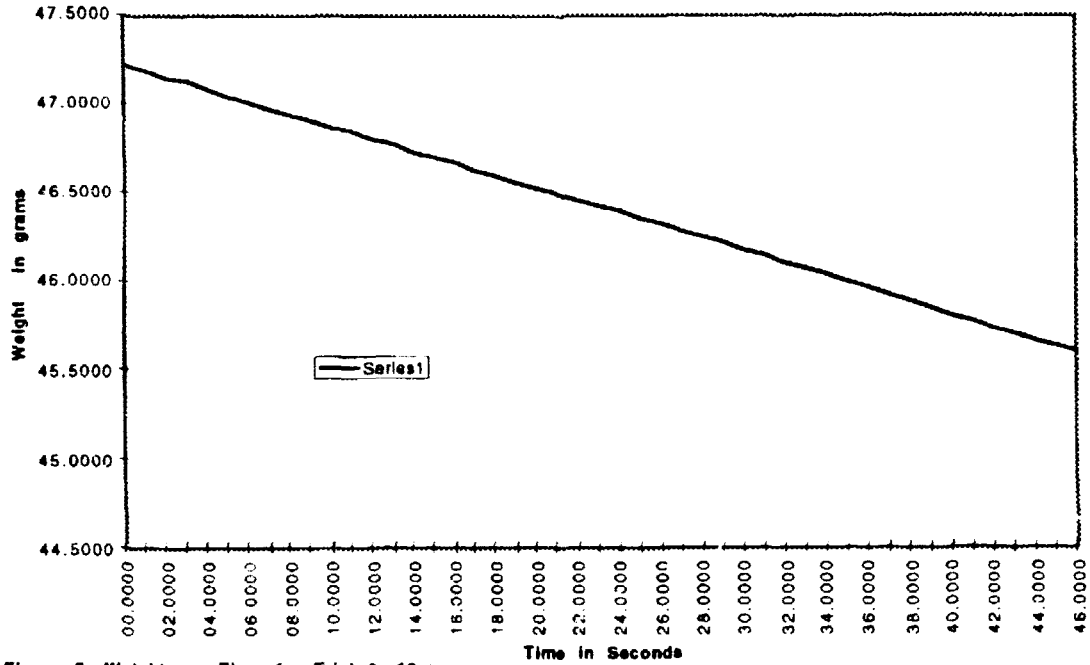
Figure 5. Weight vs. Time for Trial 2, 10-gram Target. Note again the high degree of linearity. This was the second trial using the Phase 1 test model.
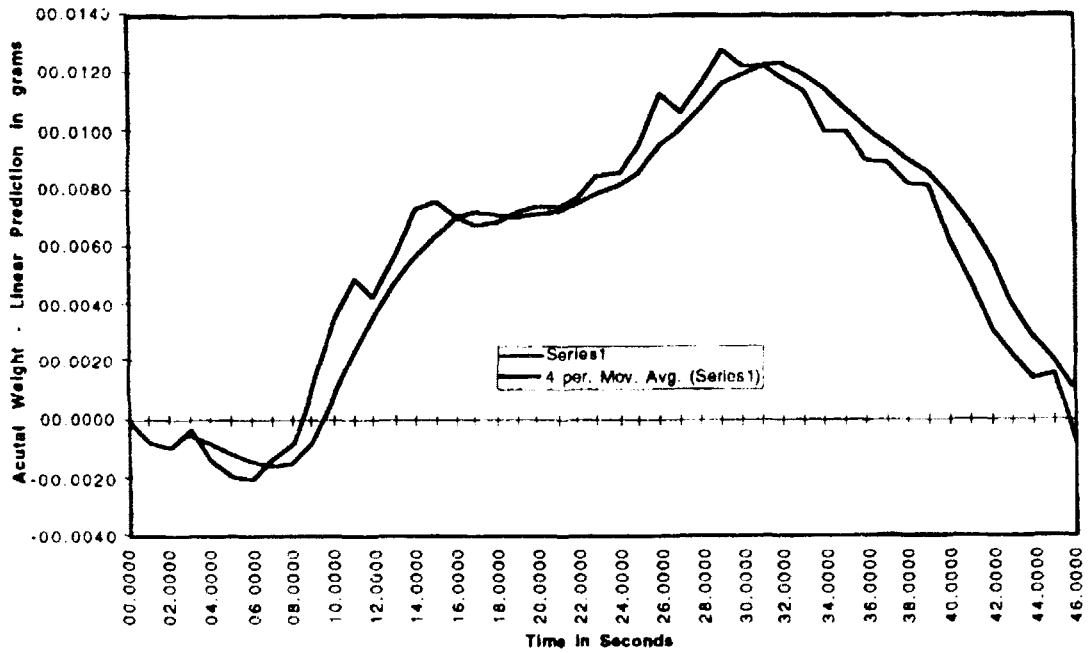
Figure 6.Actual Weight - Linear Prediction Trial 2, 10-gram target weight. The system weight anomalie appears at about 23 seconds which is later than the previous trial. The increase is again about .05% of the target weight
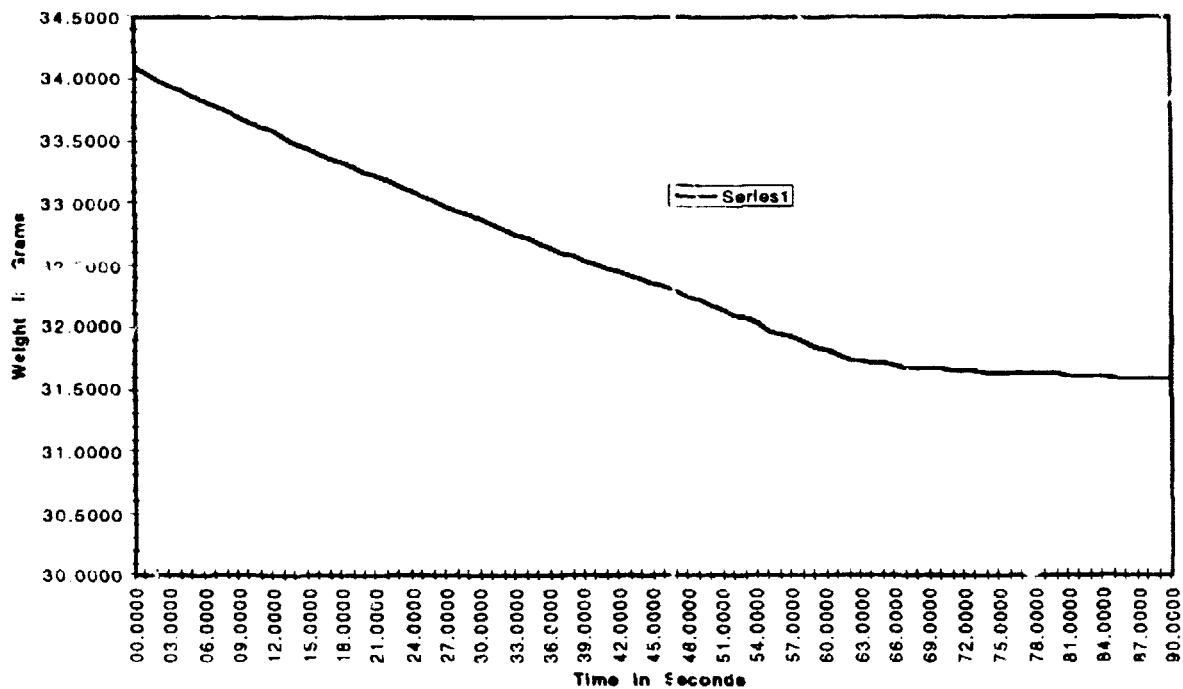
Figure 7. Weight vs. Time for Rubber Control Sample, 10-gram target mass. The evaporation is highly linear until LN2 is completely evaporated.
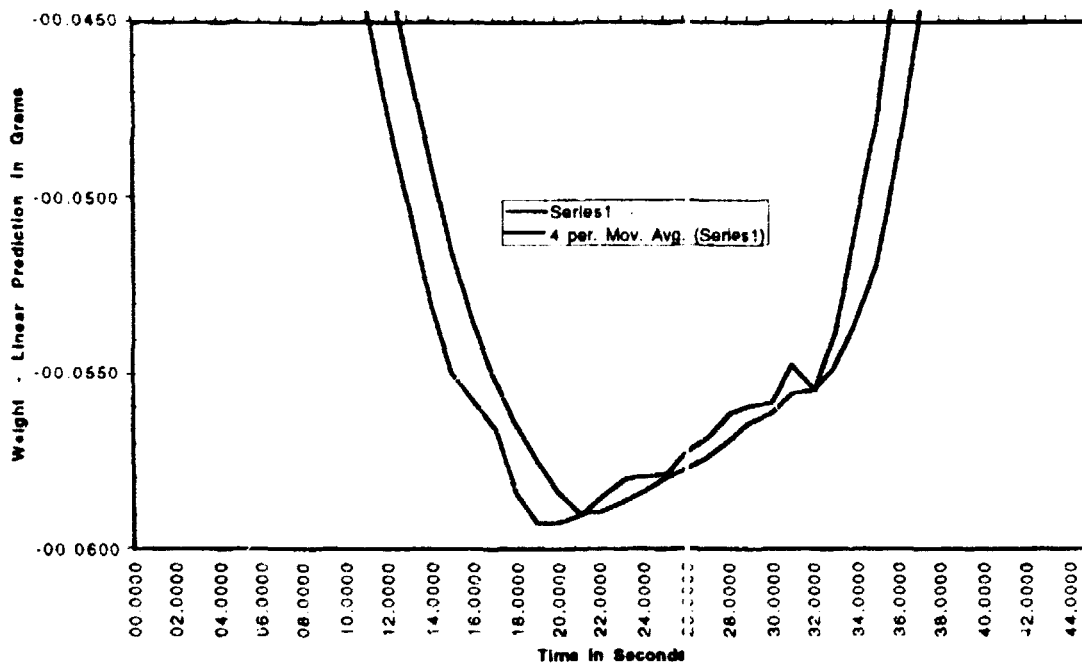
Figure 8.Weight - Linear Prediction for Rubber Control Sample, 10-gram target mass. No significant weight anomalies occur that can be distinguished from noise.
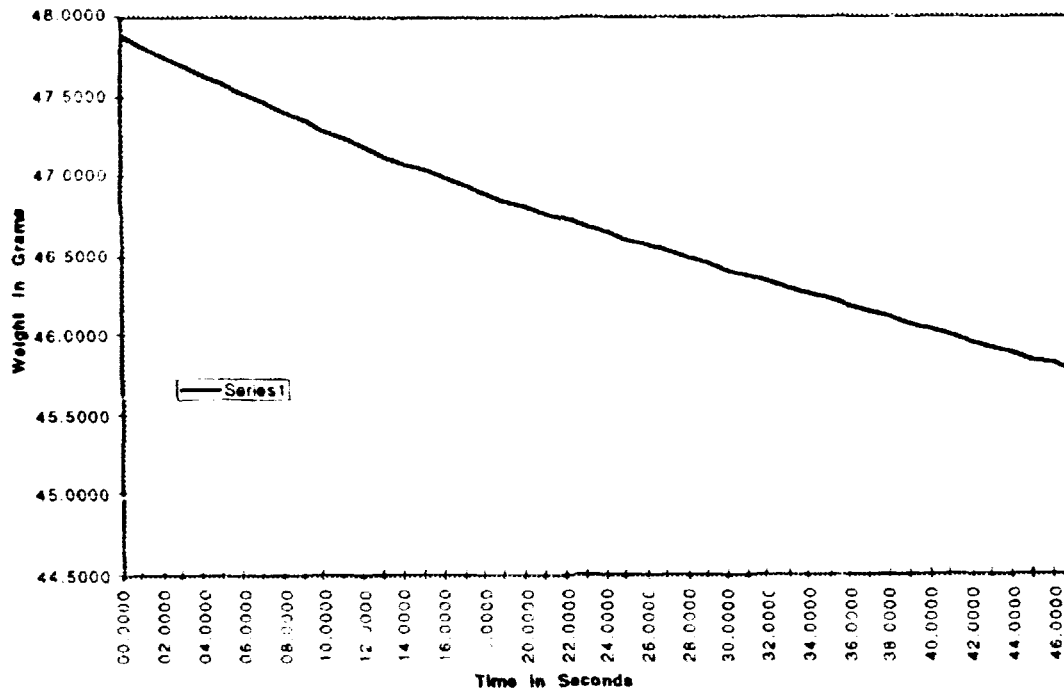
Figure 9. Weight vs. Time for Brass Control Sample, 10-gram target.
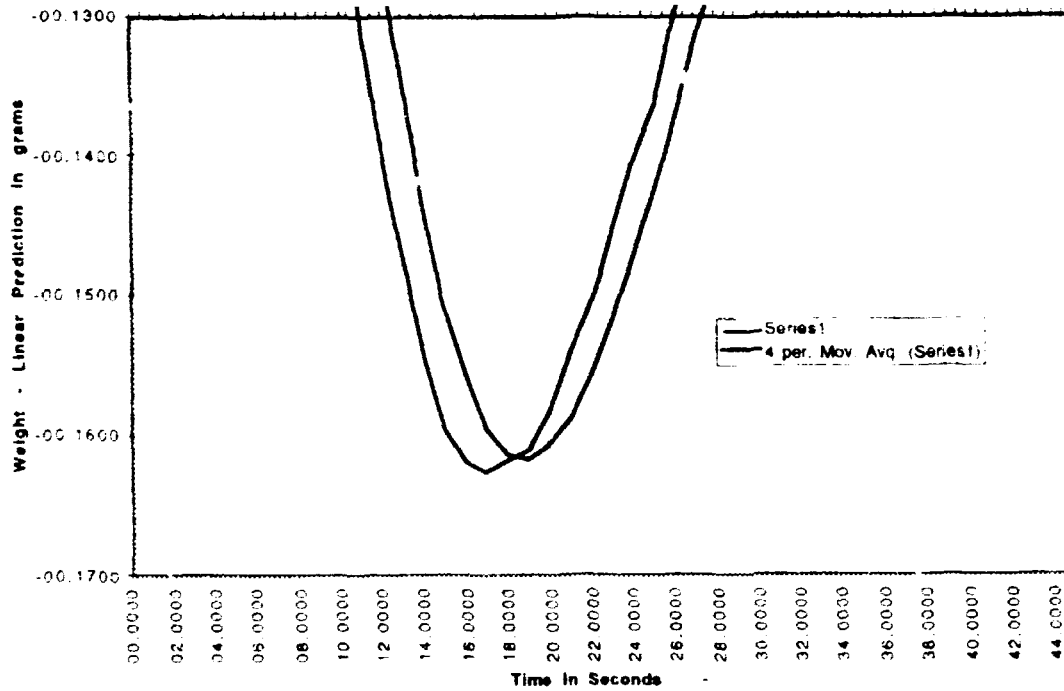The evaporation curve is more nonlinear

Figure 10. Weight - Linear Predicted Weight for Brass Control Sample, 10-gram
target mass. The evaporation curves are more nonlinear, but
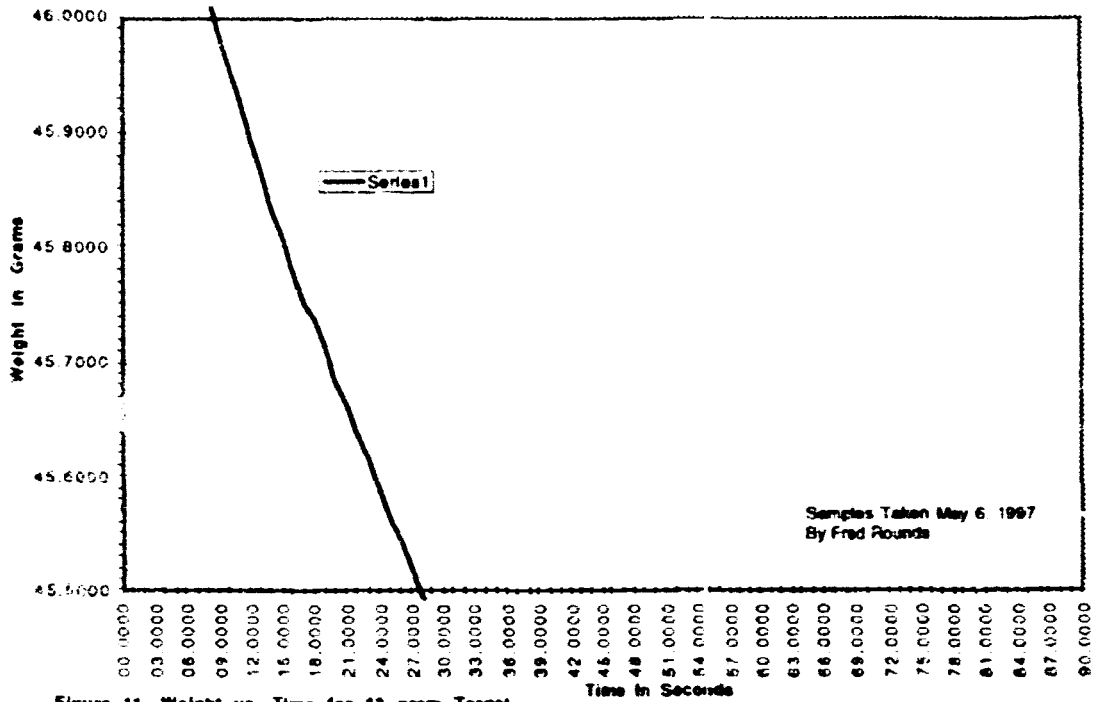weight anomalies can not be detected beyond the noise

Figure 11. Weight vs. Time for 13 gram Target.
Note the anomaly at 17 seconds. This displays a instantaneous
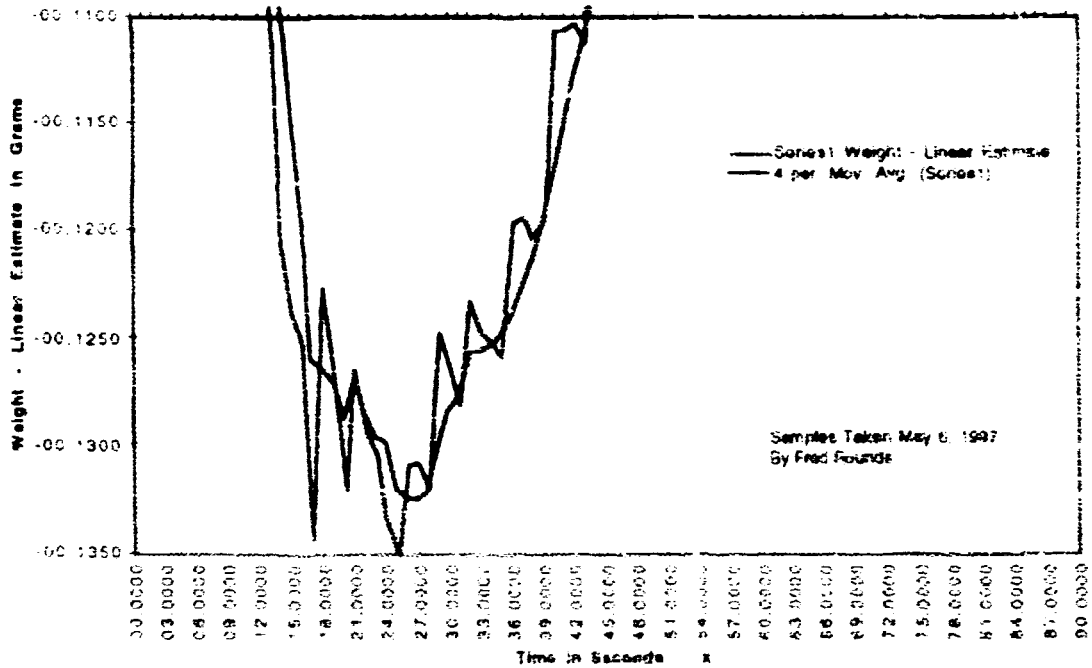decrease in slope which points to an increased system weight.

Figure 12. Weight - Linear Estimate for 13 gram Target.
The anomaly is difficult to see but it occurs at 17 seconds.
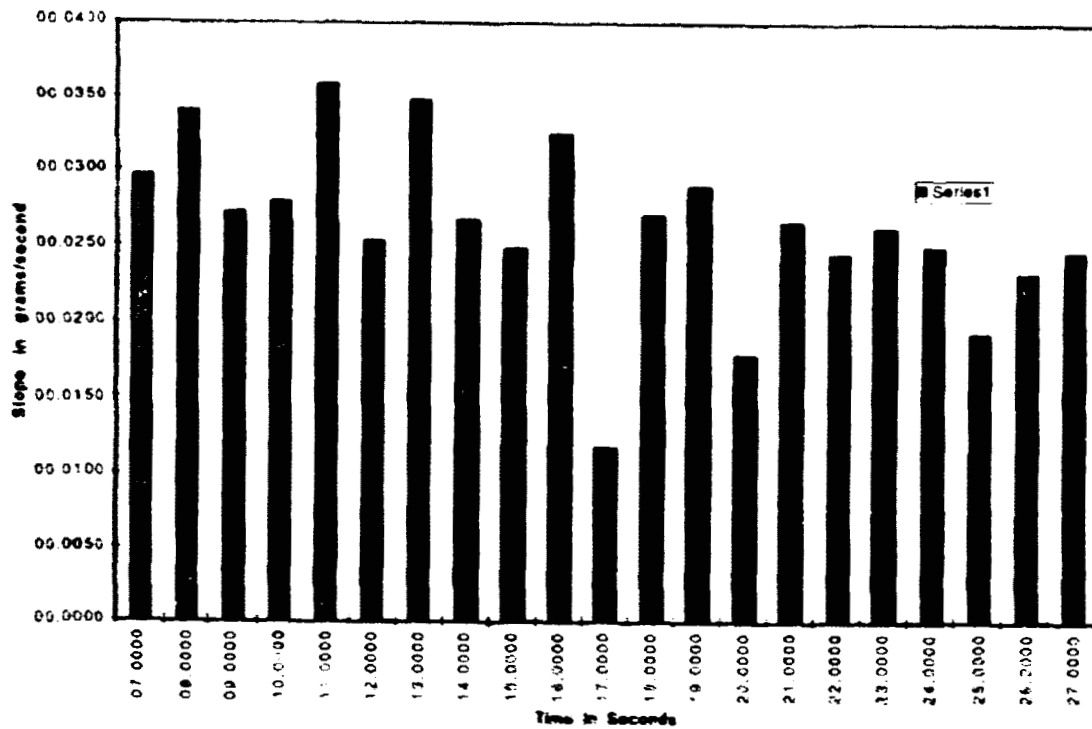See the bar chart for a clearer view.

Figure 13 Slope behavior of Trial with 13 Gram Target.
Note the significant drop in slope at 17 seconds. This
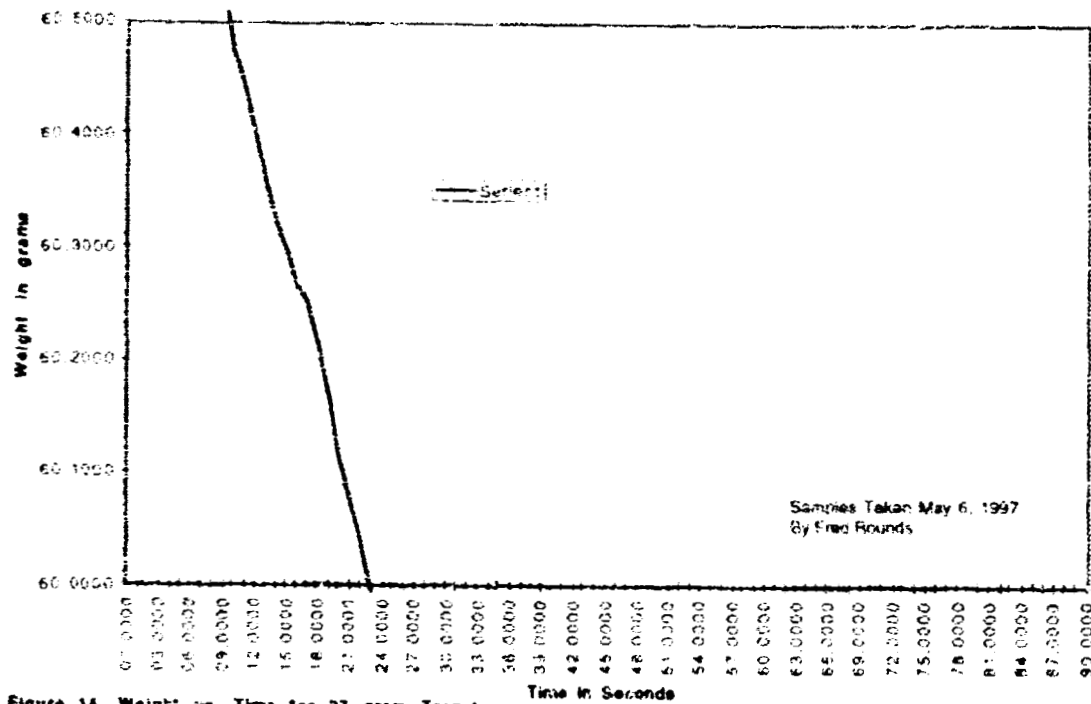could represent a .05% to .1% increase in system weight.

Figure 14. Weight vs. Time for 27 gram Target
Note the anomaly at 16 seconds. It occurs at approximately
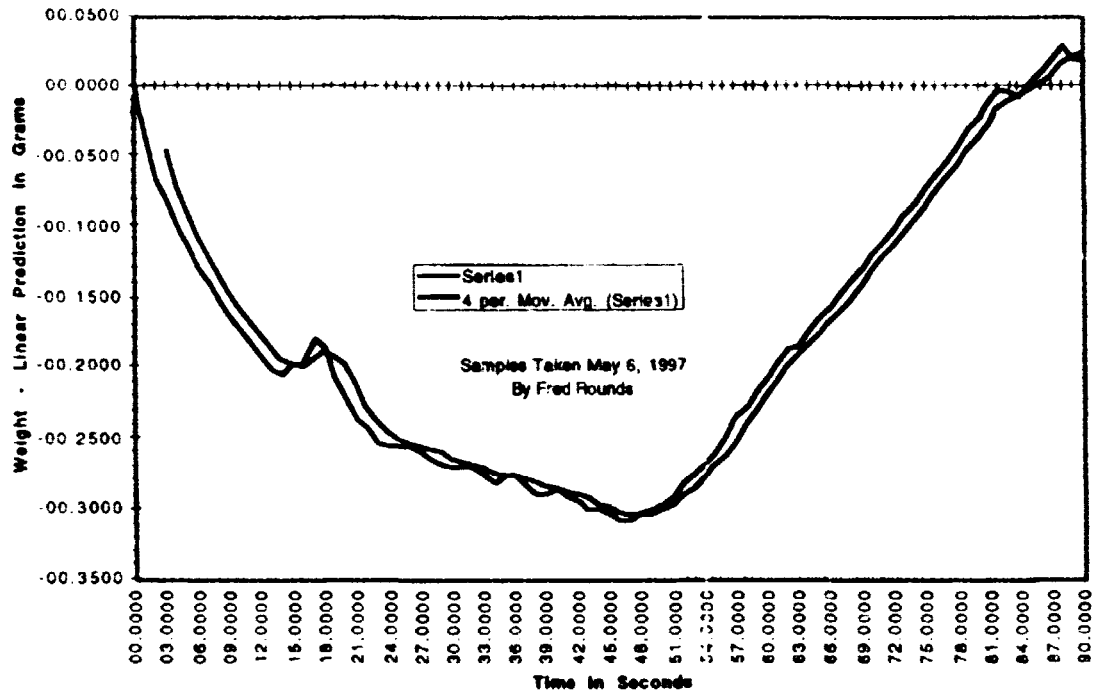at the same time sequence as the 13-gram trial.

Figure 15. Weight - Linear Estimate for 27 gram Target.
Note the obvious anomaly at 16 seconds. This represents
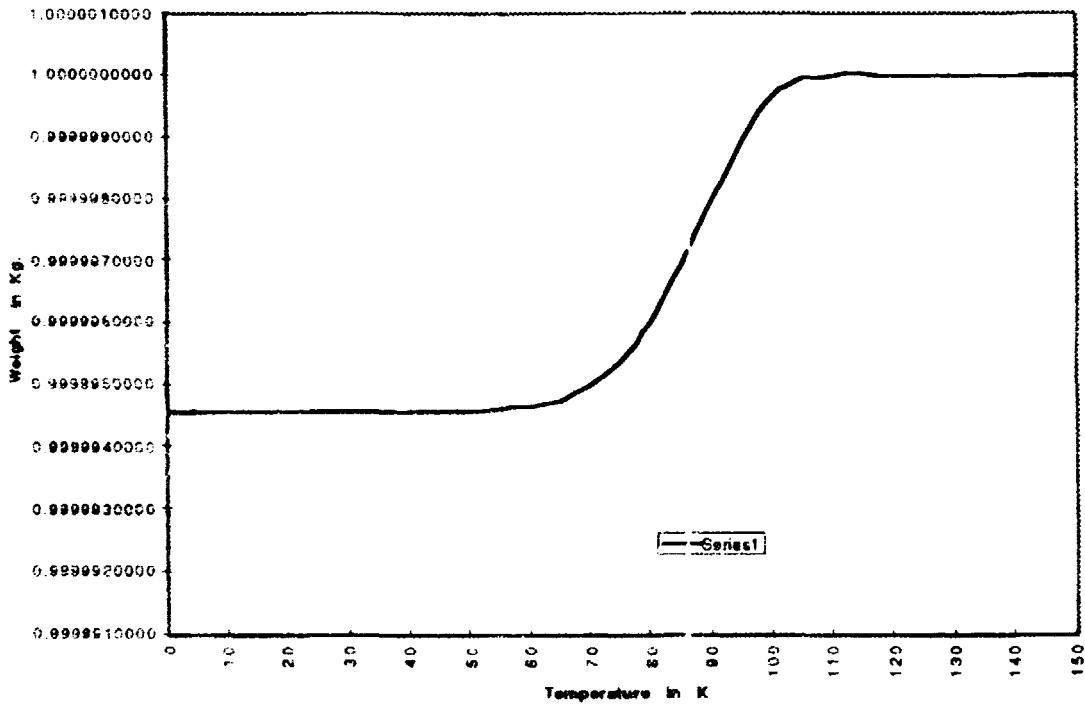again system weight increase of from .05% to .1%.

Figure 16. Weight vs. Temperature.
The weight behaves as a step function
near the critical temperature.

NEXT DOCUMENT

Static and Dynamic Casimir Effects

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ABSTRACT

I briefly review a number of phenomena that arise when static and dynamic boundary conditions are imposed on the electromagnetic vacuum. The static effects I treat are the zero-temperature and finite temperature Casimir effects and the extraction of energy from the vacuum. The dynamic effects include fluctuations of the static Casimir force, the inertia associated with vacuum energy, vacuum induced drag, mass fluctuations and mass anisotropies of scatterers, and the production of photons from vibrating quantum cavities.

INTRODUCTION

Physical consequences arising from the imposition of boundary conditions on the vacuum state of the electromagnetic field were first predicted by Casimir in 1948. Since then these "Casimir effects" have been found to be important in a remarkably diverse range of physics, from condensed matter and particle physics to atomic physics and cosmology (for reviews see [1-2]). Despite the enormous amount of theoretical work relating to the measurable consequences of the Casimir effect, only a few experiments have been performed to test the large number of theoretical predictions. Furthermore, all experiments to date have been directed towards measuring the static Casimir effect, where the boundaries are either held fixed, or are varied adiabatically. Since it has been my experience that few physicists are aware of the rich range of phenomena predicted for Casimir-type effects, I have collected together a few of the more interesting ideas and predictions regarding static and dynamic Casimir effects, so that the interested reader might be made aware of them, and in the hopes that this may stimulate the investigation of these effects experimentally.

STATIC CASIMIR EFFECTS

The Casimir effect between conductors

The Casimir effect is usually described as the force of attraction between two neutral conducting plates in vacuum due to the reduction in the number of zero-point electromagnetic field modes within the cavity. For a pair of perfectly conducting flat plates, the force per unit area exerted on the plates is

$$F_{Casimir}(d) = -\frac{\pi^2 \hbar c}{240 d^4}$$

where d is the spacing between the plates, $\hbar$ is Planck's constant (reduced), and c is the speed of light [3]. In this case the Casimir force is attractive. In general, however, the magnitude and sign of the force depend intimately on the geometry of the cavity and, in particular, can be repulsive as well as attractive [4-7]. For instance, in the case of a spherical shell the energy density inside the cavity is positive leading to a repulsive Casimir force [7,8].

Casimir's result for the force between conductors due to electromagnetic zero-point oscillations was extended and generalized by Lifshitz [9] to include the force between dielectrics in vacuum. Lifshitz' treatment is far more complicated and less obviously a manifestation of zero-point effects, however, the theory does reproduce Casimir's predictions exactly in the limit that the dielectric constant goes to infinity

Both Casimir's and Lifshitz' results have been re-derived a great number of times using a wide variety of approaches [1,2], [10-15].

Measurements of the Casimir effect

Because the Casimir force is exceedingly weak and short ranged (for conductors with a plate separation of 5 microns the force between the plates is a minute $2.08 \times 10^{-3} dynes/cm^2$), measurements of the effect are difficult. These difficulties are further compounded by the necessity of bringing together macroscopic plates to within a few microns of one another, requiring optically flat surfaces free of dust and dirt. Further hurdles involve the elimination of electrostatic effects, which can mim c or washout the Casimir force. With dielectrics, such as glass or mica, the above mentioned difficulties are more easily dealt with than for conducting surfaces, and for this reason, the majority of measurements of the Casimir effect have been done using dielectric surfaces. Accurate measurements of the Casimir force between dielectrics have all been in good agreement with theory (see for instance [16,17]).

Remarkably, only two experiments have been undertaken to measure the Casimir effect between conductors, and these were performed nearly forty years apart. The first attempt was made in 1958 by Sparnaay, but was inconclusive due to a relative error in the measurement of approximately 100% [18]. This experiment is incorrectly quoted in most of the literature as being the first measurement of the Casimir force. In fact, it was not until 1996 that the Casimir effect between conductors was actually measured [19].

Finite temperature Casimir effect

There are a number of corrections to the static Casimir force between conducting or dielectric plates. These include corrections for surface defects, imperfect conductivity misalignment of the plates, and others. Probably the most physically interesting correction is the finite temperature correction. This takes into account the supplemental radiation pressure caused by therma photons, which modifies the zero-temperature Casimir force. At high temperatures, i.e. when the characteristic quantity $(4\pi kTd/\hbar c) \gg 1$, the zero-temperature expression for the Casimir force given above becomes

$$F_{temp}(d) = -\frac{2.4kT}{4\pi d^3}.$$

where k is Boltzmann's constant, T is the temperature of the p ates, and d their separation [20]. Note that in this case the force varies as $1/d^3$, rather than as $1/d^4$, as in the zero-temperature Casimir force. For low temperatures, i.e. when $(4\pi kTd/\hbar c) \ll 1$, the expression for he force is [21].

$$F_{temp}(d) = -\frac{\pi^2 \hbar c}{240d^4}\left[1 + \frac{16}{3}\left(\frac{kTd}{\hbar c}\right)^4 - \frac{240}{\pi}\left(\frac{kTd}{\hbar c}\right)e^{-\pi \hbar Td}\right].$$

The general effect of the temperature correction is to increase the force between the plates.

Extracting Energy from the Vacuum

Forward has suggested that it may be possible to extract energy from the vacuum using the Casimir effect [22]. His idea is to manufacture microdevices consisting of a large number of parallel leaves made from ultrathin metal foil, which are free to move along the axis normal to their surfaces. Each of the leaves would be connected to a bidirectional power supply, so that a small amount of charge could be placed on them. Sensors that automatically adjust the magnitude of the charge on the leaves to maintain uniform spacing would monitor the spacing between the leaves. When the spacing between the leaves was on the order of a few microns, they would experience an attractive force due to the Casimir effect. (Initially it is assumed that the devices are manufactured so that a sufficient distance separates the leaves such that they do not cohere prematurely). By placing charge of the same polarity on each of the leaves, an electrostatic force of repulsion may be maintained that opposes the attractive Casimir force. The charge placed on the conductors could then be varied so that the electrostatic force would be less than, equal to, or greater than the Casimir force. In the first instance, work would be done on the device by the Casimir force (vacuum) to reduce the

spacing between the leaves In the second instance, no work is being done since the contributions from the electrostatic and Casimir forces cancel. In the third instance, the electrostatic field does work on the device to increase the spacing of the plates. Used as such, these devices would act as "vacuum batteries", storing and retrieving minute amounts of charge under the action of the Casimir force. By allowing the conductors to cohere, net energy could be extracted from the vacuum.

There is no contradiction between Forward's idea and the laws of thermodynamics [23]. It must be remembered, however, that only on the *initial* "in" sweep of the plates is the vacuum doing any net work on the system. After the plates have been brought to their minimum distance, work must be done on them (by the bidirectional supply) to push them back apart. The amount of work required to separate the plates must be equal to or greater than that acquired by letting the plates come together under the influence of the Casimir force. We can very roughly estimate an order of magnitude for how much net energy might be generated by such a device. Let us assume a device composed of 101 foliations, each foliation separated by 5 microns and with an area per foliation of $A = 0.1 mm^2$. Since the Casimir energy for a pair of conducting plates is

$$U_{Casimir} = -(\frac{\pi^2 \hbar c}{720a^3})A,$$

the total energy generated by such a device would be approximately

$$E \cong 3.5 \times 10^{-11} Joules.$$

To reiterate, this is the maximum energy that could be liberated from the vacuum by such a device. Subsequent expansions and contractions of the system would not generate any further net energy. Also, dissipative effects would cost energy each expansion/contraction cycle. If we allowed the device to cohere in a millisecond, the power generated would be on the order of

$$P \cong 3.5 \times 10^{-8} Watts.$$

Obviously, this is an extremely impractical way to obtain large amounts of free energy. It should be pointed out that this is not because the device suggested by Forward is itself intrinsically flawed, rather it is due to the fundamental physics of the Casimir effect. It is because the magnitude of the Casimir force is so small that appreciable amounts of energy cannot be extracted from the vacuum. Nonetheless, we can imagine that such a device in the form of a vacuum battery may find future use in nanomachines.

Fluctuations in the static Casimir force

As first pointed out by Barton [24], standard calculations of the Casimir force yield an *expectation value*, that is, an average value obtained after a large number of measurements. In contrast, individual measurements of the (identically prepared) ground states of the Casimir plate system will return slightly different values for the Casimir force, representing the fluctuations of the force about the mean. Fluctuations of the Casimir force are too small to measure presently, however, in the near future it may be possible to measure them using atomic force microscopes [25]. Indeed, these fluctuations will probably be the fundamental limit to force microscopy resolution. Another consequence of these fluctuations is that they lead to dynamical effects such as the viscous damping of the motion of a scatterer undergoing non-uniform acceleration.

DYNAMIC CASIMIR EFFECTS

Dynamic Casimir effects arise when the boundaries defining the Casimir cavity are rapidly varied. As indicated in the previous section, cavities that undergo non-uniform acceleration are subject to dissipative forces, which lead to a number of interesting phenomena.

Inertia of the Casimir Energy

The equivalence of energy and mass, $E = mc^2$, implies that energy obeys the principle of inertia [26]. Hence, a massless box in vacuum will have associated with it an inertial mass due to the stored vacuum energy, and will resist motion. (The inertial effect of the energy stored within the box is separate from,

though related to, the viscous drag associated with bodies mov ng through the vacuum with non-uniform accelerations- discussed below.) Since the inertial mass is inde endent of the type of field contributing to the stored energy of the system, a cavity formed by two massle is, neutral, conducting plates will necessarily have an associated inertial mass given by the Casimir energy within the cavity divided by c^2 [27]. This means that the Casimir energy within a cavity *must* gravitate in order to satisfy the principle of equivalence.

Because the vacuum energy density is infinite, it has been argued that the zero-point energy cannot be real since it should gravitate and there is no cosmological evidence to support this [28,29]. One might then wonder if it is possible to derive the same inertial effect without asserting the reality of the vacuum fluctuations. Of further interest is that the energy density within a Casimir cavity depends on the geometry of the cavity, so that the inertial mass of a cavity formed from two flat plates will be different from that formed from two hemispheres (the volumes being equal). Indeed, in the first case the vacuum energy density is negative, which leads to a negative inertial mass correction, indicating that a massive Casimir cavity of this type would appear to have a slightly reduced total inertia due to the vacuum energy stored within it. It might thus be possible to experimentally measure and distinguish the inertial effects of a Casimir cavity formed from parallel plates and a cavity formed from hemispheres. Such a measurement would be very interesting.

Friction associated with non-uniform acceleration of mirrors in the vacuum

The effect of uniform and non-uniform accelerations on particles in the vacuum and in thermal fields has been studied extensively in connection with quantum field theories in curved spacetimes . Particles moving with a uniform acceleration are known to experience the vacuum as a thermal state with a temperature $T = \hbar a/2\pi kc$, where a is the particle's acceleration, and k is Boltzmann's constant. This result is the well-known Unruh-Davies effect.

Some 20 years ago, Fulling and Davies calculated the dissipative force on a perfectly reflecting mirror in the vacuum state of a 2d scalar field [30]. Their result may be approximated to first order as

$$\delta F(t) = (\hbar/6\pi c^2)\delta \dddot{q}(t),$$

where q is the coordinate variable. This indicates that a mirror undergoing non-uniform acceleration in a 2d scalar vacuum will experience a viscous force that is proportional to the third time derivative of the position. It is important to note that there will be no force on a perfect scatterer moving with uniform velocity or uniform acceleration through the vacuum as required by Lorentz invariance.

The effect of non-uniform acceleration on scatterers in the (4d) electromagnetic vacuum can also be calculated, with the resulting viscous force proportional to the fifth derivative of the coordinate. For instance, the transverse oscillation of a pair of conducting plates in the vacuum corresponds to an effective force of friction given by

$$F = \frac{\hbar^2 \omega^5 A}{60\pi^2 c^4},$$

where ω is the frequency of observation, and A is the area of the plate [31]. This force of friction associated with the dissipative action of the vacuum fluctuations on a scatterer is many orders of magnitude too small to observe directly, however, it may be measurable under resonance conditions.

Braginsky and Khalili have suggested an experiment to measure this vacuum friction using the resonant enhancement of an oscillator mode in an LRC circuit [31]. The idea is to place a dielectric having an acoustic mode resonant with the circuit inside of a high Q ($\sim 10^{11}-10^{12}$) cavity, and look for the oscillator frequency shift induced by the (resonant) frictional force of the vacuum. A related shift in the frequency of oscillation of the cavity is predicted to be on the order of 1 part in 10^{14}.

As an interesting aside, the fundamental nature of vacuum friction implies that any mechanical oscillator or electromagnetic resonator must have a finite Q. Of course this vacuum induced friction is so small for any

macroscopic oscillator that it is essentially negligible. Only when the quality factor involved is extremely high that the vacuum friction plays a significant (measurable) role.

Mass Fluctuations and Anisotropies for Scatterers in Vacuum

For "real" mirrors, i.e. those with finite reflectivities, the scattering of virtual photons from the boundary has an associated time-delay which leads to energy storage in the surface of the mirror. Since the energy density of the vacuum is constantly fluctuating, and because of the equivalence of energy and mass, the vacuum fluctuations must induce a fluctuating component to the macroscopic mass of a mirror [32]. Golestanian and Kardar [33] have proposed that the relative motion of two mirrors with corrugated surfaces will induce an anisotropic mass correction, such that the mass in the direction parallel to the motion will be slightly increased whereas the mass in the direction perpendicular to the motion will be unchanged. For macroscopic plates the estimated mass correction is on the order of $\delta m / m = 10^{-34}$, and as such is unobservable. However, the mass anisotropy may be observable by comparison of the oscillation frequencies of (microscopic) plates in perpendicular directions.

Photon production from oscillating quantum cavities

It has been repeatedly suggested that dynamically altering boundary conditions should give rise to the emission of photons from the vacuum. This remarkable prediction can be understood in terms of the mechanical squeezing of the vacuum by the boundaries. In a sense, the mechanical modes of the oscillator pump energy into the vacuum modes, creating photons from the vacuum state. Schwinger utilized this dynamic Casimir effect to explain the phenomena of sonoluminescence, in which intense bursts of radiation are emitted by the rapid collapse of acoustically generated micro-bubbles in a liquid [34]. While the mechanism underlying sonoluminescence is still not understood, Schwinger's theory has led to a number of studies of photon production from oscillating quantum cavities [35].

Lambrecht, Jaekel, and Reynaud have recently calculated the photon production from a high finesse cavity formed from two non-ideal mirrors [35]. There are two photon fields associated with the vibration of such a cavity: an emitted photon field due to the finite reflectivities of the mirrors, and a steady-state field within the cavity. Assuming the mirrors to undergo harmonic motion at the same frequency Ω, with amplitudes a_1 and a_2, they find that the number of photons N emitted over an oscillation time T is

$$\frac{N}{T} = \frac{\Omega'}{3\pi c^2}\left(a_1' + a_2'\right) + \frac{\Omega}{6\pi c^2}\left(\Omega' - \frac{\pi'}{\tau'}\right)\frac{\sinh(2\rho)(a_1 + a_2)^2}{\cosh(2\rho) + \cos(\Omega\tau)} + \frac{\Omega}{6\pi^2}\left(\Omega' - \frac{\pi'}{\tau'}\right)\frac{\sinh(2\rho)(a_1 - a_2)^2}{\cosh(2\rho) - \cos(\Omega\tau)}.$$

In this expression the cavity finesse is measured by $\frac{1}{\rho}$, where $\rho = -\frac{1}{2}\ln r_1 r_2$, and τ is the time that a photon takes to travel from one mirror to the other. The number of photons $N_{k,k}$ produced by the motion of the mirrors in a pair of cavity modes is

$$N_{k,k} = \frac{k\pi}{c\tau}\frac{k\pi}{c\tau}\frac{2[a_k - (-1)^{k+k'}a_{k'}]^2}{4\rho^2 + (\Omega\tau - k\pi - k'\pi)^2}$$

where k and k' are the wavevectors of the pair of modes. At exact resonance these expressions for N and $N_{k,k}$ simplify to

$$N \approx \frac{\Omega T}{2\pi}\frac{v^2}{c^2}\frac{1}{\rho}, \quad \text{and} \quad N_{in} = \frac{v^2}{c^2}\frac{1}{\rho^2},$$

where N_{in} indicates the number of photons within the cavity, and where v indicates either the sum or difference of the peak velocity of the mirrors.

For a superconducting cavity with a finesse on the order of 10^9 and a peak cavity oscillation velocity on the order of $v = 1$ m/s, the above equations give a radiated photon flux of approximately 10 photons, and a steady-state photon number within the cavity of 10. The parameters for the finesse and peak velocity of the

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cavity are not beyond present technology and so it may be possible to measure this effect using a suitable technique.

CONCLUSION

The Casimir effect has continued to interest physicists since its discovery 50 years ago. In this brief review I have outlined just a few of the more interesting theoretical results of the effect of static and dynamic boundary conditions on the electromagnetic vacuum. While the amount of theoretical work related to the Casimir effect is enormous, the number of experiments that have been performed to test the various predictions have been very limited both in number and in scope. Of particular significance is the fact that no experiment has yet been performed to investigate dynamic Casimir effects. The experimental investigation of these phenomena is, in my opinion, a potential source of great importance to our further understanding of the quantum vacuum.

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NEXT
DOCUMENT

Propulsion and Energy Generation Using the Electron Spiral Toroid

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ABSTRACT:

A new propulsion method could potentially reduce propellant needed for space travel by three orders of magnitude. It uses the newly patented electron spiral toroid (EST), which stores energy as magnetic field energy. The EST is a hollow toroid of electrons, all spiraling in parallel paths in a thin outer shell. The electrons satisfy the coupling condition, coupling into an electron matrix. Stability is assured as long as the coupling condition is satisfied. The EST is held in place with a small external electric field; without an external magnetic field. The EST system is contained in a vacuum chamber. The EST can be thought of as a hot entity, with electrons at 116,000,000 °C (10,000 electron volts). Propulsion would not use combustion, but would heat propellant through elastic collisions with the EST surface and eject them for thrust. Chemical rocket combustion heats propellant to 4000 °C; an EST will potentially heat the propellant 29,000 times as much, reducing propellant needs accordingly. The thrust can be turned ON and OFF. The EST can be recharged as needed. The EST can also be used for power generation

INTRODUCTION

Three major barriers exist to practical interstellar travel: propellant mass, trip time, and propulsion energy [reference 7]. Propellant mass reduction and on board energy production limitations can be addressed and potentially overcome with technology based on the electron spiral toroid (EST). A concept design of a propulsion system is presented which could reduce the need for rocket propellant by three orders of magnitude as a minimum. Also, a concept design of an EST based on-board energy storage and power generation method is presented which is light in weight, stores large amounts of energy as magnetic field energy, and is rechargeable.
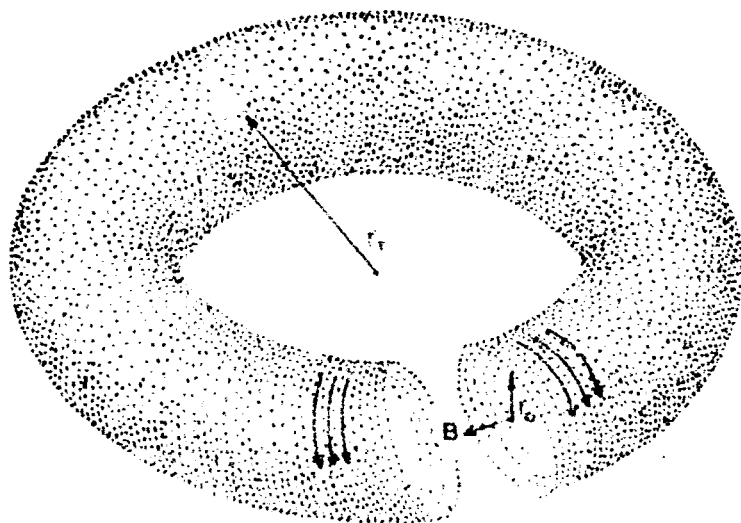

Figure 1 A drawing of the Electron Spiral Toroid showing the hollow construction, the parallel paths of the electrons, the thin outer shell, and the magnetic field contained in the hollow toroid.

THE ELECTRON SPIRAL TOROID (EST)

EST initiation

To initiate an EST, an electron beam is trapped in a circular magnetic field as shown, causing it to spiral

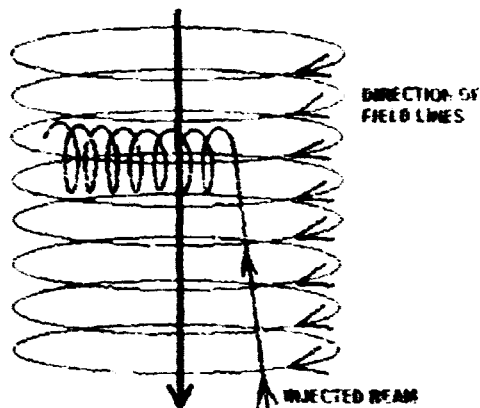

Figure 2   Electron Beam injected into a Circular Magnetic Field

Since the magnetic field is circular, the electrons will spiral around the magnetic field, following field lines. With proper initial conditions, the spiraling electron beam will rejoin itself, a unique feature of the EST. It is shown schematically in Figure 3., and further described in US Patent 5,175,466
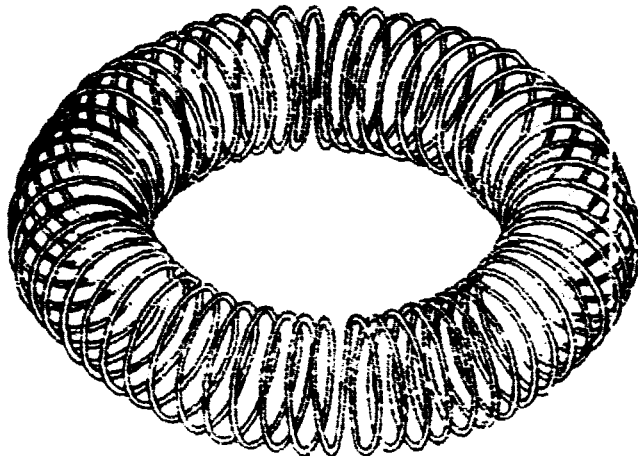

Figure 3   Electron Orbits set up within the EST Surface

EST Surface

Once the EST is established, the electrons will spread out into a thin sheet as shown in Fig 1. The electrons are all in parallel orbits and at the same velocity. The electrons have substantially the same energy since they all come from the same electron beam. Also, multiple spiraling in the initiating field ensures electrons with greater or lesser velocity will be moved into higher or lower orbit levels respectively, further ensuring adjacent electrons will have the same energy. When the energy between adjacent electrons is close enough the electrons will couple together. The surface will become an electron matrix shell. Many shells will form, one for each energy level. The total of these matrix shells form the EST outer shell. The overall thickness of the outer shell is in the order of 10^{-19} meters (18,000 electron diameters)

EST Surface Coupling Condition

The transition of states (gaseous to crystal) for one component plasmas is governed by the coupling factor Γ, described in Gilbert [2], Kraeft [4], and Malmberg [6]. Γ relates to the Coulomb and thermal energies of adjacent particles of the same charge. Γ is stated here in terms of the Boltzmann constant k_B, Temperature T, particle charge q, vacuum permittivity ε_0, and particle density n_s:

$$\Gamma = (1/k_B T)(q^2/4\pi\varepsilon_0)[4\pi n_s/3]^{1/3} \tag{1}$$

where Γ relates the difference in energy between particles, rather than the absolute energy. The value of Γ needs to be > 170 for coupling to occur [2]. Chen [1] has confirmed that conditions for coupling do exist in the EST surface.

EST Stability

Once the EST is formed, and the shell becomes a matrix, it will remain in this state as long as the coupling factor conditions remain satisfied. At this point, the external initiating magnetic field can be removed, as long as a small electric field is maintained to satisfy the coupling conditions. Since it is stable, many coulombs of electrons can be readily stored, for high total energy.

EST Properties [From reference 9].

1. Specific Energy of the individual electrons: 1.76×10^{15} J/kg = $(1.602 \times 10^{-19}$ J/ev$)(10^4$ ev/e$)(1/9.11 \times 10^{-31}$ kg/e). This compares favorably with the specific energy of liquid hydrogen which is 1.2×10^8 J/kg, or only about 10^{-7} as much as the EST. Actually, the comparison is far better, since more than 99% of the energy stored in an EST is stored as magnetic field energy [9]. The specific energy of the EST itself (not including containment) is thus 1.76×10^{17} J/kg.

2. Total energy. Calculations indicate large amounts of energy can be stored in the magnetic field of the EST as it is scaled upward in size (see Table 1).

3. Energy Density calculations show the energy density of the EST to be 1.09×10^{10} J/kg.

4. Containment: this requires a vacuum container, with a metal protective cover. Typical calculated values are shown in Table 1, based on an estimated 5 kg per square meter mass for the containment.

5. Energy Addition. An established EST can have energy added to it in a number of ways. Using microwave energy, the energy can be added at an absorption efficiency of approximately 70%. Thus, once the EST is established, energy can be added to increase magnetic field energy as required.

6. Energy Removal. Energy can be removed in a variety of ways. For a rocket, the EST would be placed in the combustion chamber of the engine. The EST can be thought of as a hot entity. Electrons reside at 116,000,000 °C. A thruster gas is brought into the chamber, heated to extremely high temperatures, and ejected, producing thrust. There is no combustion as such. The heating process can be started and stopped as needed by shutting down the flow of incoming gas.

7. Safety. The EST is stable, is non-nuclear, and non-polluting.

8. Thruster Gas. the EST will be omnivorous; able to use any gas for thrust. This has a powerful implication in that a deep space rocket could refuel itself wherever it is as long as it has access to any gas for propellant, and energy that can be added to the EST.

9. Power Losses. An established EST will store electrons for a long period of time. Since no external magnetic field is required for containment, losses will be low. Total power loss from all sources are calculated to be a few watts, but work is continuing to define this more precisely.

10. Temperature. The EST will operate at all temperatures; from a few degrees Kelvin, to many thousands of degrees. As long as the coupling factor remains satisfied, the EST will remain stable. This has implications for deep space missions, since the EST will not require nuclear heaters.

CONCEPT DESIGN: EST PROPULSION SYSTEM:

This section describes a propulsion system using the EST tecł nology. An EST is enclosed in a chamber, similar to a vacuum chamber where the atmosphere can be controlled. This is shown schematically in Figure 4. The EST is shown in its containment 1. An injec or valve 2 is used to inject propellant gas 3 into the chamber. There is no combustion, instead the prop ellant is heated by collisions with the EST. The heated gas moves around the EST and out the exhaust port 4, providing thrust.
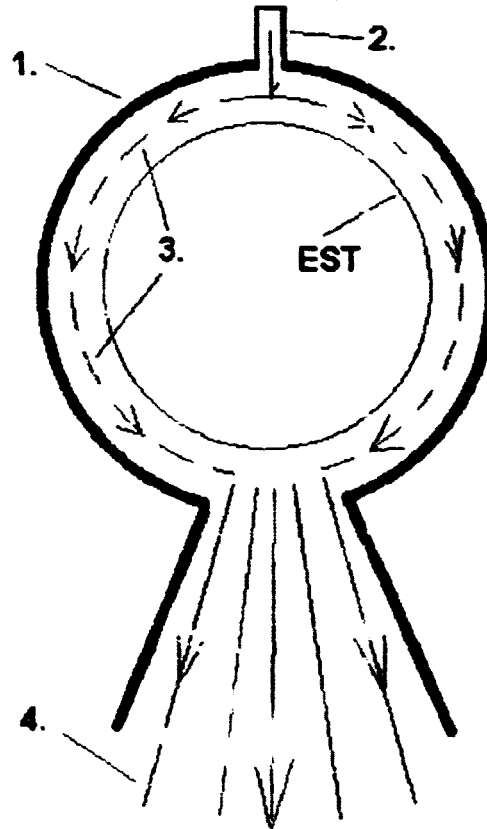

Figure 4. The EST Propulsion System.

The resulting propellant gas temperatire can be up to 116,000,000 °C. For this discussion the heating will be limited to one tenth that amount, or 11,600 000°C. By comparison, a typical chemical based rocket will use combustion to heat propellant to 4000 °C [5.].

The exhaust velocity of the propellant such as hydrogen will be in the order of 1.4×10^6 m/s , compared to the exhaust velocity from rockets of approximitely 4000 m/s. Because of this increase in velocity, the specific impulse will increase from the 300 seconds of a typical rocket to 1.43×10^5 seconds for the EST propulsion system. This will translate into a mass flow of propellant that is less than a chemical rocket by 476 for the same thrust. For a deep space mission, 99.5 % of a launch vehicle is fuel and fuel containment, while the remainder is payload [3]. The potential is for a reduction in the 99.5% by a factor of 10^3 with a complete design based on the EST.

Several features need to be discussed briefly. Firs , since the propellant will be super heated, contact with the chamber walls or the exhaust nozzle need to be minimized. This is possible with this system since the propellant will be an ionized gas. If the hea ed ions try to collide with the chamber, they will be repelled since the chamber walls are at a positive pot ntial and will repel the positive ions. At the same time, the ions will not combine with the electrons in the EST since the ions are traveling at a low enough velocity to preclude recombination, and in addition, the electrons reside in a matrix in which the ions will not find a place.

The EST will contain 1.76×10^{17} joules/kilogram (j/kg) of energy, compared to 1.2×10^8 j/kg for liquid hydrogen. Total energy to raise a 1000kg payload to earth orbit is in the range of 10^{11} joules. An EST to contain this amount of energy would have a radius of 1.2 meters and a height of .40 meters. Calculations show the containment for an EST with this much energy would weigh 94 kilograms. Very large amounts of energy can be stored with low mass and low volume, as shown in Table 1.

Table 1. EST Energy Storage Parameters

Total Energy (Joules)	EST Radius (meters)	Orbit Radius (meters)	EST Area (m^2)	EST Plus Containment Mass (kg)
10^8	.30	.1	1.2	6
10^9	.48	.16	3.0	15
10^{10}	.76	.25	7.5	38
10^{11}	1.2	.40	18.7	94
10^{12}	1.9	.63	47.0	235
10^{13}	3.0	1.0	1.9	595

CONCEPT DESIGN: EST POWER GENERATION

Power on board a space vehicle can be generated using energy from the EST. Some of the heated gas which is used for propellant can be diverted for use to generate electrical power. There are many methods which might be used for this. A magnetohydrodynamic (MHD) is a typical system that can be used. The MHD system has the advantage of having few moving parts, and so will have the high reliability required for space missions. A schematic of the MHD system is shown in Figure 5. An EST is used to store energy in the chamber 1. Gas is inserted from a supply 2. It is heated by the EST and moves into a heat exchange 3. Where it heats MHD gas, shown as the darker line. A small turbine 4. moves the MHD gas through the MHD plates where electricity is generated. The MHD gas is then cooled using a radiator, and returned to start the cycle. A more complete description is available from EST, Inc.
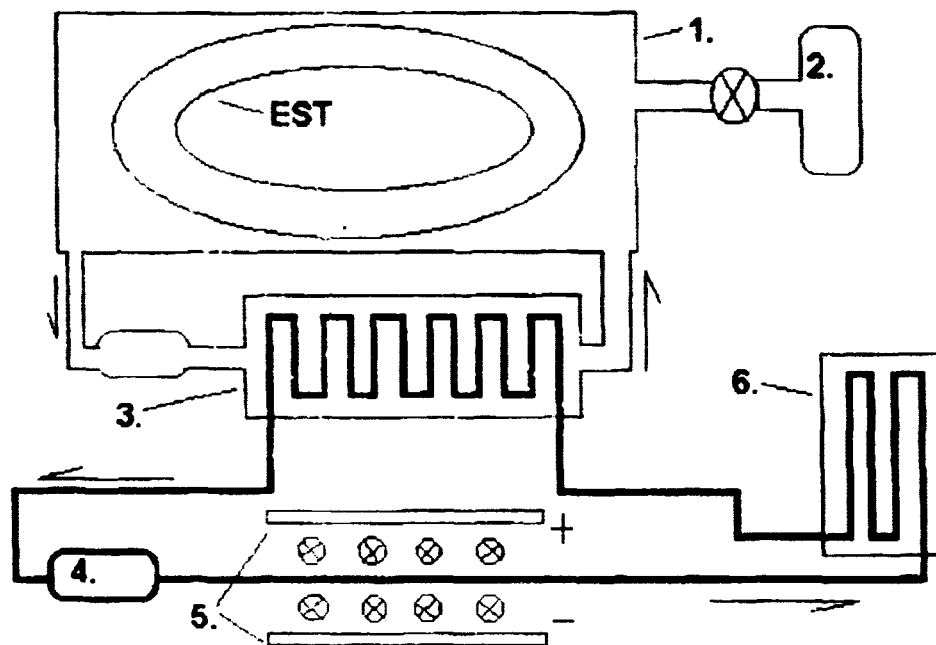

Figure 5. Schematic of an MHD system using the EST as an energy source.

STATUS OF THE EST THEORY

Much work has been done over the past three years to obtain an independent confirmation and derivation of the physics of the EST. This has been largely completed, and the work is ongoing. It is stressed here that, while the theory of the EST itself has been independently derived and largely confirmed to date, the concept designs of the propulsion system and the power generation system have been reviewed only, and await a rigorous independent design and confirmation.

Independent Confirmation Summary of the EST: [Excerpts from reference 1.]

Dr. Chen, a Senior Research Scientist, at the MIT Plasma Fusion Center, has summarized his work over the past three years to independently derive and confirm the physics of the EST technology. He concludes "... the EST energy-storage concept faces no fundamental physics limitations...". He goes further:

1. He confirms that a hollow EST with a thin outer shell of electrons is supported by his work.

2. He agrees his analysis "... supports the experimental observations of the EST observed by Seward ...".

3. He presents his conclusion that the electron temperature is extremely low, "... which may suggest the electrons are strongly coupled, as shown by Seward."

4. He confirms that "... the EST equilibria exist in the absence of any applied toroidal magnetic field."

5. He confirms that the total amount of energy stored in the magnetic field of an EST can be very large.

Proof of Concept Experiments

Proof of concept tests have been conducted in the laboratory of EPS, Inc. over the past five years. The results have confirmed much of the theory, and testing is ongoing. Experiments have created multiple EST's. These have been in the free state; that is, uncaptured.

Test Apparatus: the test apparatus is an extension of the apparatus detailed in EPS patents, with enhancements. The beam supply is capable of producing electron beams in atmosphere. It is an assembly of batteries capable of producing 1500 amperes at up to 5)0 VDC. The coil supply is also a battery supply, which can deliver 1000 amperes DC through a coil used to produce the initiating magnetic field. The electron beam and coil are contained in a bell jar where he atmosphere can be controlled.

Test description: An electron beam of 750 amperes was generated at 150 VDC. The event was recorded on various instrumentation, including video cameras. A test event lasts for under 3 seconds. Several hundred tests have been run and recorded. In these tests, many toroids have been observed and recorded on the camera. Their size is measured to be 5mm to 1 cm in total toroid diameter, and 1 mm to 3mm in orbit diameter. Duration: >166 milliseconds observed. A typical toroid is described in Figure 6:
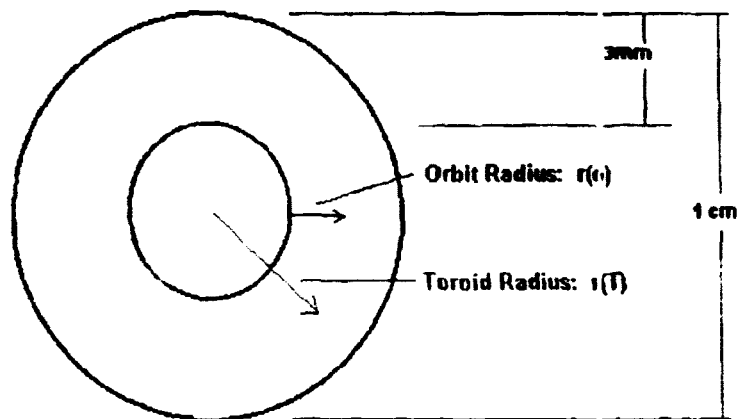

Figure 6. Drawing of Observed EST

Discussion.   1. Dimensions: r_T : 1.5mm 5.0mm; r_0 : .75mm to 1.5 mm
                2. r_0 is set by the amount of charge and the velocity, and is observed at .75mm.

Patents and Licensing

Two US patents have been issued, and three more applied for. One international patent is applied for. Licensing of the patents is available.

NEXT EXPERIMENT; DEMONSTRATION MODEL

The demonstration of the technology will be done using an extension of the testing under way at EPS. These tests will seek to extend the proof of concept results into a full sized EST that can be captured and measured. These experiments will seek to duplicate on a larger scale, the conditions described in the initiation section above. The demonstration will consist of the following steps:
1. Establish the atmosphere required for electron beam. Previous EPS work has determined this.
2. Produce an electron beam of up to 50,000 A at 200 VDC for 200 milliseconds across a 10 cm gap. EPS is presently conducting tests with beams >15,000A.
3. Capture the beam in a circular magnetic field to make the beam spiral.
4. Retain the captured EST around the coil.
5. Measure the properties of the EST.
6. Review the results with independent consultants.

Schedule.

The experiment will require up to three years. The schedule in months from start:
1. 6m. Produce a 15,000 ampere beam.
2. 9m. Capture the EST around a coil.
3. 12m. Report observations.
4. 18m. Produce a 50,000 ampere beam.
5. 21m. Capture the EST. Measure its properties.
6. 30m. Add energy. Report results.
7. 36m. First portable prototype.

Cost of the Experiment.

1. Cost of the Power Supply: to produce a supply of this magnitude is estimated to be $500,000.
2. Cost of the apparatus: Various components need to be bought or manufactured to control the power supply and to generate the beam and coil. These parts are estimated to be $200,000.
3. Cost of the instrumentation. Test equipment to observe the EST is estimated at $140,000.
4. Cost of Labor: The test will require four people full time for 36 months. This is estimated to cost $1100K.
5. Facility: The space needed must have an overhead crane, ventilation, climate control, and power. It is estimated this will cost $100k per year, or $300K.
6. Independent Consultants will review this each month : $160K.
7. Overhead Support Functions: $300,000.
8. Cost to build the first portable demonstration unit. $300,000.

Total cost over three years: $3000K

PROJECTED COST OF EST PROPULSION AND POWER GENERATION:

1. The cost of an EST generator will be similar to the cost of he power supply and the apparatus used in the experiment, and is estimated at $340,000.

2. The cost to recharge an EST to add energy will be simila to the cost to generate microwave power; about $1k per kilowatt hour capability.

3. The EST containment is seen to be low in cost, as it is s milar to a vacuum housing in its simplest form. A small unit from Table 1 above would be about $200, based on the cost of similar vacuum tubes. There is an additional cost for the housing to hold the pressure which will be generated. The pressure for a system of this sort will be a great deal less than the pressure of a rocket housing, and will approach a few hundred pounds per square inch, well within the bounds of normal materials. Thus the cost of an EST housing would be estimated to be about $100 per m^2 for Table 1 above. There would be valves and controls associated with this containment, but nothing exotic.

4. An EST power generation system would cost about $500 per kilowatt. This is detailed more precisely in reference 8.

CONCLUSIONS:

1. Calculations and a detailed theory indicate the EST is a candidate for a breakthrough in propulsion power for space travel.

2. Calculations and a detailed theory indicate the EST is a candidate for a breakthrough in energy storage and power generation for space travel.

3. A demonstration test has been designed which will prove all aspects of the EST theory.

ACKNOWLEDGEMENTS

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NEXT DOCUMENT

The Modified Casimir Force in a Uniformly Accelerating Reference Frame and in a Gravitational Field

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ABSTRACT

This paper discusses the modification of the Casimir Force as a consequence of the spectral energy distribution of the ZPF in an accelerated frame. In the leading terms, the ZPF spectral energy density in an accelerated frame takes the form:

$$\rho'(\omega) = \rho_o(\omega) + \Delta\rho'(\omega) = \frac{\hbar\omega^3}{2\pi^2c^3} + \frac{\hbar\omega a^2}{2\pi^2c^5}$$

The accelerated observer thus sees the ZPF spectrum as observed in a Lorentz frame, $\rho_o(\omega)$, enhanced by the additional term, $\Delta\rho'(\omega)$. Applying the equivalence principle then implies that the additional spectral contribution seen in a frame with acceleration a would also be seen in a nonaccelerating frame with a local gravitational field $g = -a = GM/r^2 \; \hat{r}$ (Puthoff 1988) where the mass M is the source of the gravitational field. A gravitational field therefore produces a gradient along $\hat{r}$ in the ZPF spectral energy density which takes the form:

$$\Delta\rho'(\omega) = \frac{\hbar\omega G^2 M^2}{2\pi^2c^5r^4}$$

The Casimir Force between parallel conducting plates is computed with the additional spectral contribution in both a uniformly accelerating frame and in a gravitational field. It is found that in a uniformly accelerating frame, the additional spectral contribution produces a repulsive force between the plates. It is also shown that the gradient induced in the ZPF by the additional spectral contribution in a gravitational field produces a net force on the system, which acts in the same direction as gravity. Also, by rigidly coupling parallel conducting plates to a gravitating mass, it is shown that a propulsive effect is induced which will accelerate the system without the use of propellant. The work presented in this paper demonstrates an electromagnetic ZPF force which is induced by a gravitational field.

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1. Introduction

The existence of electromagnetic Zero-Point Fluctuations (ZPF) is a clear prediction of Quantum Electrodynamics (QED) resulting from the quantization of harmonically oscillating radiation modes. The ZPF can be regarded as a propagating electromagnetic field in free space with spectral energy density:

$$\rho(\omega)d\omega = \left(\frac{\omega^2}{\pi^2 c^3}\right)\left(\frac{\hbar\omega}{2}\right) =: \frac{\hbar\omega^3}{2\pi^2 c^3}d\omega \tag{1}$$

where the first factor in parenthesis corresponds to the density of normal modes, and the second factor is the average energy per mode. In this paper, the ZPF will be treated as a random classical electromagnetic background. The treatment of quantum field-particle interactions on the basis of interaction with a background of a random classical electromagnetic ZPF is a technique known as Stochastic Electrodynamics (SED). SED is successful in yielding precise quantitative agreement with full QED treatments of Casimir forces and related effects (Boyer 1975; Puthoff 1988). The primary difference between SED and QED is that QED predicts the existence of the ZPF, whereas SED assumes the existence of the ZPF *a priori* (Haisch *et al.* 1994).

The ZPF spectrum in equation (1) is Lorentz invariant (Boyer 1975). However, in an accelerated reference frame, the ZPF spectrum takes the form (Puthoff 1988):

$$\rho(\omega)d\omega = \left[\frac{\omega^2}{\pi^2 c^3}\right]\left[1 + \left(\frac{a}{\omega c}\right)^2\right] \times \left[\frac{\hbar\omega}{2} + \frac{\hbar\omega}{\exp(2\pi c\omega/a - 1)}\right]d\omega \tag{2}$$

This effect was first described by Davies (1975) and Unruh (1976) using quantum field theory and later by Boyer (1980) using SED formalism.

This paper discusses the modification of the Casimir Force as a consequence of the spectral energy density of the ZPF in an accelerated frame. In the leading terms, the ZPF spectral energy distribution in an accelerated frame takes the form:

$$\rho'(\omega) = \rho_o(\omega) + \Delta\rho'(\omega) = \frac{\hbar\omega^3}{2\pi^2 c^3} + \frac{\hbar\omega a^2}{2\pi^2 c^5} \tag{3}$$

The accelerated observer thus sees the ZPF spectrum as observed in a Lorentz frame, $\rho_o(\omega)$, enhanced by the additional term, $\Delta\rho'(\omega)$. Applying the equivalence principle then implies that the additional spectral contribution seen in a frame with acceleration a would also be seen in a nonaccelerating frame with a local gravitational field $g = -a = GM/r^2$ $\hat{r}$ (Puthoff 1988) where the mass M is the source of the gravitational field. A gravitational field therefore produces a gradient along $\hat{r}$ in the ZPF spectral energy density which takes the form:

$$\Delta\rho'(\omega) = \frac{\hbar\omega G^2 M^2}{2\pi^2 c^5 r^4} \tag{4}$$

The Casimir Force between parallel conducting plates is computed with the additional spectral contribution in both a uniformly accelerating frame and in a gravitational field. It is found that in a uniformly accelerating frame, the additional spectral contribution produces a repulsive force between the plates. It is also shown that the gradient induced in the ZPF by the additional spectral contribution in a gravitational field produces a net force on the system, which acts in the same direction as gravity. By rigidly coupling parallel conducting plates to a gravitating mass, it is shown that a propulsive effect is induced which will accelerate the system without the use of propellant.

2. Modified Casimir Force

We are interested in calculating the correction to the standard Casimir Force between two infinite plane parallel conducting plates in a uniformly accelerating reference frame. The expression for the standard Casimir Force is

$$\frac{F}{A} = -\frac{\pi^2 \hbar c}{240 d^4} \tag{5}$$

where d is the separation between the plates and the minus sign indicates that the force pushes the plates together. Now consider three perfectly conducting plates, with the two outer plates fixed at a separation D, and a third movable plate at a distance z from one of the plates (see Figure 1) in the limit $D \to \infty$. Changing z will effect the ZPF energy contained within the volumes between the walls. We can define a force (F) on the plates as minus the derivative of the change in energy with respect to z:

$$F = -\frac{d}{dz}\Delta W(z) \tag{6}$$

where $\Delta W(z)$ is the difference in energy between the two and three plate configurations in Figure (1).
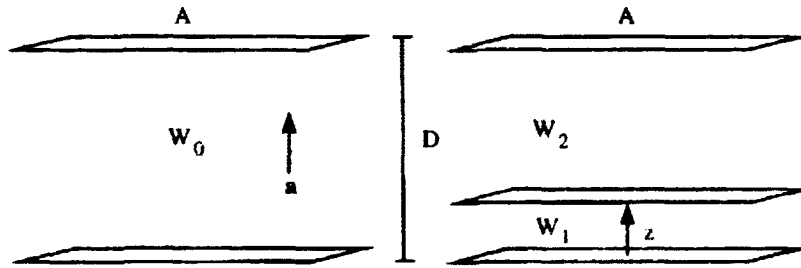

Fig. 1.— Parallel plate geometry used ·ᴐ evaluate the force per unit area between two parallel perfectly conducting plates with area A at a separation z in a uniformly accelerating reference frame with acceleration a. We assume that $D \gg z$ and take the limit $D \to \infty$. W_0, W_1, and W_2 represent the energy of the additional contribution to the ZPF spectral energy density in an accelerating reference frame in the volumes indicated.

We will consider only the additional term in the ZPF spectral energy density in a uniformly accelerating reference frame ($\Delta\rho'(\omega)$ in equation (2)) because the Lorentz frame contribution ($\rho_o(\omega)$ in equation (2)) will simply yield the standard Casimir Force in equation (5). By making the substitution $\omega = ck$ we obtain the following form for the leading order term in the ZPF spectral energy density in a uniformly accelerating reference frame with acceleration a:

$$\Delta\rho'(k)dk = \frac{\hbar k a^2}{2\pi^2 c^3}dk \tag{7}$$

The total additional ZPF energy (W) contained within a volume V is then:

$$W = V \int_0^\infty \Delta\rho'(k)dk = V \int_0^\infty \frac{\hbar k a^2}{2\pi^2 c^3}dk \tag{8}$$

We then make the substitutions $k = (k_x^2 + k_y^2 + k_z^2)^{1/2}$ and:

$$\frac{1}{8}\int_0^\infty 4\pi k^2 dk = \int_0^\infty dk_x \int_0^\infty dk_y \int_0^\infty dk_z \tag{9}$$

to obtain the following expression for the additional ZPF energy:

$$W = V \int_0^\infty dk_x \int_0^\infty dk_y \int_0^\infty dk_z \frac{\hbar a}{\pi^3 c^3} \left(k_x^2 + k_y^2 + k_z^2\right)^{-1/2}$$

(10)

For electromagnetic fluctuations confined between conducting plates separated by a distance L, we can make the substitution $k_z = n\pi/L$ where n is an integer from 1 to ∞. The energy confined between conducting plates of area A and separation L (with $A^{1/2} \gg L$), as in Figure (1), then becomes:

$$W = AL \int_0^\infty dk_x \int_0^\infty dk_y \int_0^\infty \frac{\pi}{L} dn \frac{\hbar a^2}{\pi^3 c^3} \left(k_x^2 + k_y^2 + \left(\frac{n\pi}{L}\right)^2\right)^{-1/2}$$

(11)

The integral $\int_0^\infty dn$ can be replaced within the sum $\sum_{n=1}^\infty$ which yields the final expression for the additional ZPF energy confined within the volume between parallel conducting plates:

$$W = A\frac{\hbar a^2}{\pi^2 c^3} \int_0^\infty dk_x \int_0^\infty dk_y \sum_{n=1}^\infty \left(k_x^2 + k_y^2 + \left(\frac{n\pi}{L}\right)^2\right)^{-1/2}$$

(12)

Let W_0 be the addition ZPF energy originally contained within the volume between the two plates in Figure (1). Let W_1 be the ZPF energy contained in the volume between the plates at $z = 0$ and $z = z$ and W_2 be the ZPF energy contained within the volume between the plates at $z = z$ and $z = D$ in Figure (1). Using equation (12) we have the following expressions for the additional ZPF energy in each of the regions:

$$W_0 = A\frac{\hbar a^2}{\pi^2 c^2} \int_0^\infty dk_x \int_0^\infty dk_y \sum_{j=1}^\infty \left(k_x^2 + k_y^2 + \left(\frac{j\pi}{D}\right)^2\right)^{-1/2}$$

(13)

$$W_1 = A\frac{\hbar a^2}{\pi^2 c^3} \int_0^\infty dk_x \int_0^\infty dk_y \sum_{u=1}^\infty \left(k_x^2 + k_y^2 + \left(\frac{u\pi}{z}\right)^2\right)^{-1/2}$$

(14)

$$W_2 = A\frac{\hbar a^2}{\pi^2 c^3} \int_0^\infty dk_x \int_0^\infty dk_y \sum_{m=1}^\infty \left(k_x^2 + k_y^2 + \left(\frac{m\pi}{D-z}\right)^2\right)^{-1/2}$$

(15)

The energy difference $(\Delta W(z))$ between the two and three plate scenarios in Figure (1) is $\Delta W(z) = W_1 + W_2 - W_0$ and the resulting force on the plate at z using equation (6) becomes:

$$F = -\frac{dW_1}{dz} - \frac{dW_2}{dz} + \frac{dW_0}{dz}$$

(16)

From equation (13) it is obvious that $dW_0/dz = 0$, so we can ignore this term. Taking the derivative of W_1 with respect to z we obtain:

$$\frac{dW_1}{dz} = A\frac{\hbar a^2}{c^3 z^3} \int_0^\infty dk_x \int_0^\infty dk_y \sum_{n=1}^\infty n^2 \left(k_x^2 + k_y^2 + \left(\frac{n\pi}{z}\right)^2\right)^{-3/2}$$

(17)

Then by making the substitutions

$$r^2 = k_x^2 + k_y^2$$

(18)

$$\int_0^\infty dk_x \int_0^\infty dk_y = \frac{1}{4} \int_0^\infty 2\pi r \, dr$$

(19)

we obtain

$$\frac{dW_1}{dz} = A\frac{\pi\hbar a^2}{2c^3 z^3}\int_0^\infty r\, dr\sum_{n=1}^\infty n^2\left(r^2 + \left(\frac{n\pi}{z}\right)^2\right) \tag{20}$$

Making the substitution:

$$y = \frac{z^2 r^2}{\pi^2}\ , \quad dr = \frac{\pi^2}{2z^2 r}dy \tag{21}$$

and doing a little algebra gives us the final expression:

$$\frac{dW_1}{dz} = A\frac{\hbar a^2}{4c^3 z^2}\sum_{n=1}^\infty\int_0^\infty n^2\left(y + n^2\right)^{-3/2} dy \tag{22}$$

Taking the derivative of W_2 with respect to z we obtain:

$$\frac{dW_2}{dz} = -A\frac{\hbar a^2}{c^3(D-z)^3}\int_0^\infty dk_x\int_0^\infty dk_y\sum_{m=1}^\infty m^2\left(k_x^2 + k_y^2 + \left(\frac{m\pi}{D-z}\right)^2\right)^{-3/2} \tag{23}$$

Since $D \gg z$ and we are considering the limit $D \to \infty$, we can replace the summation with the integral over m and make the substitution $k_z = m\pi/(D-z)$ and $dk_z = \pi/(D-z)dm$ to obtain:

$$\frac{dW_2}{dz} = -A\frac{\hbar a^2}{\pi^3 c^3}\int_0^\infty dk_x\int_0^\infty dk_y\int_0^\infty dk_z\, k_z^2\left(k_x^2 + k_y^2 + k_z^2\right)^{-3/2} \tag{24}$$

Then by making the substitutions as in equations (18), (19), and (21) and doing a little algebra we obtain

$$\frac{dW_2}{dz} = -A\frac{\hbar a^2 z}{4\pi^3 c^3}\int_0^\infty dy\int_0^\infty dk_z\, k_z^2\left(y + \left(\frac{zk_z}{\pi}\right)^2\right)^{-3/2} \tag{25}$$

Now by making the additional substitution $u = zk_z/\pi$ we obtain the final expression:

$$\frac{dW_2}{dz} = -A\frac{\hbar a^2}{4c^3 z^2}\int_0^\infty\int_0^\infty u^2\left(y + u^2\right)^{-3/2} dy\, du \tag{26}$$

Both dW_1/dz and dW_2/dz are infinite, but it is only the difference that is physically meaningful.

From equations (16), (22), and (26), we have an expression for the force per unit area induced on the plates by the additional ZPF energy in a uniformly accelerating reference frame:

$$\frac{\hbar c^2}{4c^3 z^2}\left[\sum_{n=1}^\infty\int_0^\infty n^2\left(y + n^2\right)^{-3/2} dy - \int_0^\infty\int_0^\infty u^2\left(y + u^2\right)^{-3/2} dy\, du\right] \tag{27}$$

To extract a first physical result, we can use a formal application of the Euler-Maclaurin summation formula:

$$\sum_{n=0}^\infty f(n) - \int_0^\infty f(n)\, dn = \frac{1}{2}f(0) - \frac{1}{12}f'(0) + \frac{1}{720}f'''(0) + \cdots \tag{28}$$

provided $f^{(k)}(\infty) = 0$, where

$$f(n) = \int_0^\infty n^2\left(y + n^2\right)^{-3/2} dy \tag{29}$$

This method gives of the final expression for the force per unit area between parallel, perfectly conducting plates induced by the additional contribution to the ZPF spectral energy density in an accelerating reference frame:

$$\frac{F}{A} = +\frac{\hbar a^2}{24c^3 z^2}$$

(30)

Here, z is the separation between the plates and the plus sign indicates that the force acts to push the plates apart, which is opposite the standard Casimir Force in equation (5). The total force between the plates is still attractive, since the acceleration induced force is many orders of magnitude smaller than the standard Casimir Force, as described in the following section.

3. Modified Casimir Force in a Gravitational Field

Applying the equivalence principle implies that the additional spectral contribution seen in a frame with acceleration a would also be seen in a nonaccelerating frame with a local gravitational field $g = -a = GM/r^2 \hat{r}$ (Puthoff 1983) where the mass M is the source of the gravitational field. Substituting the gravitational acceleration into equation (30) yields the following expression:

$$\frac{F}{A} = +\frac{\hbar G^2 M^2}{24c^3 d^2 r^4}$$

(31)

The above expression represents a repulsive electromagnetic ZPF force between conducting plates separated by a distance d induced by a gravitational field. The force between plates with separation $d = 1\mu m$ at the surface of the Earth is only $\sim 10^{-47}$ N/m^2, which would be impossible to measure with current technology, whereas the standard Casimir Force is of the order 10^{-3} N/m^2. Even in the intense gravity at the surface of a neutron star where $g \sim 10^{12}$ m/s^2, the repulsive modified Casimir Force is only $\sim 10^{-25}$ N/m^2 for $d = 1\mu m$. Although the gravitationally induced Casimir Force in equation (31) is extremely weak, it illustrates an effect that links gravity and electromagnetism which is, at least in theory, physically observable. The effect demonstrates an electromagnetic ZPF force which is induced by a gravitational field.

However, a gravitational field does not represent a uniformly accelerating reference frame. Instead, a gravitational field produces a gradient in acceleration which is exhibited by tidal forces. Consider the experiment illustrated in Figure (2), in which two parallel, perfectly conducting plates, separated by a distance d, are placed in a gravitational field, perpendicular to the direction of gravitational acceleration. The modified Casimir Force derived above acts to push the plates apart. However, the gravitational acceleration felt by the lower plate, at a distance r from the center of the gravitating mass, is stronger than the acceleration felt by the upper plate, at a distance $r + d$ from the center of the gravitating mass. As a result, there is a gradient in the modified Casimir Force. This gradient produces a net force on the two plates which takes the form:

$$\frac{F_{net}}{A} = \frac{\hbar G^2 M^2}{24c^3 d^2} \left[-\frac{1}{r^4} + \frac{1}{(r+d)^4} \right] \hat{r}$$

(32)

We assume that $r \gg d$ and approximate the above expression to find:

$$\frac{F_{net}}{A} = -\frac{\hbar G^2 M^2}{6c^3 d r^5} \hat{r}$$

(33)

The gradient in the gravitational field produces a net force on the two plates which acts in the same direction as gravity. However, the net force on two plates with separation $d = 1\mu m$ at the surface of the Earth is only $\sim 10^{-59}$ N/m^2.

One interesting aspect of this effect is that a solid conducting slab may take the place of the parallel conducting plates. Electromagnetic fluctuations inside a conductor behave as if they were confined between parallel plates. Therefore, a conducting sheet of thickness d will experience a net force acting in the same direction as gravity, making the conductor appear "heavier" in a gravitational field. As discussed above, the effect is very small.
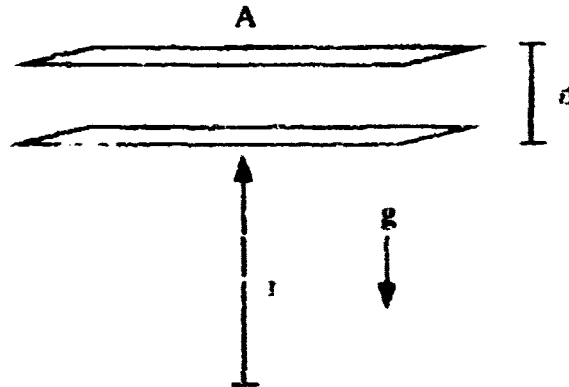

Fig. 2.— Two parallel perfectly conducting plates with area A at a separation d in a gravitational field, $g = -GM/r^2$, used to evaluate the gradient in the modified Casimir Force induced by the gravitational field.

4. Propulsion using the Modified Casimir Force in a Gravitational Field

The previous section has shown that the gravity/ZPF induced modified Casimir Force can be used to produce a net acceleration of two parallel, perfectly conducting plates. It can also be shown that by rigidly coupling the plates to the gravitating mass, the system, including the gravitating mass, can be accelerated without the use of propellant. Figure (3) illustrates an example of this scenario. The magnitude of this effect is very small and is derived as follows. First, the net acceleration of the system must be added to the acceleration in equation (30). The acceleration of the system acts to weaken the apparent acceleration felt at rest in a gravitational field, in the same way that accelerating downward in an elevator makes you feel lighter. The net force on the two plates in Figure (3) is then:

$$\frac{F_{net}}{A} = \frac{h}{24\pi^3 d^2}\left[\left(\frac{GM}{r^2} - a_{net}\right)^2 + \left(\frac{GM}{(r+d)^2} - a_{net}\right)^2\right] \hat{r} \tag{34}$$

We can assume $r \gg d$ and the above expression simplifies to:

$$\frac{F_{net}}{A} = \frac{-h}{6c^3 d}\left[\frac{G^2M^2}{r^5} - \frac{GM}{r^3} a_{net}\right]\hat{r} \tag{35}$$

The net acceleration can now be obtained by using $F_{net} = (M + m)a_{net}$ where M is the mass producing the gravitational field and m is the mass of the two plates with $M \gg m$. Solving for a_{net}, we find:

$$a_{net} = \frac{-GM}{\left(\frac{6c^3 d}{AM} r^5 + r^2\right)} \hat{r} \tag{36}$$

The maximum acceleration that can be produced in this way is equal to the gravitational acceleration felt by the two plates from the gravitating mass M. This is apparent in the limit $d \to 0$ or $A \to \infty$: $a_{net} \to -GM/r^2$. The magnitude of this effect is very small; for example, for $M = 11.7 \times 10^3$ kg (1 m^3 of Lead), $d = 1\mu m$, $A = 1$ m^2, and $r = 2$ m, the net acceleration of the system in Figure (3) is only $\sim 10^{-72}$ m/s^2. Practical applications would require advances in shielding the electromagnetic ZPF using methods other than the parallel conducting plates described here. However, this effect is interesting because it provides a mechanism for creating a propulsive force without the use of propellent, which is a necessity for someday enabling interstellar travel.
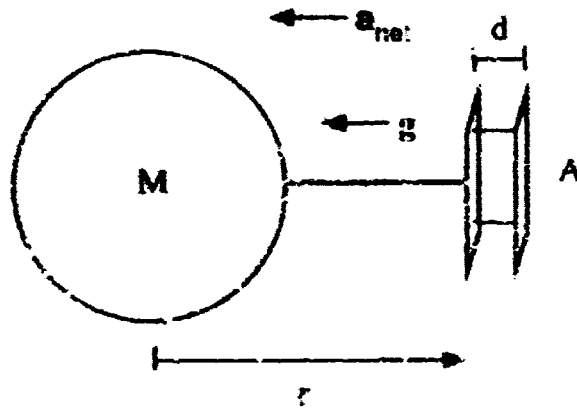

Fig. 3.— Illustration of a propulsion device which utilizes the modified Casimir Force in a gravitational field to produce a net acceleration without the use of propellant. The parallel conducting plates are rigidly coupled to each other and to the gravitating mass M.

5. Conclusions

The work presented here is significant because it uses known physics to demonstrate phenomena linking gravity and electromagnetism: that are, in theory, physically observable. It is found that in a uniformly accelerating frame, the additional ZPF spectral contribution produces a repulsive force between parallel conducting plates. This effect will also be induced by a gravitational field via the equivalence principle. The gradient induced in the ZPF by the additional spectral contribution in a gravitational field produces a net force on the system, which acts in the same direction as gravity. By rigidly coupling parallel conducting plates to a gravitating mass, a propulsive effect is induced which will accelerate the system without the use of propellant, which is a necessity for someday enabling interstellar travel.

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Lurking Breakthrough Physics

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ABSTRACT:

A theory of the authors where electromagnetism (EM) and gravitation are united by geometric structure is summarized. Recent developments on teleparallel Euclidean connections are described. They point to a geometric quantum mechanical sector for this theory, canonically determined by a subset of the differential invariants that define TP. It is shown that the theory's macroscopic part could have been obtained by Einstein when attempting unification through teleparallelism (TP, or absolute parallelism), had he implemented in his 1929 field equations two key suggestion by Cartan. Connections with the work of Ringermacher, Yilmaz and Puthoff are emphasized. Its Cartan-Einstein pedigree, its unification of gravitation and (a superseding) electrodynamics, its promise to reduce quantum mechanics to classical (tangent bundle) differential geometry, and its connections to the work of other participants in this workshop speaks of this theory's potential as foundation stone for the development of breakthrough transportation technologies.

INTRODUCTION:

Einstein tried a geometric unification of the physics with TP[1,2]. We claim that he had the right instincts, but missed the "right rules" for implementing them. By not adopting two key rules suggested to him by Cartan, Einstein failed to make contact with both Maxwell's electrodynamics and 1915 gravitation (GR). Retrospectively, the classical part of our theory is what the **Einstein** system would have become had he followed Cartan's suggestions. Highlights:

1. The identification under appropriate conditions of the Cartan-Einstein geometric field equations with the system of Maxwell-Einstein requires the connection to be Euclidean non-linear (i.e. Euclidean of the Finslerian type). The relation between the EM field and the torsion then yields the **Ringermacher** connection.

2. The statement that the Einstein part of the affine curvature is zero yields gravitational field equations à la **Yilmaz**, i.e. GR type field equations but with gravitational terms on the right hand side (Since there is no strong argument to believe that the metric should be non-Riemannian and since Finslerian connections exist on Riemannian metrics[3], Finslerian theories with Riemannian-looking gravitation are possible).

3. TP is a statement about the curvature, and not just Einstein's tensor. This implies that gravitation is switched off when one switches off other fields, which is a **Puthoff** modification for gravitation of a Sakharov thesis for boson fields. The vacuum of this theory is instrumental in making possible the gravitating of neutral matter.

MODIFICATION SUGGESTED BY CARTAN OF EINSTEIN'S TELEPARALLEL THEORY:

Einstein's Field Equations And The Cartan Suggestions

Since "in Riemannian geometry there is no parallelism at a distance"[2], Einstein postulated TP, his field equations being:

$$R^\iota_{\varphi\kappa,\iota} = 0 \qquad (1a) \qquad\qquad R_{\varphi\iota\kappa,}{}^\eta + R_{\varphi\eta\iota}R^\eta{}_\kappa = 0 \qquad (1b)$$

where the $R^\iota_{\varphi\kappa}$ are the components of the torsion. Semicolon denotes covariant differentiation. In correspondence with him[4], Cartan explained that a physicist may assume that he is living in a teleparallel universe and not require that his system of equations determines the teleparallelism. But his system "will of course contain the 16 equations

$$R_{\varphi\kappa\lambda,\eta} + R_{\varphi\lambda\eta,\kappa} + R_{\varphi\eta\kappa,\lambda} + R_{\varphi\iota\lambda}R^\iota_{\eta\kappa} + R_{\varphi\iota\eta}R^\iota_{\kappa,} + R_{\varphi\iota\kappa}R^\iota_{\lambda\eta} = 0" \qquad (2)$$

(first Cartan suggestion). Equation (2) is the first Bianchi identity with affine curvature set equal to zero. Cartan failed to mention to Einstein the all-important role which this equation plays as an integrability condition. Equations (1), on the other hand, are of the nature of restrictive conditions that the theorist can choose.

The second suggestion is related to what Einstein did with his system. Because a teleparallel connection has zero affine curvature, constant frame fields can be chosen over finite regions of t ne manifold. *The structure can then be completely specified by the coefficients $h_{\mu\nu}$* (and derivatives thereof) relating a co nstant frame field and a coordinate basis field. The torsion, in particular, can be expressed in terms of $h_{\mu\nu}$ (and deriva ives), which can then be taken to a system S of equations for the torsion to make a system S' for $h_{\mu\nu}$. Einstein tried to solve S', i.e. he tried to solve for the full (teleparallel) structure. This is not the task of what Cartan called the physicist, but what, for expository purposes, he called the *demiurge* or builder of universes. The problem is not that Einstein tried to be a demiurge (the ideal physicist-geometer), but rather his trying to do so with a system which was in essence a system for just the torsion, the metric being independent of the torsion. This appears to have prompted the following Cartan comments.

The laws of the demiurge, Cartan stated, must "allow him to recognize that his space is curvature free". He went on to say that system (1)-(2) is deterministic for the purposes of the phys cist, but not deterministic for the purposes of the demiurge, and that the system (1)-(2) "might be taken as a starting point for a physical theory which would rely on the general notion of Riemannian space endowed with curvature and torsion but in order that its physics be deterministic, *other equations would have to be added to bring in the curvature*" (second suggestion, our emphasis). Einstein only briefly discussed the extension (1)-(2) of his system (1) and incorrectly dismissed it. He considered extensions by a curvature equation only indirectly and briefly. In June 1930, Einstein reported to have abandoned his system (1) because "...according to those field equations, there are no gravitational effects ...". In a 1938 letter, Einstein stated with respect to TP that (a) one does not arrive at any tensorial expression for the electromagnetic field and (b) the theory leaves too much freedom for the choice of field quantities[5]. In another 1938 letter, Einstein stated: "... teleparallelism does not lead in any way to an expression for the electromagnetic field"[5].

Implementation Of Cartan's Suggestions

Einstein apparently failed to notice that a Euclidean connection $\omega_\mu{}^\nu$ can always be written in terms of the Levi-Civita object $\alpha_\mu{}^\nu$, now playing only a metric role, and the contortion $\beta_\mu{}^\nu$

$$\omega_\mu{}^\nu = \alpha_\mu{}^\nu + \beta_\mu{}^\nu \qquad (3)$$

Details on the treatment of this equation in the language of forms are given elsewhere[6] (The connection, $\Gamma_\mu{}^\nu{}_\lambda$, and the Christoffel symbols of the tensor calculus are nothing but the components of $\omega_\mu{}^\nu$ and $\alpha_\mu{}^\nu$ respectively). The components of the contortion, $\beta_\mu{}^\nu$, are linear combinations of the components $R_\mu{}^\nu$; of the torsion form Ω^μ:

$$\Omega^\mu = d\omega^\mu - \omega^\nu \wedge \omega_\nu{}^\mu \qquad (4)$$

d is the exterior derivative and the ω^ν's are such that the sum of their squares is the metric. Had Einstein noticed eq. (3), he would have substituted it in the expression for the affine curvature in terms of the connection

$$\Omega_\mu{}^\nu = d\omega_\mu{}^\nu - \omega_\mu{}^\lambda \wedge \omega_\lambda{}^\nu \qquad (5)$$

A fully geometric equation of the type

$$G_{\mu\nu} = T_{\mu\nu} \qquad (6)$$

would have emerged. Here $G_{\mu\nu}$ is the Einstein tensor of general relativity (GR) and $T_{\mu\nu}$ is a geometric tensor (details to follow), as Einstein had hoped. The connection between the geometry in $T_{\mu\nu}$ and the different terms that one puts on the right hand side of Einstein's field equations of 1915 has to wait until further development of the theory allows for the different physical concepts to be expressed in terms of geometric concepts.

By finding gravitation in eq. (6), Einstein would be left with the task of identifying electrodynamics in the system (1)-(2). He would have linearized this system, as he linearized his system for $h_{\mu\nu}$, consistently with his opinion "But no reasonable person believes that Maxwell's equations can hold rigorously. They are, in suitable cases, first approximations for weak fields" (p. 93 of Ref. 4). Had Einstein dropped the quadratic terms in his equations (2) and (1b), he would have found

$$R_{\varphi\eta\kappa,}{}^\eta = 0 \qquad (1b') \qquad\qquad R_{\varphi\kappa\lambda,\eta} + R_{\varphi\lambda\eta,\kappa} + R_{\varphi\eta,\lambda} = 0 \qquad (2')$$

Identification of R_{0ij} with the components F_{ij} of the EM form gives Maxwell's equations, but this system would not be invariant under boosts. This difficulty vanishes if Eqs. (1b')-(2') are Finslerian equations. The system

$$R_{0\kappa\lambda\eta} + R_{0\lambda\eta\kappa} + R_{0\eta\kappa\lambda} = 0 \qquad (7a) \qquad\qquad\qquad R_{0\eta\kappa}{}^\eta = 0 \qquad (7b)$$

must be pictured to result in the process of transforming a pure-field Finslerian theory to a particles-in-external-fields theory. Finslerian terms should also enter the Einstein system in principle, and should vanish in the same process.

An obvious course of action for Einstein at this point would then be to drop Eq. (1a) as unnecessary and to add a current term to Eq. (1b),

$$R_{\psi\kappa\lambda\eta} + R_{\psi\lambda\eta\kappa} + R_{\psi\eta\kappa\lambda} + R_{\psi\mu\lambda}R'_{\eta\kappa} + R_{\psi\mu\eta}R'_{\kappa\lambda} + R_{\psi\mu\kappa}R'_{\lambda\eta} = 0 \quad (8a) \qquad R_{\psi\eta\kappa}{}^\eta + R_{\psi\eta\mu}R''_\kappa = J_{\psi\kappa} \qquad (8b)$$

Thus, when linearizing this system, one would get a current term on the right hand side of (7b). The system (8), which would only be valid under conditions which allow one to neglect the properly Finslerian terms of the torsion, has to be complemented with either Eq. (6) or the full curvature equation from which Eq. 6 is derived.

One can only speculate on the evolution of differential geometry and of this theory in particular if Einstein and Cartan had reached the system of Eq. (8) and (6). Among other things, the fact that the gravity equation would now be fully geometric and that electrodynamics comes out nonlinear would have told Einstein that his instincts about unification with TP were right (Indeed, even though he got nothing out of TP, Einstein had this to say about his eventual abandonment of this postulate: "... I did need a very long time to be sure about this, since I was so very fascinated by the formal naturalness of the theory"[5]). He would have realized that this still is an incomplete picture, not only because one would have had to use the still nonexistent theory of Finslerian connections, but also because the right hand side of Eq (8b) would have to be brought from everywhere else in the physics, as with the right hand side of his 1915 field equations (made of base wood). God's subtlety would have appeared to him to be almost malicious.

ELECTRODYNAMICS AND FINSLER GEOMETRY:

The Finslerian Refibration Of The Bundle Of Frames

Let M^4 be Minkowski's spacetime and let $S(M^4)$ denote its bundle of directions (unit vectors). The set $B'(M^4)$ of proper Lorentz frames (orthonormal bases) at all points of M^4 can obviously be fibrated over M^4, but also over $S(M^4)'$, with $O(3)$ as group in the fibers. The refibration $B'(M^4) \rightarrow S(M^4)$ constitutes the Finsler bundle. In simple terms, the frames are reorganized over the base space $S(M^4)$ as follows. Take a section of $B'(M^4) \rightarrow M^4$ as origin of coordinates u^i (3-velocity) and ϕ^i (angular coordinates). Let $(\underline{x}, \underline{u})$ be any specific point $s \in S(M^4)$. In the Finsler bundle, the frames $(\underline{x}, \underline{u}, \phi)$ all lie in the fiber over $s \in S(M^4)$. Since a body of velocity $\underline{u}$ at $\underline{x}$ is at rest with respect to any frame with coordinates $(\underline{x}, \underline{u}, \phi)$, the 4-velocity u of this body has components $(1, 0, 0, 0)$ and is therefore $u = e_0$, both u and e_0 being vectors at $(\underline{x}, \underline{u})^i$. Finslerian or non-linear connections are those which live in this bundle.

Euclidean connections of the Finslerian or non-linear type are the connections that live in $B'(M^4) \rightarrow S(M^4)$. For comparison with later developments, we push forward the scalar-valued 2-form for the electromagnetic field, $F_{\mu\nu}(x)dx^\mu \wedge dx^\nu$, from a section of a regular bundle of frames $B'(M^4) \rightarrow M^4$ to a section of $B'(M^4) \rightarrow S(M^4)$. Since scalar-valued differential forms are insensitive to the affine structure (i.e. to any considerations on tangent vector spaces), their push-forward has to be given a meaning, namely the writing of the form in terms of the cotangent bases (ω^μ, ω_0') of the base space $S(M^4)$ of the Finsler bundle. We would therefore be writing F as:

$$F = F'_{\mu\nu}(x, u)\omega^\mu \wedge \omega^\nu \qquad (9)$$

with $F = F_{\mu\nu}(x, u)\omega^\mu \wedge \omega^\nu = F_{\mu\nu}(x)dx^\mu \wedge dx^\nu$. A boost of second degree covariant tensors relates $F'_{\mu\nu}(x, u)$ and $F_{\mu\nu}(x)$. The Finslerian torsion whose sole non-vanishing component are the $R_{0\mu\nu}(x)$, denoted here as $F_{\mu\nu}(x)$, is written as

$$\Omega^0 = F_{\mu\nu}(x)\, \omega^\mu \wedge \omega^\nu \qquad\qquad \Omega^i = 0 \qquad (10)$$

or, more explicitly,

$$\Omega = \Omega^\mu e_\mu = F_{\mu\nu}(x)\, \omega^\mu \wedge \omega^\nu\, e_0 \qquad (11)$$

Notice that the coefficient in (9) does not coincide with a coefficient in (11). Does the Finslerian version of (8) contain (8) itself?. General Finslerian torsions are of th form $\Omega = \Omega^i e_\lambda = R^\lambda{}_{\mu\nu}(x,u)\omega^\mu \wedge \omega^\nu e_\lambda + S^\lambda{}_\mu(x,u)\omega^\mu \wedge \omega_0' e_\lambda$ and not just Ω $R^\lambda{}_{\mu\nu}(x,u)\,\omega^\mu \wedge \omega^\nu e_\lambda$. By making the terms with S factors be zero in th e Finslerian version of $d\Omega = 0$, he obtains (8a).

Ringermacher Connections

In 1989 (published in 1991[6]), one of us found that the torsion

$$\Omega^a = (q/m)U^a F \tag{12}$$

on the Minkowski metric gives rise to connections whose autoparallels (lines of constant direction) become the equations of motion of special relativity with Lorentz force. Here F is $F_{v\lambda}(x)dx^v\wedge dx^\lambda$ and the U^a are the components of the 4-velocity vector. We did not want eq. (12) to give the true torsion, but just that torsion which a charge with ratio q/m "sees" and which excludes the torsion that this charge itself creates. The U^a in Eq. (12) is just a symbol which is manipulated as if it were the components of some vector field. It is identified with the four velocity of the charge whose motion is being considered only when it propagates through the commutation to the equations for the autoparallels. This is nonsense. Equation (12) admits, however, a sound interpretation in Finsler geometry, where the three-velocity u^i (in terms of which the U^a's are obtained as in special relativity) are just coordinates in $S(M^4)$. They become velocities of particles through the natural lifting condition $dx^i - u^i dx^0 = 0$, which makes curves in $S(M^4)$ correspond to curves on M^4.

In 1994, Ringermacher published his connections, also with torsion (12), though on arbitrary metrics[8]. Using arbitrary metrics rather than Minkowski's is not an essential difference for present purposes since metric and connection can be defined independently of each other. Since he had found this result around 1985 (before we even addressed the same question), we use the term "Ringermacher connection" to refer to any connection with this torsion. Ringermacher showed in addition that the equation of motion of the spin vector can be written as the statement that its covariant derivative is zero, if spacetime is endowed with his connection.

The proper way of way of writing the torsion (12) is

$$\Omega = \Omega^a e_\mu = (q/m)F_{\mu\nu}(x)\,\omega^\mu\wedge\omega^\nu\,e_0 \tag{13}$$

since the contraction $U^a e_\mu$ is the 4-velocity u, which is e_0 in the Finsler bundle. The would-seem-discrepancy between (13) and the torsion (11) of the linearized Cartan-Einstein theory, admits the following interpretation. The equation of motion of a charged particle P that one would derive from the field equations of the superseding electrodynamics would take the form of autoparallels moving in an *effective torsion* which is not the true torsion that exists at the position of the center of P, mainly contributed to by P, but rather q/m times the torsion that would exist if P were not there but the exterior field remained the field that the other charges create when they are moving as they do in the actual case. It should not be surprising that this field coincides with the form of the linearized Cartan-Einstein field. The strong field in Cartan-Einstein would correspond to high collision energies, where the classical (Lorentz) description does not work.

Alternative Approaches To The Cartan-Einstein System For Teleparallelism

A sensible path to the (same) field equations for the torsion actually preceded our realization of this Cartan-Einstein approach[6]. It arises from the assumption that torsion supersedes the EM field in the particular relation suggested by the Ringermacher connection. Based on it, manipulations with Maxwell's field equations (dF=0, d*F=j) yield[6]:

$$d\Omega = 0 \qquad (14a) \qquad\qquad\qquad d^*\Omega = ju \qquad (14b)$$

Recognizing the Finslerian character in the u factor, thus the loss of generality by virtue of ju being je_0, one replaces $d^*\Omega = ju$ by $d^*\Omega = J$, restoring the generality that this tentative method misses[9]. It was recently shown that $d^*\Omega = J$ still is *not quite correct*, even for linear connections, as we now explain. The Kähler calculus[10] extends Cartan's by adding a concept of interior covariant derivative in a structural way. The exterior and interior covariant derivatives are the respective exterior and interior parts of the Clifford product $\omega^k \vee d_k$, where d_k is the covariant derivative of this calculus. Kähler showed that $\omega^k.d_k$ can then be written as d^* for the Levi-Civita connection. It is clear how to develop the Kähler calculus for teleparallel connections[11]. The interior covariant derivative can no longer be written as d^* in this case. Therefore, one should view the original Maxwell equations as dF=0 and $\delta F=j$ and their generalization in TP as

$$d\Omega = 0 \qquad (15a) \qquad\qquad\qquad \delta\Omega = J \qquad (15b)$$

The expression for $\delta\Omega$ in linear TP is[11] $\delta\Omega = (R^v{}_{\eta\kappa}{}^{\eta} + R^v{}_{\eta\iota}R^{i\eta}{}_\kappa)e_v\omega^\kappa$. The system (15a,b) coincides with the system (8a,b).

Consider finally what might be called Einstein's thesis of "logical homogeneity of geometry and theoretical physics"[12] (In p. 623 of this reference we put together this thesis with quotations from Einstein, who formulated it via the example

of Euclidean geometry). The thesis states that the field equations of the physics should coincide with the equations of structure of the space. These equations constitute a differential system and should be accompanied by the integrability conditions (Bianchi identities). For teleparallel Euclidean connections, and not just teleparallel affine, stating that the affine curvature is zero (*second equation of structure* in TP) takes the form:

$$^0\Omega_\mu{}^\nu = \Omega'_\mu{}^\nu \qquad (15c)$$

where $^0\Omega_\mu{}^\nu$ is the curvature of the Levi-Civita connection and where $\Omega'_\mu{}^\nu$ is a well-defined differential form (details are provided later). The thesis of logical homogeneity demands that eq. (15c) rather than its contraction (6) makes part of the system of field equations. To this we have to add eq. (15a), since it is the *first Bianchi identity*. The *second Bianchi identity* becomes 0=0. Since (15a) already specifies the torsion partially, the *first equation of structure* need only provide a complementary, partial specification of the torsion. The Kähler calculus states that the specification of the interior covariant derivative $\delta\Omega$ constitutes this complement. We have thus reached the system of equations (15) in a third way. This system however has two problems: the phenomenological right hand side of (15b) and the lack of a concept of interior covariant derivative in Finsler geometry. We shall now show how one might solve the second problem (for TP) and that, in the process, the first problem might also be solved.

A "Microgeometry Branch" Of Classical Differential Geometry

A Clifford structure, which is essential for a Kähler calculus, does not exist on $S(M^4)$, since it has dimension seven whereas the relevant (reduced) tangent spaces have dimension 4. An alternative structure defined by the horizontal differential invariants (ω^μ, ω_0') of $B'(M^4) \to S(M^4)$ exists, however, with tangent and cotangent spaces of the same dimension. Since ω_0' defines de_0, which is du in the Finsler bundle, the set of forms (ω^μ, ω_0') in essence defines a connection of pairs, made of velocity and point of attachment. In terms of a fixed frame a_μ, we have $du = \omega_0' e_i = \omega'_0{}^\mu a_\mu$ and $dP = \omega^\mu e_\mu = \omega'^\mu a_\mu$. We have identified five vectors related to the pair $(\omega'^\mu, \omega'_0{}^\lambda)$, namely the basis a_μ, dual to the ω'^μ and the vector u. Let M^1 be a metric 1-dimensional differentiable manifold with coordinate s such that the dual tangent vector u is of magnitude 1. In $M^4 \oplus M^1$, consider the form $d\wp = \omega'^\mu a_\mu + ds\, u$. It takes values in the sum of the associated vector spaces to M^4 and M^1. Notice that ds is a true differential 1-form which becomes equivalent to $[(\omega^0)^2 - \Sigma(\omega')^2]^{1/2}$ through the natural lifting condition $d\wp(.,.)d\wp = 0$. This justifies using the symbols s and u for the coordinate and the tangent vector. Notice that physics does not require that u be a linear combination of the a_μ, only that du does. Actually measured velocities would be integrals of du and thus are appropriate such linear combinations.

What is the microgeometry that would correspond to this structure? Riemannian geometry is the theory of differential invariants determined in an invariant way by a Riemannian ds^2 (or corresponding ω^μ). It can be a Euclidean differential geometry comprising distance and transport) or just a metric differential geometry (without transport, as Riemannian geometry was before the Levi-Civita connection). Euclidean differential geometry is similarly determined by $(\omega^\mu, \omega_\lambda{}^\nu)$ where $\omega_\lambda{}^\nu$ is independent of ω^μ. A general Euclidean differential geometry contains as a subgeometry the non-affine Riemannian geometry mentioned above (identified with gravitation), since it is invariantly determined by the subset (ω^μ) of invariants of the set $(\omega^\mu, \omega_\lambda{}^\nu)$. TP allows us to also identify a "microgeometry" in the subset. Why do we use the prefix micro? By the absence of the $(\omega_\lambda{}^j)$, we are removing the properly macroscopic aspects of the frames. One frame is still needed to refer directions to, but we are no longer comparing frames in the microgeometry.

If A Microgeometry Exists: What Does It Have To Do With Microphysics?

The issue now is whether (ω^μ, ω_0') canonically determines a differential (field) equation (for microphysics). Since $M^4 \oplus M^1$ is not a differentiable manifold, a generalized concept of "covariant derivative" is needed. We proceed in reverse and get an inkling as to what it might look like. In the Dirac equation with EM coupling, we remove the mass term, charge and other real factors, as they should arise in the process of converting a deterministic pure-field QM into a probabilistic, particle-in-external-field QM. The Dirac equation expressed in terms of the Kähler calculus[13] then reads

$$\partial\psi = iA\vee\psi \qquad (16)$$

where ∂ is the sum of the interior and interior covariant derivatives in 4 dimensions, A is the potential 1-form, i is the unit imaginary, and ψ is a scalar-valued inhomogeneous differential form or clifform. Because A is scalar-valued, both

sides are taken to be scalar-valued. If A is now replaced by the potential for the torsion, dP, the valuedness of both sides of Eq. (16) is different, unless ψ is a Clifford-valued clifform.

We now have to take care of the factor i. In a Clifford algebra, we have several objects which can play the role of the unit imaginary, one of them being the unit pseudo-scalar. There is a much better candidate here. Since the math dictates a real Dirac equation in 5-dimensions, a spacetime Dirac equation such as (16) must be viewed as the complexification of an actual 5-dimensional Dirac equation. This leads tentatively to a Dirac equation of the form

$$\partial\Psi = dsuv\omega^\mu a_\mu \vee\Psi \qquad (17)$$

where the bivector part of $ads\vee dP$ would give rise to the 4-dimensional dP (with an analogy, the unit vectors of the space algebra are the Pauli matrices σ_i, not to be identified with the spatial unit vectors of the spacetime algebra, the γ_i). The Clifford products are all meant to be double Clifford products, one in each of the tangent and cotangent algebras. Because of the interpretation of Lie operators as bivectors of a Clifford algebra, the Dirac equation of the physics would be stating that the "Kähler differential" of the spinor would be the equal to the change of the spinor by an infinitesimal boost or translation. In making this statement we are using the fact that the equation $d\wp(.,.)d\wp = 0$ allows us to identify boosts with translations, and that these boosts are the rotations with generator $uds\vee\omega^\mu a_\mu$.

In this theory, the imaginary numbers in QM should be explained as resulting from the complexified spacetime picture of a real five-dimensional picture (Kaluza-Klein). U(1) then emerges as the conversion factor between the Kaluza-Klein and spacetime manifolds. Similarly, SU(2) emerges as the conversion factor between the bundle of directions and the Kaluza-Klein manifolds. SU(3) does not appear anywhere at this point. There is tremendous richness, however, in the field equations. The question arises as to whether there is room in this scheme for SU(3) as a dynamical symmetry.

GRAVITATION AND TELEPARALLELISM:

Universal Form Of Energy-Momentum Tensors And Pseudo-Tensors.

Densities of scalar and vector-valued magnitudes are scalar and vector-valued 3-forms respectively. The cotangent dual to a vector-valued 3-form is a vector-valued 1-form, which becomes a two-indices tensor in the tensor calculus. In terms of forms, the left hand side of Einstein's equations (i. e. the Einstein vector-valued 3-form) is $\Pi^\delta e_\delta$ with Π^δ defined as:

$$\Pi^\delta = [\ \omega_\alpha{}^\wedge\Omega_{\beta\gamma} + \omega_\beta{}^\wedge\Omega_{\gamma\alpha} + \omega_\gamma{}^\wedge\Omega_{\alpha\beta}] \qquad (18)$$

all four indices α, β, γ and δ being different. If the proportionality constant $8\pi\kappa/c^2$ is absorbed in the energy-momentum 3-form T^μ, Einstein's equations read:

$$\Pi^\delta = \pm\ T^\delta \qquad (19)$$

(sign depending on convention). Define $\Re = (1/2)^0\Omega_{\alpha\beta}e^\alpha{}^\wedge e^\beta$. The current 3-form on the left hand side of Einstein's' 1915 field equations then is:

$$\Pi^\delta e_\delta = dP(\wedge, .)^*\Re \qquad (20)$$

where the star to the left of $\Re$ denotes its dual in the tangent space. The first product (∧) refers to the exterior product of forms and the second product is the interior product of tangent vectors. This construction applies to any *antisymmetric* 2-tensor-valued 2-form. The antisymmetry of the 2-tensor is required so that the right hand side of expressions that parallel the right hand side of (18) will be antisymmetric with respect to all three indices.

Energy-Momentum In Teleparallelism.

Substituting Eq. 3 in the expression for the curvature, one gets:

$$d\omega_\mu{}^\nu - \omega_\mu{}^\lambda\wedge\omega_\lambda{}^\nu = d\alpha_\mu{}^\nu - \alpha_\mu{}^\lambda\wedge\alpha_\lambda{}^\nu + d\beta_\mu{}^\nu - \beta_{.}{}^\lambda\wedge\beta_\lambda{}^\nu - \alpha_\mu{}^{.\lambda}\wedge\beta_\lambda{}^\nu - \beta_\mu{}^\lambda\wedge\alpha_\lambda{}^\nu \qquad (21)$$

We now assume teleparallelism. The affine curvature is zero and we nay rewrite the equation as

$$d\alpha_\mu{}^\nu - \alpha_\mu{}^\lambda\wedge\alpha_\lambda{}^\nu = [(\beta_\mu{}^\lambda\wedge\beta_\lambda{}^\nu) + (-d\beta_\mu{}^\nu)] + [\alpha_\mu{}^\lambda\wedge\beta_\lambda{}^\nu + \beta_\mu{}^\lambda\wedge\alpha_\lambda{}^\nu)] \qquad (22)$$

It is important to notice that the contents of the two square brackets are not tensors, but the contents of the parentheses are. These two tensors are zero in Riemannian geometry. The identification of the two pseudotensors respectively with the non-gravitational and gravitational interaction is dictated by what the different terms depend on.

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For comparison (left to the reader) with the Yilmaz theory[14], denote $d\alpha_\mu{}^\nu - \alpha_\mu{}^\lambda \wedge \alpha_\lambda{}^\nu$, $\alpha\alpha_\mu{}^\nu$ and $\alpha_\mu{}^\lambda \wedge \alpha_\lambda{}^\nu$ as $\mathfrak{R}$, U' and u'. Further denote the forms in the square brackets as U and -u, and those in the parentheses as τ and t. Eqs. (22) then yield:

$$\mathfrak{R} = U' - u' = U - u = \tau + t \tag{23a}$$

Notice that $\mathfrak{R}$, U', u', U, u, τ and t are all antisymmetric in terms of orthonormal frame fields We designate as $\mathfrak{R}$, U', u', U, u, τ and t the respective contractions with $e^\mu \wedge e_\nu$. Acting on them with $dP(\wedge, .)^*$ on the left yields seven vector-valued 2-forms and pseudo-2-forms. In parallel to (23a), their cotangent duals $\underline{\mathfrak{R}}$, $\underline{U'}$, $-\underline{u'}$, $\underline{U}$, $-\underline{u}$, $\underline{\tau}$ and $\underline{t}$ satisfy:

$$\underline{\mathfrak{R}} = \underline{U'} - \underline{u'} = \underline{U} - \underline{u} = \underline{\tau} + \underline{t} \tag{23b}$$

The components of $\underline{\mathfrak{R}}$ and of $\underline{u'}$ constitute Einstein's tensor and pseudo-tensor, except that $\underline{u'}$ refers to orthonormal frames (this pseudo-tensor is usually presented in terms of the coordinate basis fields of the tensor calculus, which, not satisfying $dg_{\mu\nu}=0$, the antisymmetry property $\omega_{\mu\nu}+\omega_{\nu\mu}=0$ is not complied with; one has to move the $dg_{\mu\nu}$ around in order to achieve the same purposes as for orthonormal frames). From the definitions, it follows that

$$\underline{U} = \underline{\tau} - dP(\wedge, .)^* d\beta_\mu{}^\nu e^\mu \wedge e_\nu \tag{24}$$

We now name $-d\beta_\mu{}^\nu e^\mu \wedge e_\nu$ as z and the cotangent dual of $-dP(\wedge, .)^* d\beta_\mu{}^\nu e^\mu \wedge e_\nu$ as $\underline{z}$. We thus obtain:

$$\underline{U} = \underline{\tau} + \underline{z} \tag{25a} \qquad\qquad \underline{u} = -\underline{t} + \underline{z} \tag{25b}$$

GRAVITATION AND THE DYNAMICAL VACUUM OF TELEPARALLELISM:

Stochastic Electrodynamics And The Puthoff Modification Of The Sakharov Conjecture.

Sakharov developed the conjecture that the "Lagrange function of boson fields (gravitational, electromagnetic and meson) is generated by vacuum polarization effects of fermions"[15]. In Puthoff's version of this conjecture *"gravitation is not a fundamental interaction at all, but rather an induced effect brought about by changes in the quantum-fluctuation energy of the vacuum when matter is present"*[16] (our emphasis). In the emphasized part of the statement, gravitation has parted ways with the electromagnetic and meson interactions. Finally, Puthoff states that gravitational theory is recognized to be essentially phenomenological in nature Here we think that Puthoff goes too far, as we now explain.

Puthoff formulates his thesis in the context of Stochastic ElectroDynamics (SED). In SED one takes for granted a classical EM radiation field with divergent energy density $(\omega^2/\pi^2 c^3)(\hbar\omega/4\pi)d\omega$. Whereas a divergent density constitutes no problem in QM (*everything goes* provided we find a rule to subtract infinities), an infinity is a difficulty to be removed in classical physics. Is the zero point itself not as phenomenological or more than gravitational theory?

A Model Of The Vacuum In Non-Linear Electrodynamics.

We shall use the term *dead vacuum* to refer to a region of space where there is no non-gravitational fields, whether background field or not. If there were regions of dead vacuum in a teleparallel world, the torsion and not only the curvature would have to be zero. But this is Minkowski spacetime. Hence, bodies immersed in such vacuum would not gravitate. TP would not explain that the earth goes around the sun. TP thus complies with the Puthoff version of the Sakharov thesis, in that switching off the non-gravitational fields switches off the gravitational field also.

Fortunately, dead vacuum may be inconsistent with the field equations of TP, as we now explain. In a unified classical theory, the equation for the physical microscopic field should be one and the same at all points of spacetime (including within a fermion and within a boson). This is consistent with the Dirac equation amounting to a statement as general as in our interpretation of (17). The Kahler calculus gives the recipe for the Dirac current in terms of Ψ and thus the current to feed into the right hand side of Eq. (15b). Of course, for solutions one would have to integrate the full system of coupled microscopic and macroscopic equations. The different "options" (matter, radiation, vacuum) would correspond to regions where the same solution of this full system exhibits different properties: those of fermions, bosons or of vacuum. The bosons and the vacuum correspond to regions where the generalized Dirac current be ones zero.

No study has been performed of any solutions of any of our still tentative field equations. Muraskin, however, has studied a system of equations that bear resemblance to ours. it transpires that bosons would emerge as soliton solutions

in a modulated background which one may refer to as the vacuum[17] (the present authors recently reprinted[18] the most relevant part of the study). In principle, the torsion should not be zero in this vacuum and gravitation would be restored. Of course, this entanglement vacuum-bosons propagates into an entanglement vacuum-fermions due to the fact that the bosons themselves are deeply entangled with fermions in the natural interpretation of bosons and fermions in the Kähler calculus. Contrast between the Riemannian (non-entanglement) and teleparallel (entanglement) Kähler calculi is very illuminating[19]: for weak boson fields, the teleparallel regime looks Riemannian, and disentanglement follows.

The Ringermacher Connection As A Crutch For The Nonlinear Stochastic Vacuum.

Vacuum thus appears as the shared extension of all matter everywhere, if we want to picture matter as a causal agent. It will therefore be, by nature, stochastic. From the macroscopic perspective (i.e. of the torsion itself, rather than of the Ψ from which the torsion's current is made), the weak field approximation is given by the linear terms (the non-linear terms are the case; however for the existence of solutions). These linear terms constitute the Ringermacher torsion. This torsion has the nice property that it gives a non-zero contribution to the source of the metric curvature regardless of any assumption about absence of correlations of the stochastic background. For simplicity, neglect the contribution of x_μ^ν to the connection. The Ringermacher contortion is readily calculated[6]:

$$\beta_0' = \beta_0^i = -E_i\omega^0 + (1/2)(B_i\omega^k - B_k\omega^j) \qquad \beta_j^i = -\beta_j^i = (1/2)B_i\omega^0$$

It then follows that:

$$\beta_0^\mu \wedge \beta_\mu^i = (-1/4)[(B_j)^2 + (B_k)^2]\omega^j\wedge\omega^0 + (1/4)\beta_i(B_jc^k + B_k\omega^k)\wedge\omega^\nu$$

$$\beta_i^\mu \wedge \beta_\mu^j = -(1/2)[B_k\omega^0\wedge(E_i\omega^j + E_j\omega^i) + \omega^0\wedge\omega^j(E_iB_j + E_jB_i)] + (1/4)\beta^k[B_j\omega^i \omega_k^j + B_jc^k\wedge\omega^j + B_kc^j\wedge\omega^i]$$

The presence of the B^kB_k term guarantees the existence of a non-zero term under any assumption about correlation properties of a background stochastic field. It ensures that the strong EM field at close proximity to matter, which becomes weaker and weaker as one recedes from it, will also contribute with at least one surviving term on the right hand side of the curvature equations. Notice that one is not claiming that the weak field is the source of the curvature of spacetime; it is used here only as evidence. The source of the curvature of spacetime, to the extent that such pictures in terms of sources are valid in dealing with these sophisticated systems of differential equations, will be "located" where the vacuum strongly couples with (the not so neutral) matter. The information, however, appears to propagate in the modulated background field, if we may draw implications from Muraskin's solution.

A Remark On The Zero Point Field Of Stochastic Electrodynamics.

Let us return to SED. It is not sensible to think that there is more than one classical background radiation in the universe, namely the cosmic background and the zero-point fields (the latter being out of the question because of its divergence). Since the torsion equations are non-linear, it is possible in principle to have a vacuum whose tail is the 2.7^0 radiation and with a head at each piece of matter, which it hugs as if were a zero-point field. The non-linearity of the fields has to be presumed to be associated with the hardness of nuclear matter, hardness which is in turn connected with the effective wavelengths for the cut-off of the gimmick known as the zero-point field.

CONCLUSION:

The postulate of Finslerian TP has been shown to yield a very sophisticated geometry which increasingly looks like the physics. It should take the effort of many a physicist to make it useable (just think of the development of QM, or even starting around 1960). Could we safely leave this theory undeveloped?

Since there are no physical magnitudes in this theory and since the field equations mimic the closed system of Maxwell-Einstein-Dirac, all the physical magnitudes can in principle be pulled from this theory. This should happen in the process of transforming this deterministic quantum theory that refers to a non-dualistic (pure field, no particles) world into a practical, dualistic quantum theory where one separates clumps of field and identifies them as matter (This process has all the limitations that the nature of the field equations and the absence of precise boundary conditions in such clumping impose). All this in addition to the characteristics of this theory which were emphasized in the abstract and introduction. What else could we want? If not this, what?

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NEXT DOCUMENT

A First Tangible Step in the Quest for Hyperluminal Space Travel

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Abstract

It order to demonstrate that it is possible for the speed of light to be exceeded, the first and only tachyon model to agree with experiment is outlined here. This produces extensive agreement with experiment for the electron, the proton, the neutron, the lighter nuclei, and the mesons. The data that is used to verify this model is well known from the standard physics literature. No source that is controversial, or possibly bogus, is used. This model is, in short, a reinterpretation of existing particle data that is accepted by and used by the physics community. A possible method of artificially generating tachyons is also proposed.

1. The Origin of the Magnetic Moments of the Electron and the Muon

This model uses a negative mass tachyon as opposed to the well known imaginary mass tachyon. The imaginary mass model has never produced agreement with experiment. Note that a negative mass particle is an antigravity particle.

This model is extremely simple. It is a unified Bohr-like revolving particle model that utilizes the negative mass tachyons to generate magnetic moments. The tachyons, being unable do drop below the speed of light, cause the point charge in electrons, muons, protons, etc. to revolve in relatively large orbits, thus generating magnetic moments.

To summarize the electron model, a pion captures a negative mass tachyon and becomes, overall, a less massive muon. The muon captures still another negative mass tachyon, and becomes an even lighter electron. The orbital velocities of the revolving charged particles are constant at the speed of light, with only the orbital dimensions and the overall energy of the system changing during the transition from one particle system to another. Based on this, an electron and a muon are fundamentally revolving systems of pions. And based on the meson equation's origin in resonating pions (see Eq. 27), when high energy electron-positron collisions produce the meson energies, we can conclude that they are due to resonating pions.

Further, based on this model, *it is mandatory* that the byproducts of high energy electron-positron collisions include muons and pions. This is observed to be the case experimentally.

Neutrinos have been detected, so therefore, they exist. However, estimates of the of the electron's neutrino masses via Kurie measurements give upper limits of about 10 - 20 eV, so it does seem rather strange that it could be believed that the shape of the $\mu \rightarrow e$ curve (up to 52.6 MeV) can really be determined by such small, non-photonic particles. In any case, there is more than enough residual energy in this model to account for these artifacts.

2. A Derivation of the Bohr Magneton for the Electron and the Muon

We will now present a sketch of the derivation of the magnetic moment of revolving charged point particles, namely the Bohr magneton.. Many necessary justifications will no be given here, but more detail is available to the interested reader in **The Physics of Tachyons** and in the pa)ers referenced below.

The masses of the muon's and electron's tachyons are

$$M_{T\mu} = M_\mu - M_\pi = -33.9091 \text{ MeV}. \tag{1}$$

$$M_{Te} = m_e - M_\mu = -105.147388 \text{ MeV}. \tag{2}$$

Next, we will need to utilize half of these masses as binding energies I.e., we have

$$E_{T\mu} = - 16.9546 \text{ MeV}. \tag{3}$$

$$E_{Te} = - 52.573694 \text{ MeV} \tag{4}$$

The sum of these energies is

$$E_\mu + E_{Te} = - 69.5283 \text{ MeV} \tag{5}$$

Next, examine Fig. 1. It is a composite of two particle conversion curves. The μ-> e curve on the left is well known and is cont ined in most particle physics books. The right most curve, the direct π -> e conversion curve, is less well known, the direc. conversion of a pion into an electron is relatively rare, about one in 10^4 pion conversions.

The interpretation used here is different for the V-A theory. The the reaction during the capture of a tachyon by a muon has a residual energy whose distribution is described by the μ-> e curve. However, if the reaction energy is greater than that of the binding energy of the electron's tachyon to the charged particle, there will be no capture and hence, no electrons will be produced. The point at which this happens, 52.6 MeV, is the cutoff energy of the μ -> e curve. This compares nicely with the energy of Eq 4

The π -> μ capture, on the other hand, produces monoenergetic muons at an energy 4.119 MeV, so that there is no cutoff energy. Therefore, another approach must be taken. So compare Eq. 5 with the 69.5 MeV cutoff energy of the π -> e curve. The double tachyon capture implies that the total binding energy of the muon and electron's tachyons is half of sum of their masses, and hence, the binding energy of the muon's tachyon is also half of its mass energy. Note, incidentally, that the difference in he two cutoff energies is 16.9 MeV, which is half the muon's tachyon's mass energy as given in Eq 3.

Because of its negative mass, a revolving tachyon will have an inwardly directed force, not an outwardly directed force, which will balance the outwardly directed force of he orbiting charged particle, thus maintaining the particle systems in tightly bound orbits. The bal ince conditions of a negative and positive mass particle are illustrated by a mechanical analog in Fig. 2

Based on the above, in general, the magnitude of the binding energy of the tachyon, which is the same as the ground state energy, is given by half the tachyon mass, or

$$E_T = \frac{M_T c^2}{2}. \tag{6}$$

Considering the above, the de Broglie wavelength for the tachyon, in very simplistic terms, is given by

$$\lambda_T = \frac{h}{p} = \frac{h}{\sqrt{2 M_T E_T}},$$

(7)

where h is Planck's constant, M_T is the mass of the tachyon in grams, and E_T is the energy of the tachyon. Using Eq. 6 for the energy in Eq.7, we have

$$\lambda_T = \frac{h}{\sqrt{2 M_T M_T c^2/2}},$$

(8)

$$\lambda_T = \frac{h}{M_T c}$$

If we assume a single de Broglie wavelength, λ, for the circumference of the tachyon's orbit around the charged particle, we may divide equation 8 by 2π. This gives us the tachyon's orbital radius, $r_{\lambda T}$, as it orbits the charged particle *in the charged particle's frame of reference*. That is,

$$r_{\lambda T} = \frac{\hbar}{M_T c}.$$

(9)

Here, the subscript λT refers to the de Broglie wavelength, and $\hbar = h/2\pi$. This bizarre shape is shown in Fig. 3. Note that better discussions are provided in the book, **The Physics of Tachyons**, listed in the references.

The balance conditions for a negative mass particle that is coupled to a positive mass is illustrated in Fig. 2. For the electron, we define

$$R_e = \frac{M_\mu}{m_e} = 206.76826$$

(10)

For the muon,

$$R_\mu = \frac{M_\pi}{M_\mu} = 1.320932.$$

(11)

The equation describing the balance of this system for the electron model is

$$M_\mu r_{\alpha} + M_{Te} r_{Te} = 0,$$

(12)

$$M_\mu r_{\alpha} + M_{Te}(r_{\alpha} + r_{\lambda Te}) = 0,$$

where we used the fact that $r_{Te} = r_{\alpha} + r_{\lambda Te}$. Using Eq. 2 (for M_{Te}) in Eq. 12, we have that

$$M_{\mu}r_{\alpha} + (m_e - M_{\mu})(r_{\alpha} + r_{\lambda Te}) = 0,$$

$$M_{\mu}r_{\alpha} + m_e r_{\alpha} + m_e r_{\lambda Te} - M_{\mu}r_{\alpha} - M_{\mu}r_{\lambda Te} = 0. \tag{13}$$

The $M_{\mu}r_{\alpha}$ terms cancel, so that Eq. 13 becomes, after a little rearrangement,

$$r_{\alpha}m_e = (M_{\mu} - m_e)r_{\lambda Te}. \tag{14}$$

Dividing both sides of 14 by m_e and then using Eq. 10, we obtain

$$r_{\alpha} = (R_e - 1)r_{\lambda e}. \tag{15}$$

Also, rewrite Eq. 2 using Eq. 10 to obtain

$$M_{Te} = m_e - M_{\mu} = (1 - R_e)m_e \tag{16}$$

Using Eq. 9 for $r_{\lambda Te}$, Eq. 15 becomes

Using M_{Te} as defined by Eq. 16, we eliminate $(R_e - 1)$ and M_{Te} from Eq. 17 so that

$$r_{\alpha} = \pm (R_e - 1)\frac{\hbar}{M_{Te} c}. \tag{17}$$

for the electron

$$r_{\alpha} = \pm \frac{\hbar}{m_e c} = 386.1593 \text{ fm} \tag{18}$$

Using an identical approach for the muon model, the orbital radius of the muon's pion is

$$r_{c \mu} = \pm \frac{\hbar}{M_{\mu} c} = 1.8675947 \text{ fm}. \tag{19}$$

The magnetic moment of a current loop is, in general,

$$\mu = IA, \tag{20}$$

where I is the current in the loop, and A is its area. (Note that the letter μ is not to be confused with the subscript μ representing the muon.)

Current is, in general, given by the number of charges passing a point, i.e.

$$I = \frac{e}{c}f, \tag{21}$$

where f is the frequency of the particle's rotation, and for a light speed particle is given by

$$f = \frac{c}{2\pi r_c},$$ (22)

where c is the velocity of the charged particle and r_c is its orbital radius. Hence, the magnetic moment of a single, revolving charged particle is obtained from Eqs. 20, 21, and 22, as

$$\mu = (\frac{e}{c})(\frac{c}{2\pi r_c})(\pi r_c^2),$$ (23)

where πr_c^2 is used for the area, A, of the current loop of Eq. 20. Eq. 23 then becomes

$$\mu = \frac{e r_c}{2}.$$ (24)

Using equation 18 in Eq. 24, the magnetic moment of the electron is

$$\mu_e = \pm \frac{e \hbar}{2 m_e c}.$$ (25)

Using Eq. 20 in Eq.24, the magnetic moment for the muon is

$$\mu_\mu = \pm \frac{e \hbar}{2 m_\mu c}.$$ (26)

These are the Bohr magnetons for the electron and muon respectively. These values for the magnetic moments agree with experiment to within 0.17 % for the electron and 0.12 % for the muon. No particular significance is attached to the plus and minus versions of the magnetic moments at this time

3. The Proton, Neutron, Mesons, and the Deuteron Model

Using the above configuration and the magnetic moment of the proton to calculate its dimensions, the dimensions of its outer diameter (the tachyon's orbit) and the smaller dimensions of the charged particles orbit are calculated. The radius of the Σ hyperon's revolving charge is 0.58736077 fm, and the orbital radius of the tachyon is 2.782 fm. Both agree with experiment to within 3 %.

Adding a similarly orbiting, but smaller negatively charged pion to the center of the proton produces a neutron. That is to say, it is a coaxial model with the orbits sharing the same plane. Using the magnetic moment of the neutron to calculate the pion's dimensions, the orbital radius of the revolving pion's charged particle, while it is in the neutron, is 0.18503077 fm. Its energy levels are found to be

$$E_m = 4076/n^2,$$ (27)

with values of the index, n, ranging from 1 through 9. This will provide the energy levels of most of the mesons from the psi mesons on down, and will be referred as the meson equation from here on. These levels and their transitions are shown graphically in Fig 5. The mesons that arise from the transitions are shown in Fig. 6 - Fig. 8

Note, however, that there is a group of mesons with masses above 2100 MeV that are not included in this model. These probably arise from the upsilon resonances, but this has not been explored at this time.

Now consider the attraction of neutrons and protons to form a deuteron. If a proton approaches a neutron, its sigma hyperon will attract the neutron's pion, thus axially deforming the neutron and causing it to behave as a deformable dipole. While the sigma hyperons electrostatically repel one another, they are both attracted to the pion, thus causing this model to be somewhat similar to the Yukawa model. This produces a highly nonlinear attractive force, so that an experimental evaluation of the force would cause it to appear to have no relationship to simple electrostatic forces. Fig. 9 illustrates the geometry of the deuteron. Using the dimension shown here, the sum of the calculated electrostatic and magneto static binding energies is 2.381 MeV, as compared with the measured deuteron's binding energy of 2.2246 MeV, a 7.0 % difference.

4. The Electron as a Bound Photon.

If we substitute Eq. 18 into Eq. 22, we find that the rotational frequency of the electron or muon is given by

$$ f = \frac{m c^2}{h} . \tag{28} $$

If we treat the revolving charged particle as a photon and use the Einstein photoelectric equation with Eq. 28, we find that its energy is

$$ E = m c^2. \tag{29} $$

In this, we find that the electron (& other spinning particles) may be viewed as photons that are trapped in quantized orbits. As was previously noted, this is probably source of the quantization of Eq 8, this quantization being mapped onto the tachyon. Note that Eq. 28 is half the Dirac Zitterbewegung frequency.

5. Non Radiation and Electrodynamics of a Revolving Light Speed Charged Particle

Normally, one would expect that a revolving charged particle would radiate its energy away. However, as a particle with a linear velocity approaches the speed of light, the electric fields lines begin to converge to a plane that is perpendicular to the direction of motion. This is also true of a revolving particle, so that there is no electric field parallel to the direction of motion, a condition necessary for radiation. See Fig. 4

Note that a nearby observer would detect an electric field pulse as the charged particle passes on the near side of the orbit, and a pulse as it passes on the far side, i.e., he would experience pulses at twice the frequency of Eq. 28, albeit with alternating stronger and weaker pulses. Overall he would experience pulses at the Dirac Zitterbewegung frequency. Just how this propagates out into an atom and relates to the Dirac model is not clear at this time, but it is not unlikely that this has an effect on atomic phenomena.

Note also that Gauss' law still holds for an imaginary sphere surrounding the electron, but it is a dynamic phenomena, not a static phenomena. Furthermore, the field would sweep over a nearby, finite sized object at hyperluminal velocities.

6. A Proposed Experiment to Generate Tachyons.

If a high energy charged particle is injected into a high intensity magnetic field, it will be forced into a highly curved trajectory. In a region near the orbit but outside of it, the velocity of the extended orbit will will have a velocity greater than the speed of light. In this region, time will be reversed, so that the radiation emitted here will have a negative value.

Two detection methods are proposed. The first is to carefully measure the shape of the electrons trajectory and determine if a balance between the negative radiation and the cyclotron radiation affects its shape.

The second detection method is to determine if the tachyons, after being allowed to impinge on a source of decaying muons, will decrease the decay rate of the muons

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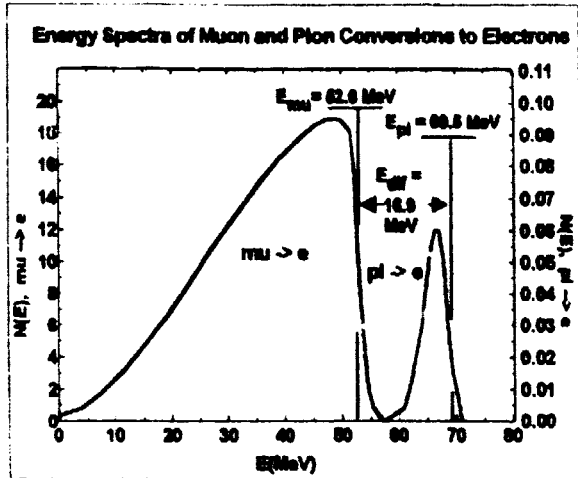**Energy Spectra of Muon and Pion Conversions to Electrons**

Fig 1. The cutoff energies of theses curves determine that the radii of the revolving charged particles of the muon and electron are their Compton radii. 52.6 MeV is half the mass of the electron's tachyon and 16.9 MeV is half the mass of the muon's tachyon.
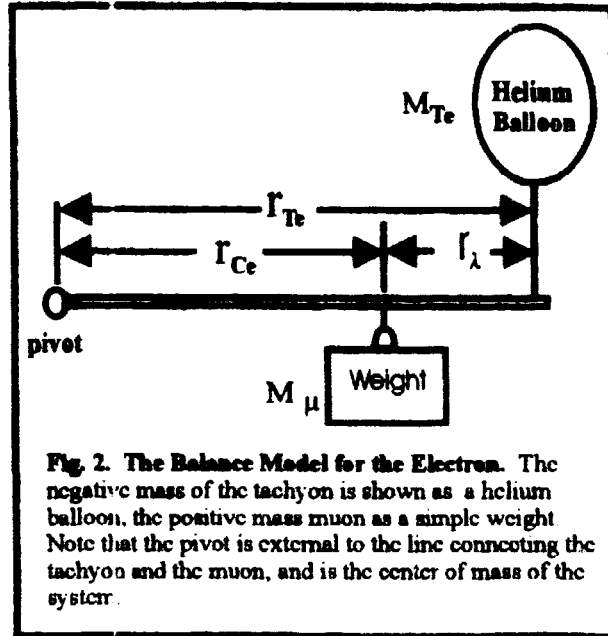

Fig. 2. The Balance Model for the Electron. The negative mass of the tachyon is shown as a helium balloon, the positive mass muon as a simple weight. Note that the pivot is external to the line connecting the tachyon and the muon, and is the center of mass of the system.

CM
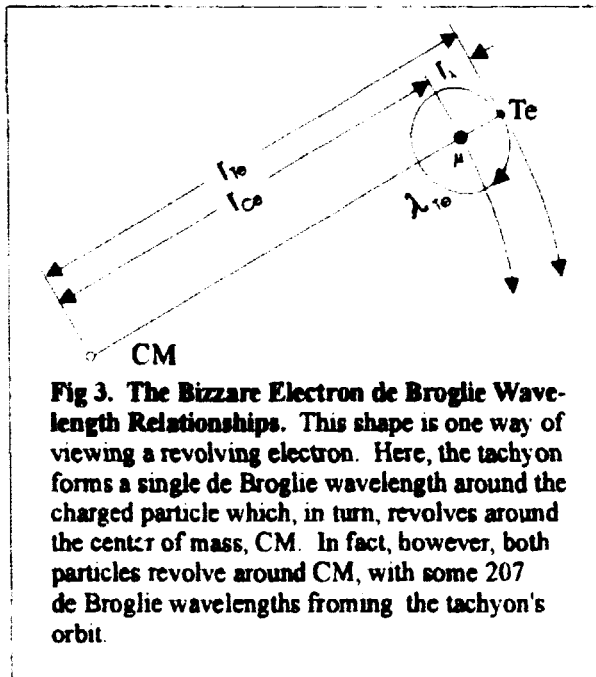
Fig 3. The Bizzare Electron de Broglie Wavelength Relationships. This shape is one way of viewing a revolving electron. Here, the tachyon forms a single de Broglie wavelength around the charged particle which, in turn, revolves around the center of mass, CM. In fact, however, both particles revolve around CM, with some 207 de Broglie wavelengths froming the tachyon's orbit.
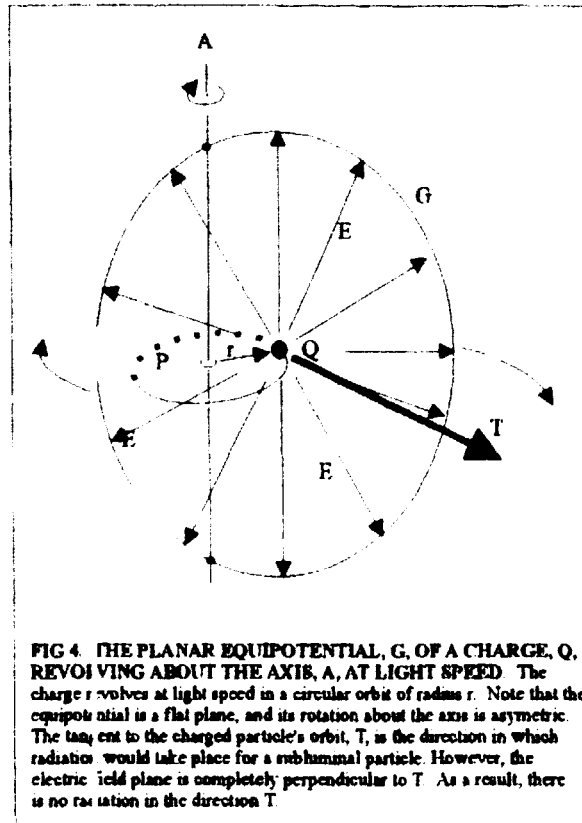

FIG 4. THE PLANAR EQUIPOTENTIAL, G, OF A CHARGE, Q, REVOLVING ABOUT THE AXIS, A, AT LIGHT SPEED. The charge revolves at light speed in a circular orbit of radius r. Note that the equipotential is a flat plane, and its rotation about the axis is asymetric. The tangent to the charged particle's orbit, T, is the direction in which radiation would take place for a subluminal particle. However, the electric ield plane is completely perpendicular to T. As a result, there is no radiation in the direction T.
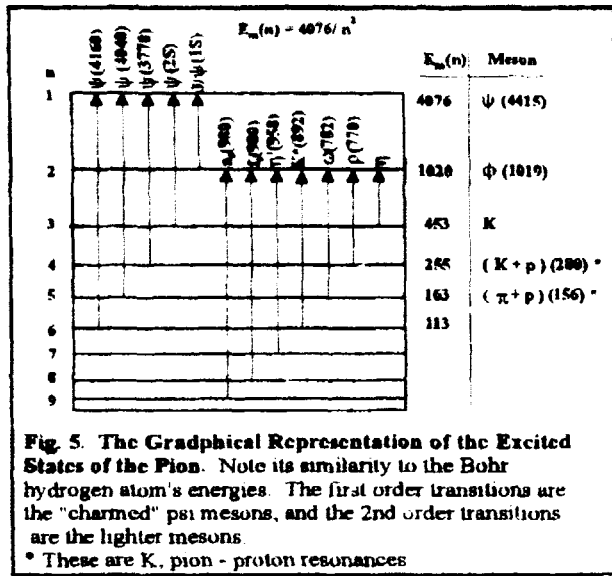
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Fig. 5. The Gradphical Representation of the Excited States of the Pion. Note its similarity to the Bohr hydrogen atom's energies. The first order transitions are the "charmed" psi mesons, and the 2nd order transitions are the lighter mesons.
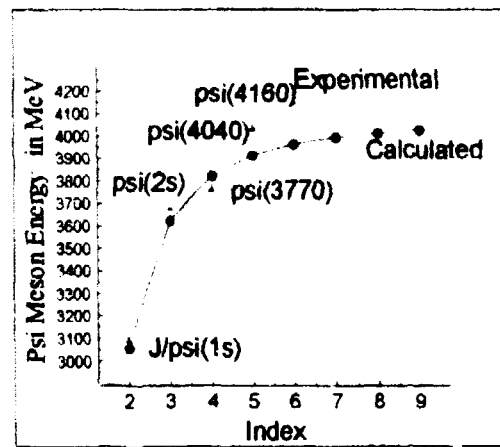* These are K, pion - proton resonances

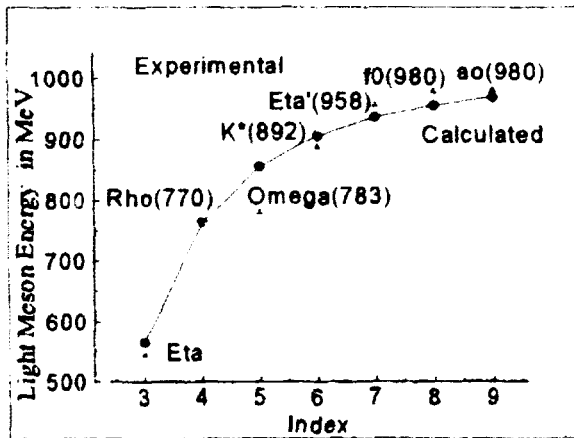**Fig 6. Psi Mesons.** These mesons agree with experiment to within 4.7 %.

Fig 7. The Second Order Transitions, or the Light Mesons. Theses mesons agree with experiment to within 2.3 % except for the omega(783) which is to witthin 9.5 %.
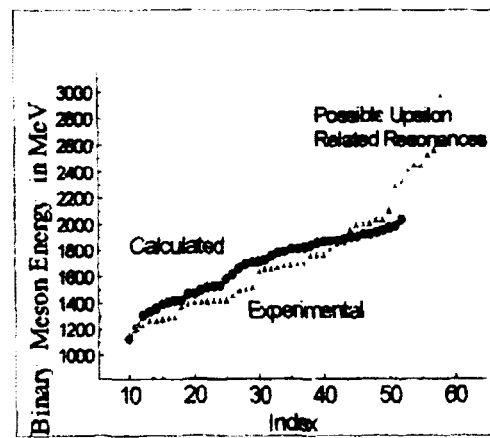

Fig 8. The Binary Mesons. These mesons agree with experiment to within 16 %.
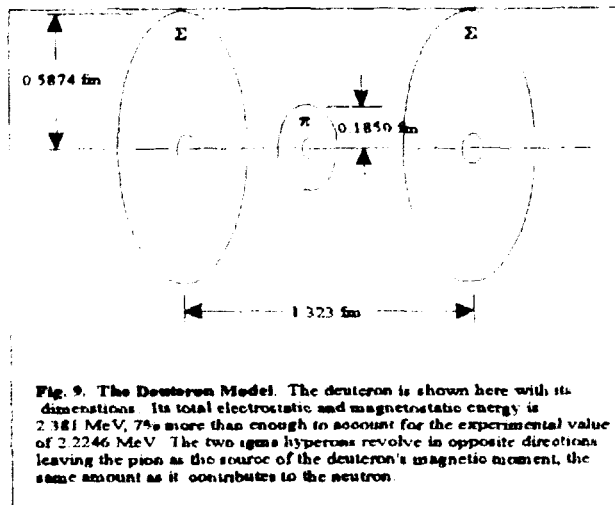

Fig. 9. The Deuteron Model. The deuteron is shown here with its dimensions. Its total electrostatic and magnetostatic energy is 2.381 MeV, 7% more than enough to account for the experimental value of 2.2246 MeV. The two igone hyperons revolve in opposite directions leaving the pion as the source of the deuteron's magnetic moment, the same amount as it contributes to the neutron.

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Challenging The Speed of Light

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ABSTRACT:

This paper challenges the currently believed limitation of particle and information speeds to the speed of light c. It does so by exploring a new model for light that involves a two-step propagation process: a period of expansion/extension from a source, followed by a period of contraction/collapse to an absorber. Such a model turns out to be extraordinarily rich with implications: it reproduces the predictions that are the main observational confirmations for GRT, it captures the main kinematic features of SRT, and it exposes what may have been a conceptual miss-step in the original development of SRT that led to the now dysfunctional belief that c is a real, physical limit.

1. WHY START OVER?

Space travel to distant star systems seems now to be impractical because of the huge distances involved. One of the several problems involved is that huge distance implies huge time unless we can meet or exceed the apparently fundamental limitation to the speed of light c implied by Einstein's special relativity theory (SRT). Before NASA can hope to meet or surpass c, it must undertake to re-examine the origin and meaning of the speed limit.

To this end, observe that there is a crucial difference between classical Galilean speed, which is unlimited, and Einsteinian speed, which is limited to c. But at Eq.(1) in 1905, Einstein could not yet foresee the outcome, and so did not make such a distinction. He began his development of SRT from the Galilean transformation equation $x' = x - vt$, with v being coordinate-frame velocity. At that point, he interpreted v to be Galilean velocity. But then v later turned out to be limited to c. That means that from the very outset, Einstein introduced a confusion between classical Galilean speed, which is unlimited, and Einsteinian speed, which is limited to c.

In retrospect, it is clear that the Einsteinian development does not make sense. After all, a coordinate frame is nothing but a mental construct. Why should it be speed-limited like a massive particle is in SRT? At the very least, the limitation $v \leq c$ excludes all rotation, because for large enough r, one has classical Galilean speed $V = r\omega > c$. But rotation is essential for meaningful physics. Furthermore, rotation is inevitable in SRT because the compilation of non-collinear Lorentz transformations leads to Thomas rotation. So limiting coordinate frames in SRT to non-rotational motion and speed $v \leq c$ is fatally self-contradictory.

But protests about such issues have so far rarely been taken seriously. At the present juncture, we have a very odd situation in Science. The two main pillars of twentieth century are relativity theory and quantum mechanics. Both are thought to be essentially correct in numerical predictions of observable phenomena. But only in the case of quantum mechanics have parallel discussions about the philosophical underpinnings and interpretations of formulae been more or less acceptable. In the case of relativity theory, the scientific community has been reluctant to do other than accept the whole package, equations and words, without serious critique.

So we need to start over on SRT, in part for practical reasons: how else will NASA ever get to the stars? But even more importantly, we need to apply a more consistent attitude about what it is to do science. We need to resurrect the most basic criterion: no matter how much data is in place, a *scientific* theory is never "confirmed". Experiment can only *dis*-confirm. Science remains always open for new experiments and/or improved theoretical constructions.

2. WHY START FROM A TWO-STEP PROPAGATION MODEL?

Delving a bit further, note that SRT fundamentally derives from assumptions about the speed of light, about it being independent of source motion, and it being frame-invariant. But the very phrase "the speed of light" assumes already a great deal more than can actually be confirmed. "The" implies just one, with no direction dependence, no source dependence, etc. But those should be properties to determine, not properties presumed by the language. "The Speed" implies some identifiable thing that, any definite time, has a definite position, and it moves continuously. But we cannot actually track light. "The Speed of Light" implies some non-self-referential way to measure light speed. But in fact we do not have such a method. All of these unfortunate hidden assumptions are good candidates for revision. Here goes:

The current concept of "wave/particle duality" is applied to light because neither of those models proves entirely satisfactory by itself. Light propagation exhibits interference effects, which suggest continuous, oscillating waves, but emission and absorption appear to be discrete and quantized, and that suggests individual, localized photon bullets. So is propagating light an infinitely extending wave? Or a collection of compact particles? The conventional twentieth-century response has been "both" a wave - expanding spherical, plane. or converging spherical, as needed - or a photon bullet as needed.

But some quantum effects display non-locality, and that seems to disqualify *both* the waves and the photons, on account of apparently infinite propagation speed. So perhaps our problem has been in looking to much backward, and saying "both", when we should have been looking forward and saying "neither".

This paper explores a departure from the existing models for light: it looks at light not as a "thing" (e.g. a wave or a photon), but rather as a "process" (i.e. the transfer of energy from one mass-bearing particle to another)

The model prescribes two steps for this propagation process: a period of expansion/extension from a source, followed by a period of contraction/collapse to an absorber. If there is no relative motion between source and absorber, then each step takes half the total time involved. The process progresses as if two signals traveled in sequence, each one at speed 2c. From this point all else follows.

The proposed model is essentially Galilean in nature, but it turns out to be extraordinarily rich with implications that are relativistic in nature. But the Galilean model is not within the scope of Maxwell's equations, and so does not mandate Einstein's historical path of development, going from Maxwell's equations to special relativity theory to general relativity (GRT).

We can start instead with GRT. The main observational confirmations of GRT (gravitational red shift, light-ray deflection, deviation from Keplerian planetary orbit, and radar-ranging signal delay) are explained simply and exactly with a two-step light-propagation model. The interpretation of the results is, however, completely different. Where GRT regards these effects as manifestations of something real and physical happening to the subjects (e.g. a clock slowing, a perihelion advancing), the present theory regards them as essentially optical illusions, created by two-step light propagation to an observer who expects only one-step light propagation.

Then, by eliminating the gravitational effects of mass, we have only the kinematics usually described by SRT. The main features (light-speed invariance, time dilation, length contraction, particle-speed limitation and its attendant apparent mass increase) follow from a two-step light-propagation model. The match to SRT is however not exact. A tiny discrepancy allows preliminary experimental tests to see if this theory works better than SRT

3. MATCHING THE OBSERVABLES OF GRT:

The main observational results that are said to validate Einstein's GRT are:

1) The gravitational red shift of light emitted by a source in free fall in a strong gravitational field.

2) The deflection of light emitted by a distant star into a path that grazes a nearer star, such as the Sun

3) The apparent secular advance of the perihelion of the elliptical orbit of a planet like Mercury, close in to its Sun

4) The slowing of a radar ranging signal sent on a grazing path past the Sun to Mercury on the far side of its orbit.

All of these effects can be predicted equally well with the two-step propagation model for light signals. Two-step propagation means light is always attached to an anchor particle that experiences gravitational acceleration. The implications in each case are detailed below.

3.1. On the Gravitational Red Shift:

Imagine a star of mass M, radius R, at $z = 0$, observed from earth "below" at $z \to -\infty$. Light travels from the star surface at $z_0 = \sqrt{R^2 - x^2}$ to the observer. During propagation over an incremental propagation path $-dz$, the anchor particles accelerate "up" by

$$dv = a_z dt = \frac{GM\left|-z\right|}{r^3}\frac{\left|-dz\right|}{c} = \frac{(GM/c)zdz}{\left(x^2 + z^2\right)^{3/2}}$$

Over the whole path, the anchor particles have accelerated by

$$\Delta v = \int_{z_0}^{\infty} dv = \frac{-(GM/c)GM}{\left(x^2 + z^2\right)^{1/2}}\Bigg|_{z_0}^{\infty} = \frac{GM}{Rc} = \frac{|\Phi|}{c}$$

This causes a Doppler-like red shift

$$v = v_0(1 - \Delta v/c) = v_0\left(1 - |\Phi|/c^2\right)$$

which is in fact observed.

GPT also predicts not just this red shift at the observer, but also an actual clock slowing at the source. The Galilean theory definitely says the red shift is real, but suggests that the clock slowing may be an illusion. The mechanism creating the illusion is the acceleration of anchor particles in the propagation path by which the image of a clock reaches a distant observer. If a falling clock could be observed, it would appear to run slow by the same factor $\left(1 - |\Phi|/c^2\right)$.

So there exists a point of contention by which observation could eventually discriminate between GRT and the presently proposed theory. The question is: do clocks *really* run slow just by virtue of their position in a gravitational field? Possibly the GPS system could resolve this. To keep synchronization with an observer on Earth, satellite-mounted clocks do seem to require a rate adjustment. But the amount of adjustment required cannot be accounted for neatly from just the gravitational slowing predicted by GRT. There is an additional adjustment required. While similar to the clock effects predicted by SRT, the non-gravitational residual here is not identical to that.[10] So at present, the situation is unclear.

In any event, the slowing of a clock image is a special case of the slowing of light, which leads to deflection and distortion of images generally, discussed next.

3.2 On the Gravitational Deflection of Star Light:

Let a source star be above at $z \to \infty$, a deflecting star of mass M be at $z = 0$, and an observer be at $z \to -\infty$. Consider a ray passing the deflecting star at slightly positive x. During propagation over an incremental propagation path $-dz$, the anchor particles accelerate sideways by

$$dv = a_x dt = \frac{-GMx}{r^3}\frac{|-dz|}{c} = -\frac{(GM/c)x\,dz}{\left(x^2 + z^2\right)^{3/2}}$$

Over the whole path, the anchor particles have accelerated by

$$\Delta v = \int_{-\infty}^{\infty} dv = \frac{-(GM/c)xz}{x^2\left(x^2 + z^2\right)^{1/2}}\Bigg|_{-\infty}^{\infty} = -\frac{2GM}{xc} = -\frac{2|\Phi|}{c}$$

As shown by Fig. 1, the angular deflection is

$$\theta = \frac{2|\Delta v|}{c} = \frac{4GM}{xc^2} = \frac{4|\Phi|}{c^2}.$$

This result is twice what one might ..ave guessed semi-classically by saying that light has energy which is equivalent to mass and subject to gravitational attraction. Getting the 2 right was seen as a major triumph for GRT. Getting the 2 right should be seen as a major triumph here too.
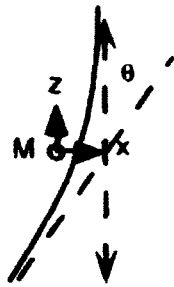

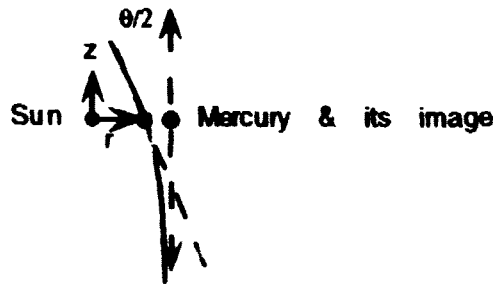
Figure 1. Deflection of
Star Light.

Figure 2. Distortion of
Planet Image

3.3. On the Gravitational Distortion of Images:

Think about the image of a planet orbiting a central mass as viewed from afar; i.e. think about Mercury orbiting the Sun as viewed from Earth. Figure 2 shows that light from the extreme orbit excursions is deflected by $\theta/2 = 2|\Phi|/c^2$. So an estimate of the orbit radius r based on th: image is large by a factor of $\left(1 + 2|\Phi|/c^2\right)$. Kepler's Law says the orbit period T satisfies $T^2 \propto r^3$, so an estimate of T is large by a factor of $\left(1 + 2|\Phi|/c^2\right)^{3/2} = \left(1 + 3|\Phi|/c^2\right)$. As a result, the observed per od is then less than the expected period by an increment proportional to the nominal period and $3|\Phi|/c^2$.

If one did not know about the image distortion and resulting estimation error, one would conclude that the orbit perihelion should advance at non-dimensionalized rate $3|\Phi|/c^2$. This inferred perihelion advance is the same as that predicted by GRT. But the present theory does not mandate that the perihelion advance be real, whereas GRT does. So again there is a point of contention that could distinguish the two theories.

There exist centuries of observational data on planet Mercury, and it definitely shows perihelion advance. A lot of this perihelion advance is attributable to Newtonian perturbation from the other planets. But it is generally claimed

that a small residue is not Newtonian, and that it matches the prediction of GRT. However, the situation is as yet somewhat unsettled, because 1) there is no one seamless calculation that covers both the Newtonian and the residual parts of the perihelion advance together,[11] and 2) there is a minority opinion that the Newtonian part, if carefully enough calculated, would actually account for the whole of the observed advance.[12]

Whether it is orbit-period estimation error caused by image distortion or real perihelion-advance predicted by GRT, Einstein's formula for it, $3|\Phi|/c^2(1-\epsilon^2)$, includes orbit eccentricity ϵ. The Galilean theory has not yet been developed to the point of including the effect of ϵ. For Mercury, the ϵ is very near zero and plays little role in the believed confirmation of GRT. Getting the $3|\Phi|/c^2$ part right was considered a big triumph for GRT, and it should be considered so here too.

3.4.   On the Gravitational Slowing of Radar Ranging Signals:

Consider the angular deflection of light per unit path length

$$\frac{d\theta}{dz} = \left|\frac{2}{c}\frac{dv}{dz}\right| = \left|\frac{2}{c^2}a_x\right| = \frac{(2GM/c^2)x}{(x^2+z^2)^{3/2}}$$

This deflection is consistent with a "slowing" per unit path length

$$\frac{d(c\Delta t)}{dz} = \int_0^x \frac{d\theta}{dz}dx = \frac{(2GM/c^2)}{(x^2+z^2)^{1/2}} = \frac{2\Phi}{c^2}$$

That incremental slowing implies total a slowing over a path

$$c\Delta t = \int_z \frac{2\Phi}{c^2}dz$$

Radar signals sent to Mercury or Venus as they pass near the sun appear to return to Earth late by such an amount. This is known as "the fourth test of GRT". But if the observed radar delay validates GRT, then it validates Galilean theory just as well.

4. MATCHING FEATURES OF SRT:

Image first a rest scenario, with no relative motion between source and absorber. Assume that the two propagation steps, expansion from the source and collapse to the absorber, consume equal time. They must then proceed as if at speed $2c$. In an at-rest scenario with a propagation path length L, each of the two propagation steps is accomplished in time $L/2c$:

step 1: expansion from source to absorber, 0 to $t_1 = L/2c$

step 2: collapse from source to absorber, t_1 to $t_2 = 2L/2c = L/c$

Now imagine inserting a moving relay particle between the source and absorber. Now there can be a compound scenario:

step 1': expansion from source to absorber, 0 to t_1'

step 1": expansion from source to absorber, t_1' to $t_1"$

step 2': collapse from source to absorber, t_1" to t_2'

step 2": collapse from source to absorber, t_2' to t_2"

where the various times depend upon not just L, but the initial position and the velocity of the relay particle. Photons are indistinguishable, so these two scenarios should be indistinguishable. That requires the $2c$ to be independent of source or absorber motion. This means *any* propagation situation in *any* coordinate frame can safely be modeled as two steps progressing at $2c$ each.

Now imagine a moving source communicating to a fixed observer. Say the source starts at x_0 and goes away along the x axis at Galilean speed V. After step 1, it is at $x_1 = x_0 + Vx_0 / 2c$. After step 2, it is at

$$x_2 = x_1 + \frac{Vx_1}{2c} = \left(1 + \frac{V}{2c}\right)^2 x_0.$$

If a one-step model $x_2 = x_0 + Vx_0 / c'$ is force-fitted to this situation, it requires $c' = c/(1 + V/4c)$. So although the two-step $2c$ is independent of source motion, the one-step c' is not. This fact makes the Galilean theory different from SRT.

Being different is, however, not necessarily the same as being wrong. Of all potentially confirmatory experimental techniques, interferometry seems to be the most delicate, and the Sagnac interferometer appears to be the most troublesome to SRT.[9] The Galilean model was derived originally in the context of the Sagnac interferometer [9, Part I], and so of course it fits that experiment exactly.

The two-step light propagation model is newer [9, Part III], and contributes more in the way of explanation. It shows *why* SRT has problems such as Sagnac and others. Einstein imagined infinitely many synchronized clocks with infinitely many observers deployed throughout an infinitely extensive coordinate frame. But reality usually provides only one clock and one observer, both located at a coordinate origin. Time coordinates of events elsewhere are inferred by assuming that the image of the event occurrence propagated at speed c to the observer. But if the "event" is the passage of a moving source through a given spatial point, then correct inference of time requires c', not c. So inferred time coordinates can be wrong. Below it is shown that this fact can account for the well-known paradoxes in SRT.

4.1.   Example: The Twins Paradox:

SRT says a moving clock looks slow to an observer at rest. But is such a clock *really* running slow? If so, then of two clocks with relative motion between them, which one is *really* moving? This question lies at the heart of the so-called Twins Paradox. One twin remains on Earth while the other makes a journey to outer space and back. We believe the differently traveling twins age differently; we believe the traveler will be younger upon his return. We believe such differential aging is actually confirmed by experimental observations such as meson lifetimes or atomic clock readings - not generally seeking alternative interpretations. More on this below.

•   **Resolution for the Twins:**

A clock passing through x at T is recorded at $t_o = T + x/c'$ and inferred to occur at $t = t_o - x/c = T + Vx/4c^2$. With $x = VT$, we have $T = t/(1 + V^2/4c^2)$. So T progresses slower than t, but only because inferred time t is simply wrong.

4.2   Example: The Ehrenfest Paradox:

SRT says a moving rod contracts. But is such length contraction real? The perimeter of a rotating disk is like a sequence of rods. So does the rotating disk shatter at the rim? For this at least there is no believed experimental data.

- **Resolution for Ehrenfest:**

A rod has two ends, x_i, $i = 1, 2$. From $t_i = T_i + Vx_i / 4c^2$, equal inferred t_i' s has to mean unequal true T_i' s. If we pair the ends for unequal T_i' s, we get a wrong length L'. Indeed if $x_1 = VT$ and $x_2 = VT + L$, then equal t_i' s mean $T_2 = T_1 - VL / 4c^2$, and $L' = L - V^2 L' / 4c^2$ so $L' = L / (1 + V^2 / 4c^2)$. A moving rod looks short, but only because inferred times are wrong.

4.3   Example: Speed Limitation:

The Galilean speed V is defined as $\Delta x / \Delta T$, and without infinitely many clocks, ΔT is not directly observable in straight-line motion. The next best thing is speed expressed in terms of coordinate time, $v = \Delta x / \Delta t$. The two speeds are related through $v = V / (1 + V^2 / 4c^2)$. V is unlimited, but v has a maximum value of c.

It is widely believed that particle speeds really are limited to less than c. For example, we believe that mesons circulating in a particle accelerator are circulating at less than c. When they seem not to decay as much as expected, we take that as evidence that the lifetime is affected by motion, or acceleration, or something. Exactly what and why is not clear.

- **Resolution for the Particle Accelerator:**

Although straight-line motion makes Galilean speed V unobservable and only Einsteinian speed v can be observed, circular motion exactly reverses the situation: V becomes easily observable and v becomes inconvenient to observe.

Clear recognition of the difference between V and v suggests that super-luminal speeds are not really impossible for physical particles. Those mesons may age less than expected because they travel faster than believed.

As is so often the case, the problem lies not with the equations, but rather with the interpretation of the symbols in the equations. Applied in a particle accelerator, the Lorentz force law says

$$m_0 V \omega = evB$$

where m_0 is rest mass, ω is circulation frequency, e is charge, and B is magnetic field. In both theories, SRT and Galilean, speed V is bigger than speed v, so the frequency ω has to be "chirped" down to compensate.

In the case of SRT, $V = \gamma v$ is covariant velocity, and v is Einsteinian velocity. The γ is regrouped with m_0 to form the mass parameter $m = \gamma m_0$ that increases with speed. The meson is presumed to travel at v, and it therefore seems to age slowly. In the case of Galilean theory, V is the Galilean velocity $R \omega$ which is unlimited, and $v = V / (1 + V^2 / 4c^2)$ is the observable velocity limited to c. The particle is known to travel at V, so there is no surprise about its lifetime.

5. SUMMARY AND CONCLUSIONS:

Light propagation has been modeled here as a process involving two sequential steps: expansion from a source, followed by collapse to an absorber. The two-step model for light propagation fits well with QM: for example, because of its non-locality, so the two-step model for light propagation may actually be right. In addition, the model is so simple that it allows the major ideas of twentieth-century physics to be reordered from the historical sequence we all experienced in school into a new and possibly more appropriate order.

The two-step model for light propagation first reproduces the "trophy" results from GRT: gravitational red shift, light-ray bending, apparent non-Newtonian orbit perturbation, and slowing of radar ranging signals. But it offers the results with different interpretations, and so suggests issues for future investigation.

The two-step model then reproduces the essential qualitative features of SRT - time dilation, length contraction, etc. But it does so without any paradoxes, and with wider scope - including rotation and acceleration, and it fits crucial experiments. Most particularly, it fits exactly in the case of the Sagnac experiment, where SRT cannot properly render any result at all because of the rotation involved. In other experiments where both theories render predictions, there are slight numerical differences which could be exploited to discriminate between the theories. If accepted, the new theory points to the real possibility of super-luminal speeds.

ACKNOWLEDGMENTS:

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NEXT DOCUMENT

Mach's Principle and Impulse Engines: Toward a Viable Physics of Star Trek?

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Mach's principle and local Lorentz-invariance together yield the prediction of transient rest mass fluctuations in accelerated objects. These restmass fluctuations, in both principle and practice, can be quite large and, in principle at least, negative. They suggest that exotic spacetime transport devices may be feasible, the least exotic being "impulse engines", devices that can produce accelerations without ejecting any material exhaust. A scheme of this sort is presented and issues raised relating to conservation principles are examined.

1. INTRODUCTION

Aerospace propulsion technology to date has rested firmly on simple applications of the reaction principle: creating motion by expelling propellant mass from a vehicle. We can do better. A peculiar, overlooked relativistic effect makes it possible to induce large, transient rest mass fluctuations in electrical circuit components [Woodward, 1990; 1992]. Such fluctuations may be combined with a synchronized, pulsed thrust to greatly increase the acceleration attainable from a given amount of ejected reaction mass. A yet more innovative implementation of the effect suggests it may be possible to make engines that accelerate without the expulsion of *any* material whatsoever. These "impulse engines" are achieved without any moving parts (in the conventional sense). The concepts involved are supported by experimental results already in hand. Moreover, due to the nonlinearity of the effect, Morris and Thorne's [1988] traversable wormholes and Alcubierre's [1994] "warp drive" may be attainable with known technology (while remaining fully in line with the established laws of physics, despite their "Star Trek" nature). Here, however, I deal only with impulse engines.

2. AN INERTIAL REACTION EFFECT

The effect to be derived is predicated upon two assumptions. 1. *Inertial reaction forces in objects subjected to accelerations are produced by the interaction of the accelerated objects with a field -- they are not the immediate consequence only of some inherent property of the object.* And 2. *Any acceptable physical theory must be locally Lorentz-invariant; that is, in sufficiently small regions of spacetime special relativity theory (SRT) must obtain.* We ask: In the simplest of all possible circumstances -- the acceleration of a test particle in a universe of otherwise constant mat-

ter density -- what, in the simplest possible approximation, is the field equation for inertial forces implied by these propositions? SRT allows us to stipulate the inertial reaction force $\mathbf{F}$ on our test particle stimulated by the external accelerating force $\mathbf{F}_{ext}$ as:

$$\mathbf{F} = - \mathbf{F}_{ext} = - d\mathbf{P}/d\tau, \tag{2.1}$$

with $\mathbf{P} = (\gamma m_0 c, \mathbf{p})$ and $\gamma = (1 - v^2/c^2)^{-1/2}$. Bold capital letters denote four-vectors and bold lower-case letters denote three-vectors, $\mathbf{P}$ and $\mathbf{p}$ are the four- and three-momenta of the test particle respectively, τ is the proper time of the test particle, v the instantaneous velocity of the test particle with respect to us, and c the speed of light.

We specialize to the frame of instantaneous rest of the test particle. In this frame we can ignore the difference between coordinate and proper time, and γs since they are equal to one. (*We will not recover a generally valid field equation in this way, but that is not our objective.*) In this frame Eq. (2.1) becomes $\mathbf{F} = - d\mathbf{P}/d\tau = - (\partial m_0 c/\partial t, \mathbf{f})$, with $\mathbf{f} = d\mathbf{p}/d\tau$. Since we seek the equation for the field (*i.e.*, force per unit mass) that produces $\mathbf{F}$, we normalize $\mathbf{F}$ by dividing by m_0. Defining $f = \mathbf{f}/m_0$, we get,

$$F = \mathbf{F}/m_0 = - [(c/m_0)(\partial m_0/\partial t), f]. \tag{2.2}$$

To recover a field equation of standard form we let the test particle have some small extension and a proper matter density ρ_0. Eq. (2.2) then is $F = - [(c/\rho_0)(\partial \rho_0/\partial t), f]$. From SRT we know that $\rho_0 = E_0/c^2$, E_0 being the proper energy density, so we may write:

$$F = - [(1/\rho_0 c)(\partial E_0/\partial t), f]. \tag{2.3}$$

To get the field equation that corresponds to F in terms of its local source density we take the four-divergence of F getting,

$$(1/\rho_0 c^2)(\partial^2 E_0/\partial t^2) + (1/\rho_0 c^2)^2 (\partial E_0/\partial t)^2 +$$

$$+ \nabla . f = - 4\pi Q_0. \tag{2.4}$$

We write the source density as Q_0, leaving its physical identity unspecified for the moment. f is irrotational in the case of our translationally accelerated test particle, so we may write $f = - \nabla \phi$, ϕ being a scalar field (or the timelike part of a vector potential field), and Eq. (2.4) is

$$\nabla^2 \phi - (1/\rho_0 c^2)(\partial^2 E_0/\partial t^2) - (1/\rho_0 c^2)^2 (\partial E_0/\partial t)^2$$

$$= 4\pi Q_0. \tag{2.5}$$

Now we must write E_0 in such a way that we get a wave equation that is consistent with local Lorentz-invariance. Given the coefficient of $\partial^2 E_0/\partial t^2$, only one choice is possible: $E_0 = \rho_0 \phi$. This choice for E_0 yields:

$$\nabla^2 \phi - (1/c^2)(\partial^2 \phi / \partial t^2) = 4\pi Q_0 + (\phi / \rho_0 c^2)(\partial^2 \rho_0 / \partial t^2) -$$

$$- (\phi / \rho_0 c^2)^2 (\partial \rho_0 / \partial t)^2 - c^{-4}(\partial \phi / \partial t)^2. \qquad (2.6)$$

If we ignore the terms of order c^{-4} and those involving derivatives of ρ_0, we have in Eq. (2.6) the usual wave equation for ϕ in terms of a source charge density Q_0. Since ϕ is the potential of a field that acts on all matter in direct proportion to its mass and is insensitive to direct interaction with all other types of charge, it follows that the source of ϕ must be mass. That is, $Q_0 = G\rho_0$. Thus the field that produces inertial reaction forces is the gravitational field [as expected in general relativity theory (GRT)].

Considering the stationary case, where all terms involving time derivatives vanish, Eq. (2.6) reduces to Laplace's equation, and the solution for ϕ is just the sum of the contributions to the potential due to all of the matter in the causally connected part of the Universe, that is, within the particle horizon. This turns out to be roughly GM/R, where M is the mass of the Universe and R is about c times the age of the Universe. Using reasonable values for M and R, GM/R is about c^2. In the time-dependent case we must take account of the terms involving time derivatives on the RHS of Eq. (2.6). Note that these terms either are, or in some circumstances can become, negative. It is the fact that these terms can also be made very large in practicable devices with extant technology that makes them of interest for rapid spacetime transport.

Although standard techniques are used to obtain Eq. (2.6), one may be suspicious of the transient source terms. After all, they are unusual to say the least. Acceleration-dependent transient rest mass fluctuations are not commonplace, especially when they are potentially so large. Indeed, they seem almost too good to be true. Remark, however, that they have a well-known counterpart in standard GRT: the Nordtvedt effect. In the Nordtvedt effect the masses of the constituent parts of accelerated extended bodies are transiently changed (due to the dragging of spacetime by the body) [Nordtvedt, 1988]. The magnitude of the mass-shift in each part of the body is proportional to the product of the acceleration and the Newtonian gravitational potential of the rest of the body at its location. In the case of our accelerated test particle, in its instantaneous rest frame the remainder of the universe appears as an enveloping accelerated body. Accordingly, we might expect it to induce a transient mass fluctuation in the test particle. Eq. (2.6), nevertheless, is not validated by the occurence of analogous effects in GRT or other theoretical speculations. Its validity is a matter of fact determined by experiments.

3. PULSED THRUST

Since the predicted mass shift is transient, large effects can only be produced by very rapidly changing proper matter (or energy) densities. This means that the duration of any substantial effect will be so short that it cannot be measured by usual weighing tech-

$$<F> = \delta m_o(t)a(t):$$

$$<F> = -2\omega^2 \delta l_o \delta m_o \cos\theta. \tag{3.5}$$

If δl_o is a few angstroms (easily achieved with normal PZTs), then when $\cos\theta \approx \pm 1$ forces on the order of several dynes or more can be produced in the laboratory. I have done this in fact employing apparatus shown in general, schematic form in Fig. 1. The enclosure is mounted via a shaft on a stainless steel diaphram (D), a spring that supports the enclosure and its contents. An exceedingly sensitive vertical position sensor (S) detects the location of the shaft. It enables one to measure the weight, and thus the mass, of the suspended apparatus. (To change $<F>$ into an equivalent weight it must be divided by the local acceleration of gravity.) Fig. 2 displays a photo of one of the capacitor arrays mounted on a PZT in the bottom part of its enclosure. (Further details of this apparatus can be found in Woodward, 1996b.)
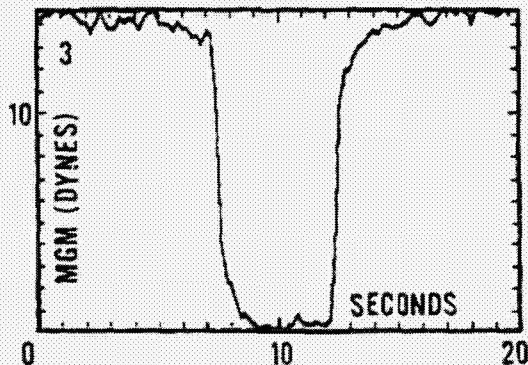

Fig. 2: A CA/PZT/E

Fig. 3: Results

In actual practice one takes the difference between runs adjusted so that $\cos\theta \approx 1$ and those where $\cos\theta \approx -1$. Recent results obtained at 14 kHz with this device are shown in Fig. 3. In the 7 to 12 second interval the CA and PZT are activated producing the displayed differential weight shift. These results are those predicted to better than order of magnitude. (Earlier results accompanied by extensive validity checks and analysis are in Woodward, 1996b.) No weight shift like that in Fig. 3 occurs when either the CA or PZT is run separately. This behavior is shown in Figures 4 and 5 respectively. These and other checks leave little doubt that the signal seen is that sought. Can we use this effect to make impulse engines? Perhaps.
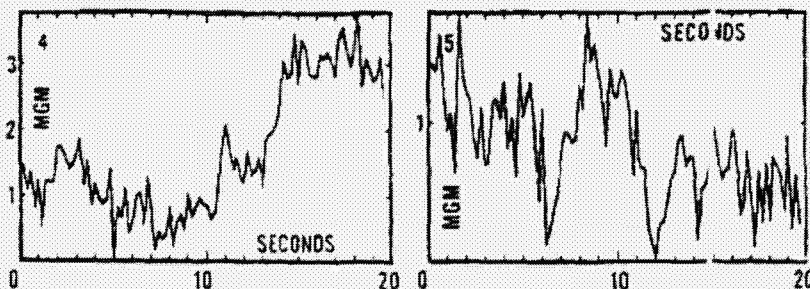
Figs. 4 and 5: Results for the CA (4) and PZT (5) run separately

4. IMPULSE ENGINES

It seems, on the face of it, that impulse engines should be possible. Consider, for example, the case of a kid on a skateboard with a brick. The brick's mass magically fluctuates periodically. The kid throws the brick in the direction opposite to where s/he wants to go when its mass is enhanced, and an attached Bungee cord returns the brick to him/her in the mass reduced state. The kid-brick-skateboard system accerates in the desired direction. You may be inclined to think that even if transient mass fluctuations can really be induced, if the power source driving the fluctuation were loaded onto the skateboard, mass fluctuation effects occuring in it would cancel the acceleration produced by repetitively throwing the brick. Were this not the case, it would seem that we would be confronted by a violation of the conservation of momentum. Since we have introduced no "new physics", violations of momentum conservation shouldn't occur.

The acceleration revealed in the magic brick heuristic, nonetheless, should happen. This is easily shown by making the system a bit more complicated: using two magic bricks instead of one. Our magic bricks will represent either two capacitors, or better yet a capacitor (C) and an inductor (L). We drive mass fluctuations in these circuit elements that have 180 degrees relative phase. (This phase relationship is what makes a capacitor and inductor desireable. They can be made components of a resonant circuit. Since the phase of the instantaneous power [the voltage times the current] in these components differs by 180 degrees, the mass fluctuations will automatically have the desired phase relationship.) Note that the mass fluctuations in the L and C elements sum to zero [at least when the mass fluctuations are small so that the coefficients of the transient terms on the RHS of Eq. (2.6) can be taken as constants], so energy conservation in this circuit per se isn't violated. We interpose a force transducer (a PZT say) between them that expands and contracts at the mass fluctuation frequency. A device of this sort is shown schematically in Fig. 6.
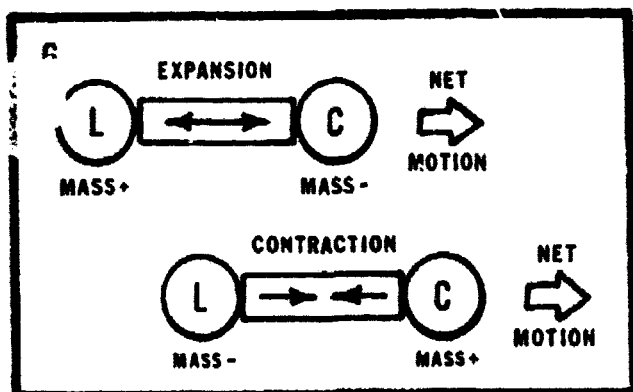

Fig. 6: Impulse Engine Operation of the CA in obtaining Equation (3.5)

When a device like that displayed in Fig. 6 is activated, a stationary force is produced by each of the mass-fluctuating elements on the ends of the force transducer. Each of the forces will be given roughly by Equation (3.5). (Even were we to assume that the mass of the force transducer to be effectively infinite -- as we assumed the enclosure of Figure 1 to be in calculating the acceleration -- a factor that reduces δl_0, and thus $<F>$, must be included to allow for the fact that the displacement involved in the acceleration of each of the elements is

only a fraction of δl_0.) We now remark that the phase difference in the mass fluctuations of the L and C circuit elements compensates for the fact that their accelerations induced by the force transducer are in opposite directions. Accordingly, the stationary forces produced by accelerating L and C as their masses fluctuate are both in the same direction; the L/C/PZT system -- an impulse engine -- experiences a steady, unidirectional accelerating force [which can be estimated with Equation (3.5)] Should we now attach the power sources to our device, they too will be carried along by our impulse engine, even if they contain fluctuating masses.

It seems that we have constructed a device that blatantly violates the conservation of momentum. Perhaps we have ignored something important. For example, consider an object (a capacitor, inductor, magic brick, whatever), moving with some velocity v with respect to us, whose mass can be made to fluctuate. When the mass changes, does the velocity change too? Ostensibly no external force acts to change the momentum. So conservation of momentum seems to suggest that the velocity must change. If the local momentum conservation implicit in this inference is true, then we can solve our problem. Local momentum conservation gaurantees that momentum must be conserved somehow point-by-point throughout our impulse engine. Thus it may wiggle a lot, but it goes nowhere. The assumption of point-by-point momentum conservation in this case, however, violates the principle of relativity, so it must be wrong.

Let us suppose that, viewed in our inertial frame of reference moving with respect to the brick, when the mass of the brick changes, its velocity changes too so that its momentum remains unchanged. (The cause of the velocity change is mysterious. After all, driving a power fluctuation in the brick to excite a mass fluctuation need not itself exert any net force on the brick. But we'll let that pass.) We see the brick accelerate. Now we ask what we see when we are located in the rest frame of the brick. The mass fluctuates, but in this frame the brick doesn't accelerate since its momentum was initially, and remains, zero. This, by the principle of relativity, is physically impossible. If the brick is observed to accelerate in any inertial frame of reference, then it must accelerate in all inertial frames. We thus conclude that mass fluctuations result in violations of local momentum conservation if the principle of relativity is right.

The appearance of momentum conservation violation in our impulse engine doesn't mean that momentum isn't conserved. It means that we can't treat the impulse engine as an isolated system. Since the effect responsible for the apparent violation of the conservation principle is inertial/gravitational, this should come as no surprise at all. As Mach's principle makes plain, anytime a process involves gravity/inertia, the only meaningful isolated system is the entire universe. Since inertial reaction forces appear instantaneous [see Woodward, 1996a and Cramer, 1997 in this connection], evidently our impulse engine is engaging in some "non-local" momentum transfer with the distant matter in the universe. With suitable choice of gauge, this momentum transfer can be envisaged as

transpiring via retarded and advanced disturbances in the gravitational field that propagate with speed c.

Gauge 'freedom muddies up discussions of inertial reaction effects [Woodward, 1996a]. Choosing a gauge where all physical influences propagate at speeds $\leq c$ has the advantage that lightcones in spacetime have an invariant meaning, whereas the surfaces of simultaneity that appear in other gauges (e.g., the Coulomb gauge) do not. As just mentioned, in the Lorentz [or Einstein-Hilbert] gauge the inertial reaction effect, and thus our impulse engine, consists of a retarded/advanced coupling between the engine and the distant matter in the universe that lies along the future light cone. The introduction of the force transducer in the engine allows us to extract a net momentum flux here and now from the potentially largely thermalized matter in the far future. The net momentum flux is accompanied by a net energy flux, so although our impulse engine, considered locally, appears to violate energy conservation, that need not necessarily be the case. The extraction of useful work from matter that may be completely thermalized raises interesting questions. Boosting, rather than borrowing, from the future, however, seems to be the nature of the process involved.

Is any of this really right? Well, one way to get a fix on this is to run the experimental apparatus described above when it is rotated by 90 degrees -- that is, oriented horizontally rather than vertically. If the observed effect is some spurious local effect or couples to local gravity fields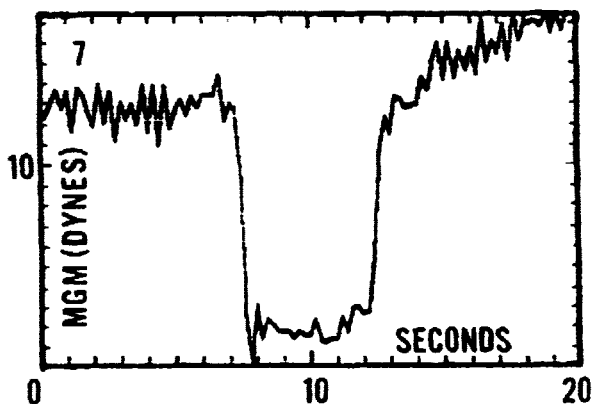, the observed effect should change when the local orientation of the apparatus is altered. But if the effect is caused by the proposed non-local interaction with cosmological matter, it should be independent of the local orientation of the apparatus. Results obtained with the apparatus oriented horizontally are displayed in Fig. 7. At the level of experimental accuracy there is no significant difference in the magnitude of the effect for the two orientations.

Fig. 7: Horizontal Results

5. CONCLUSION

It seems that at least one part of the physics of Star Trek -- impulse engines -- may lie within our grasp. Indeed, the transient Machian inertial reaction effect that makes impulse engines possible may also make "stargates" and time machines based on traversable wormholes feasible [Woodward, 1997]. This is a consequence of the strong nonlinearity of the total proper matter density as it approaches zero and negative values. (Negative mass has interesting properties. See: Forward [1989] and Price [1993].) The feas-

ibility of such schemes, however, also depends on the magnitude of the bare masses of elementary particles and the nature of the vacuum. These matters are, at the very best, conjectural. Accordingly, the schemes are a good deal more speculative than impulse engines. But they, along with impulse engines, can be explored experimentally with present technology at reasonable cost.

ACKNOWLEDGEMENT

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NEXT DOCUMENT

Electric Field Propulsion Concepts from Independent Researchers

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ABSTRACT:

The *Electric Spacecraft Journal* is a forum where independent researchers in fields related to propulsion alternatives may share their discoveries and thoughts. Some contributions are stand-alone efforts, but several others, with diverse origins, tie into a single propulsion concept: the development of interactive electrodynamic fields for propulsion. According to this concept, pulsed electrostatic potential waves can be generated and transmitted in longitudinal form from the surface of electrodes. Intense non-linear polarizing waves are thereby extended into the surrounding space, and free surface charges can be developed on nearby conductors. There is the possibility that a precision system of pulsing, phasing and directing such electrostatic pulses could develop reaction forces on surrounding objects, media and space fields. The role of magnetism in the near-field effects being investigated has yet to be considered, but will be once a certain level of clarity has been achieved regarding the electrostatics involved.

INTRODUCTION:

Since 1990, several curiosities, raising questions about accepted theories, have been reported in the *Electric Spacecraft Journal*. For example, Jerak (1996) has shown that freely-floating soap bubbles will be attracted to the terminal of a Van de Graaff generator until the first bubble touches the terminal and explodes. Then, all the other bubbles will turn around and migrate away from the terminal. In another case, Dr. T.S. Lee and his colleagues have shown that the suspension of a high-voltage point over an oil film smeared on a glass plate will create a perfectly circular, expanding wave front. The same phenomenon has also been generated in powder media (Lee-1996 and 1997). Contributions to *ESJ* range from a report that air ionizers slow the free fall of dropped nickels (Hartman-1993) to videotapes and documentation, of the random levitation, thrusting, extreme deformation and disintegration of a variety of objects subjected to uncontrolled combinations of electrostatics, intense transformer discharges, microwaves, capacitor discharges, and more (Hutchison-1991, 1992a, 1992b, and 1993). This phenomenon has been called the Hutchison effect, and has been rigorously studied by Hathaway (1991).

APPROACHES:

Theories

Alzofon (1994) performed experiments with sophisticated laboratory equipment that provide encouraging results in support of his theory that gravity can be regionally modified. In effect, a mass specimen was placed in a uniform magnetic field and exposed to pulsed, tuned, high-frequency microwaves. This caused the subatomic constituents of the atoms in the mass to realign their nuclear spin orientations. According to Alzofon's theory, which is modeled with a conservation of momentum model for collisions in an ideal gas, this would directly affect the symmetry of the mass gravity field. This asymmetry would then be manifested as a gain or loss in the measured weight of the mass. According to Alzofon's theory, the gravity field change can only occur during the electron/nuclear orientation and disorientation transition period.

Regarding the speed of light, Phipps (1986 and 1997) has pointed out how Maxwell's equations of electrodynamics are only special-case formulae of more generalized equations published in 1892 by Heinrich Hertz. Maxwell's equations were derived for scenarios involving a stationary detector. Consequently, only a partial time derivative was taken. When the total time derivative is taken in deriving the equations of electrodynamics, allowing detector motion, the speed of light is no longer required to remain constant, and the velocity of space vehicles is no longer limited. The seriousness of

the implications this has for special relativity and space-time symmetry cannot be understated. Many others (Walton-1997 and Jefimenko-1997) have taken issue with the scientific methods and trains of logic that have been involved in interpreting special relativity theory with respect to limiting velocities and space-time dilation.

Carroll (1997a and b), taking a totally different mathematical approach, calculated that the velocity of light under the influence of a gravitational field is not restricted to c. From this conclusion, he asserted that space exists solely by virtue of the mass and energy contained in an object and its associated fields. His calculations indicate that the energy density of space falls off as the inverse fourth power of the distance from matter. The relationship between space energy density and the limitation on the velocity of light is analogous to atmospheric pressure and the sonic velocity limit. In less dense media, resistance factors are less influential. According to Carroll, velocities are therefore only limited by the energy of the power supply when used in regions of zero energy density. He has calculated that meson energy drives have the potential to achieve speeds twenty million times faster than the speed of light.

Froning (1997) also suggests a way in which propulsion and faster-than-light travel might be possible. According to his concept, the energy density of space itself can be changed around an object. If this is possible, then electric field pulsing may provide a means of changing the local energy density around a craft.

Classic Effects

In the earlier publications of ESJ, much attention was devoted to investigating T.T. Brown's claims of a connection between electricity and gravity. Experiments conducted by T.T. Brown indicated that suspended capacitors underwent linear thrust when a voltage was applied (Brown-1991a). In other experiments, Brown showed that aluminum saucers, 1½ -2' in diameter, suspended from tethers on opposite ends of a rotatable bar, would move rapidly when connected to a 50 - 150kV source (Brown-1991c). Brown and Bahnson did not find an electrogravitics connection, and subsequent testing of Brown's devices (Brown-1991b and Hall-1995), which tried to eliminate coulomb forces and ion winds, have led to two definitive conclusions: (1) The coulomb forces and ion wind were all but impossible to negate, but when they were nearly eliminated, little or no force remained. (2) Transient discharge of the high voltage terminals resulted in increased thrust levels, indicative of an electrical phenomenon, and not the electrogravitics interaction that Brown and Bahnson had sought.

The use of a motorized, sectorless Wimshurst generator (Yost-1994a) facilitated the duplication of historical electrostatic phenomena. Aluminum foil could easily be levitated in a vertically-oriented field between electrodes of the Wimshurst. A polypropylene sheet placed over one electrode shifted the position of the levitating objects nearer to the other electrode in orbits coinciding with the theoretical locations of maximum field intensity. Levitating objects always floated lengthwise, with their pointiest end down, and orbited horizontally with their rotational axis aligned with the theoretical lines of force. A chain, placed on a dielectric sheet and attached to the positive terminal of an electrostatic generator, whipped around violently when the negative terminal sparked nearby (Hall and Kulba-1996).

Electrical Beams

Schlieren imaging of the region between Wimshurst electrodes (Yost-1995a and b) has shown how electrostatic forces alter the density of the surrounding air. Sparks produce cumuloform pressure bursts from both terminals. When the negative terminal is fitted with a point or a small ball, a coherent thread-like stream is emitted. A single thread could also be made to emanate from the positive terminal, but threads from the positive terminal were substantially weaker than threads with negative origins. The dual threads do not seem to interact with each other. Subsequent experiments revealed that the movement of the thread was not influenced by the location or movement of the other electrode, g ...d, or a neodymium magnet moved in close proximity. A wire probe connected to a DC microammeter registered a current

of 50 μA in the stream, and nothing immediately outside it. A mechanical wind vane, similarly, remained stationary except in positions intercepting the stream, where it would spin rapidly. While the stream had momentum and current, it seemed to be electrically neutral. It showed slight perturbations when a small steel ball placed near was suddenly whipped away.

Electrical beams with different properties have been generated by other means. Morton (1991) created a beam by

placing a glass tube having a metal end plate on a charged Van de Graaff terminal. He observed that a spark jumped from the Van de Graaff to the end plate, which then emitted a beam. The beam charged a metal target at which it was aimed, as well as everything else in its path. Later, based on Morton's observations, Schlecht (1992) recreated the phenomenon with a more sophisticated device at the University Karlsruhe, Germany. This pulse device has generated energy beams which have been able to levitate talcum powder for brief instances. These beams were accompanied by electrostatic field effects and an obvious change in air pressure noted by experimenters at a distance of 4 m. This beam was not believed to be an ion wind because a neon lamp was 25% ignited and test balls exhibited attraction-repulsion behavior when placed in its path, and its ignition spark was not of the characteristic color and form of conventional ion propulsion sparks. The Wardenclyffe Tower, constructed by Tesla (c. 1905) was designed to oscillate high electrostatic charge on its dome-shaped electrode, which had a hole in its top for the projection of a beam toward the ionosphere. These experiments suggest possible new avenues for propulsion research.

Ion Thrusting

It is reasonable that hybrid electrical energy systems that use throw-away mass and enhanced ion thrusting systems may prove to be viable in the short-term. In such systems, the savings and advantages are attributable to the fact that electrical energy can be obtained from solar or nuclear resources, thereby reducing the quantity of throw-away mass required. Recent developments have led to the construction of a high-flying, solar-powered, earth-atmosphere craft with wing loadings as light as 0.7 lb/ft^2 (Aerovironment-1997). With wing loadings of 2 lb/ft^2, ultra-light craft powered solely by ion-type thrusting devices may be able to fly directly into orbit. Power and velocity profiles indicate that this is feasible. Craft of a large, circular, rotating disk design or of a tubular wing design look most promising.

Okress has patented (Okress-1966 and 1991) a pulsed, ionized gas thrusting technique which is believed to be more powerful than ion propulsion systems now in use by several orders of magnitude. The quasi-corona propulsion system would make ion thrusting competitive with conventional jet aircraft and make possible high-thrust electrical rockets for spacecraft. Okress' technique uses the principle of rapid, high-electrostatic-field pulses on the order of two nanoseconds. The short duration of the pulses prevents electrical breakdown from progressing down a chain of molecules. By controlling breakdown, very intense electrostatic fields, with potentials greater than 100 kV/cm, are produced for the acceleration of ionized molecules. Typical pressure differentials have been calculated to reach 30 lb/ft^2.

Cox has patented (Cox-1982, 1992a, 1992b and 1996) a non-ion thrusting technique whereby alternating electric and magnetic fields can accelerate a spinning polarized molecule or particle. Polarized molecules may be rotated, much like motor rotors, if placed in a reversing electrical field. The application of a phased pulse from a magnetic field, perpendicular to the axis of rotation causes the resulting Lorentz forces on both poles to act in the same direction for a net thrust. It is believed that this technique could provide a means of accelerating electrically neutral gases to produce thrust. The major drawbacks will be difficulties in overcoming the tendencies of molecules to ionize, and difficulties getting a sufficient number of molecules to align without thermally randomizing each others' orientations.

An electricity-related propulsion prospect is the water arc explosion (Hull, Graneau, Graneau, and Hathaway-1995a, 1995b and 1997). Careful experimentation has demonstrated that when 30 joule arc discharges from a 0.5 µF capacitor occur through 1cc of water, energetic, explosive thrusting results. The output from the reaction is so energetic, conventional conservation of energy equations indicated that the output energy was greater than the input. The latest information released indicates that the energy may be accounted for as the difference in the latent heats of vaporization for fog and water. It is theorized that so much energy is delivered to the water in so little time, the water does not have a chance to change the electricity to heat, but, more expediently, uses it to transform into an explosion of fog. Water arc explosions suggest that water may be used as a propellant for reaction mass; with electricity as the energy source.

Longitudinal Wave Generation and Transmission

The concept of electrostatic waves (otherwise known as longitudinal, ionization, potential, or scalar waves) has been all but forgotten since Maxwellian transverse electromagnetic waves became the focus of electrical research. Although much experimentation is still required to understand the properties of these waves, a few fundamental notions have been established (Jefimenko-1992). The well-known electrostatic field that exists between separated charges exerts repulsion

and attraction forces and polarizes neutral media and objects. It has no magnetic field associated with it. This field is referred to as a longitudinal field because variations in the intensity of an electrostatic field are transmitted longitudinally; that is, in the same direction as the disturbance (Yost-1992a). Longitudinal electrostatic waves can be created by any variation in the electrostatic field. Variations may be caused by (1) oscillating an object holding a static charge, (2) periodically varying the amount of charge on an object, or (3) suddenly changing the charge on an object, as with a pulse or spark discharge. Longitudinal electrostatic waves transmit only electrostatic potential energy, and are not, strictly speaking, physical ion transfer mechanisms.

The Wiggle Wand

The transmission of a potential wave may be illustrated by charging a plastic rod and moving it to and fro several feet from a ball antenna, which is connected directly to an oscilloscope (Yost-1992a and 1994b, Hall-1995 and 1996). The variations in the electric field, caused by the motions of the charged rod, or wiggle wand, create an electrodynamic wave. When the wand is wiggled very near the antenna, large voltage fluctuations are induced; sixteen feet away, fluctuations of several millivolts are still detectable (the field strength falls off as $1/r^2$). The dynamic wave form on the oscilloscope corresponds with great fidelity to the motion of the rod.

Additional wiggle wand experiments (Yost-1996), with a 300-foot length of polyethylene-coated #18 wire attached to the oscilloscope, caused fluctuations which have been attributed to polarization potential variations, since the circuit was open and no current flowed beyond that which might be explained by the displacement currents. Perhaps most interesting was the fact that oscillations of the electrostatic wand could be picked up by an antenna sixteen feet away, on the other side of a closed, wooden door (Yost-1997a). When the door was opened, the signal reception was much weaker; the wand had to be half as far in order to create signals of similar intensities. It would seem that intervening solid dielectric objects transmit electrostatic force with less dispersion, just as metal conductors transmit current with very little loss. In air and vacuum, the electrostatic force falls off according to the inverse square law. In solid dielectrics, however, charges polarize, facilitating the transmission of electric fields, much like conducting materials have been presumed to conduct electric charge. Deavenport (1997) also showed that a light bulb would oscillate in response to an electrostatic field on the other side of either a 1/4" thick Plexiglas™ plate, or a 1/8" thick glass dome.

These experiments support early claims made by Tesla that electrical energy can be transmitted by means of longitudinal electrostatic forces, the ground serving as the current conductor, and the air acting as a dielectric for the displacement current. The electrostatic field has the ability to polarize all atoms (metallic and dielectric). In the case of conductors, the polarization will cause a current to flow if the conductive material is in the form of a closed circuit. Thus, as Tesla said, potentials can be developed as standing waves on the earth, and power can be tapped by putting up a metal antenna.

Electrostatic longitudinal forces are believed to be analogous to acoustic longitudinal forces. Hartman (1992) showed how strumming the low E string on an amplified guitar, with approximately 25 watts of power, could cause a speaker, placed on the ground, to levitate for five seconds. Higher frequencies only vibrated the speaker, whereas distorted, lower frequencies could levitate the speaker as much as one centimeter above the ground. In a similar experiment, Yost (1992b) demonstrated the acoustically-induced motion of a pendulum-suspended speaker. No motion was detected with a steady, intense 20-40 Hz signal. However, careful pulsing of the signal caused the woofer to swing, and the amplitude of the swinging could be increased by delivering the pulses at times coinciding with the swing period. In other experiments, Hartman (1996) floated a speaker in a tub of water and observed that certain tones would scoot it across the surface of the water, if it was initially tilted to make the force against the water asymmetric. Hartman reported that the speaker would either jump, sit still, spin, or scoot, depending on the frequency delivered. These experiments have led to speculations that electrostatic longitudinal forces might be modulated similarly.

High-Intensity Electrostatic Field Generation

Tesla's insistence that the tower at his Colorado Springs laboratory was transmitting longitudinal electrostatic waves has not been well-accepted. Nevertheless, in a working analogue of Tesla's tower, created by Kovac (1991), the partial conversion of the high-voltage output of a Tesla coil to static electricity was demonstrated. By sending high voltage RF from a Tesla coil secondary through a mercury vapor rectifier tube surrounded by a steel pipe, Kovac was able to

accumulate an electrostatic charge on a ball electrode. This static field was, in turn, modulated into a waveform, representing the combination of an 8 Hz component and a 100 Hz component, by means of mechanical switches. The RF rectifier technique allows for higher power outputs from an electrostatic wave transmitter. This technique also permits the potential on an antenna to be modulated, indicating that it might be possible to set up resonant waves. Timing the electrostatic waves in a closed system, such as on the earth sphere, allows transmitted, longitudinal electrostatic polarizations to be reflected and to return to reinforce the excitation.

Research with Tesla coils (Hull-1993b) has been a constant source of fascination for experimenters. Hall (1992) observed attractive and repulsive responses for a variety of plastic and metallic objects suspended near a Tesla coil secondary that led him to conclude that the objects were acquiring a static charge. As early as 1991, Hull and his group, known as the Tesla Coil Builders of Richmond, noticed a buildup and retention of electrostatic charge on insulated coils and metallic objects located near an operating Tesla coil (Hull-1996). Controlled experiments were therefore devised to quantify the charge buildup on a distant, insulated, conductive target (Hull-1993a). Charges of 20 kV were detectable at distances up to nine feet away. Experiments set up with a fan positioned so as to blow the air-borne charges toward, and then away from, the collector showed that charging was at least partially due to the flow of ions, but that perhaps another, faster charging mechanism was operating as well.

Hull repeated the experiments, replacing the Tesla coil with a Van de Graaff generator. The instant the Van de Graaff was turned on, a voltage of 15 kV appeared on the remote collector. But, it was discovered that in a steady static field, the collector barely picked up a charge. It was then supposed that a spark or other rapid field variation might be responsible for setting up a wave of charge transmission. Electrical waves propagating with speeds far in excess of those attainable by ionic motions have been researched in-depth (Lagarkov and Rutkevich-1993). An experiment in 1930 (Lagarkov and Rutkevich-1993) revealed that a luminous wave, created by applying 180 kV across a long vacuum tube at 20 torr, moved with a speed of 5×10^9 cm/s. Because ions cannot move this rapidly, the high velocity was attributed to the propagation of an electric potential wave. A Russian patent application (Avramenko and Avramenko-1994) refers to the oscillations of free charges as the displacement current or longitudinal electrical wave, capable of efficiently transmitting power. Jackson (1962) devotes only two sentences in his classic electrodynamics text to longitudinal electrostatic fields.

Damm (1995 and 1996) has speculated that Tesla incorporated acoustic resonant criteria in the design and modulation of his tower at Shoreham, Long Island. The dimensions of the tower's components and their acoustic resonant frequencies are well-matched to the earth's electrical resonant frequencies. Tesla's notes mention that an electric pulse would traverse the earth's diameter and return with a period of 0.08454 seconds. He also claimed that lightning could resonate the earth electrically. In an investigation of multiple-stroke lightning, Yost discovered, as Tesla suggested, that the periods between flashes corresponded to simple harmonics of the earth's diameter; 1/4-, 1/2-, and 3/4-diameter time periods being most prevalent (Yost-1992c and Ogawa-1982). This suggests that the earth behaves as a giant dipole antenna, and that the electrostatic resonance of the earth was indeed a possibility. Tesla intended to transmit potential differences over the earth and build them up as resonant standing waves.

Spark Discharges

The spark discharge method of producing pulsed electrostatic waves is simple, most promising, and little understood. It is in this pulsed wave form that T.T. Brown's electrogravitic effects were thought to be enhanced. Recent developments with spark discharges have been made possible by engineering advancements with the Tesla magnifier made by Hull (1993b). The Tesla magnifier is a third coil, which Tesla used with some of his traditional coil setups. The magnifier serves as a free-resonance transformer for creating extremely high voltages at very low amperages. The magnifier coil is driven by the Tesla coil secondary. Very small magnifier coils, on the order of 4" in diameter by 12" long, are capable of producing 10-foot sparks, without heating or shorting, from a 6000 watt power source. Their output consists dominantly of an alternating electrostatic potential field.

Hull (1996) conducted a series of experiments involving the capacitive loading of Tesla coils. In one experiment, a coil was loaded until no sparking would occur. When the coil was turned on, a distant toroid used to collect electrostatic charge remained electrically neutral, while a neon tube at the same distance glowed intensely. When a thumbtack was placed on the terminal of the transmitting coil, sparks broke out, the collector toroid registered an immediate increase in

charge, and the neon tube remained unlit. It became evident that spark discharges were necessary if the electrostatic effects were to be observed. It is now believed that the Tesla coil can serve as a field emitter of pulsed potential to its surroundings. It is not difficult to produce by this means megavolts of potential and megawatts of impulse energy.

Further experiments with capacitive loadings (Hull-1996) suggested that capacitive coupling might be occurring. A coil system was set up so as not to spark. Nearby, a similarly-loaded, grounded coil, tuned to the frequency of the transmitting coil, was passively placed as a receiver and made to produce large sparks. Rotating the resonator through 90° resulted in no change in intensity, thereby demonstrating that the sparking was not due to electromagnetic induction. It was further noticed that the capacitive loading on the coils had a direct bearing on the degree of sparking. This indicated that tuned radio communication was not the sole means of energy transmission between the coils. In yet another experiment, two separated, ungrounded, passive, capacitively-loaded coils were conductively connected at their bases. When the active coil was operated nearby, sparking took place between the passive coils, which were acting as receivers, and an alternating current flowed through their connecting base wire. These phenomena demonstrate a potential for remote charging, which might be applicable to a craft and its immediate surroundings.

Experiments by Yost (1996), designed to explore the nature of the combined fields of a Wimshurst generator and a Tesla coil, revealed that when the output from an electrostatic generator was sprayed onto the ball terminal of a Tesla coil, the electrostatic field surrounding the Tesla coil was greatly enhanced and extended. In later experiments (Yost and Hull-1997), points were used to form a 0.01" spark gap. This gap joined the positive terminal of the Wimshurst generator to the base of an ungrounded coil which had a large metal bowl capacitor on top. When the system was operating, tiny sparks were observed to jump the gap. Four feet away, an antenna picked up strong signals from the bowl with high fidelity. Oscilloscope readings indicated that the antenna was pulse charging in less than 1 μs, with a positive charge that took 500 μs to decay. In other words, electrostatic potential was being impulsively transmitted. Electrostatic oscillations of 600 kHz, generated by the LC circuit, were superimposed on the exponentially decaying potential. The bowl on top of the magnifier coil had accumulated an intense static charge, which it retained even after the power source was shut off.

METHODS:

The electrostatic field variations are projections of longitudinal electrostatic forces, and not electromagnetic waves (Yost-1997b and Jefimenko-1992). There are no currents transmitted, nor any need for conductors in order for such forces to transmit. Instead, a displacement current develops within the confines of individual atoms, as polarization.

Spark discharge experiments hint that it might be possible to design a craft that could be launched by generating positive or negative pulses, provided it can produce a repulsive force in its surroundings. The demonstrated techniques will need to be enhanced in order to develop a high-power, polarized, phased wave capable of thrusting a craft. The electrostatic coulomb force is understood to fall off as the inverse square of distance. This relationship applies to the field around point static charges. The pulse discharging of large, dielectric surfaces seems to provide greater latitude for the development of coulomb forces which do not deteriorate according to an inverse square law. It is speculated that pulsed potentials carrying frequencies on the order of 100 MHz may allow electrodynamic longitudinal forces to be directed by a practical sized craft 10 meters in diameter.

It is not possible to focus a static force field (analogous to a constant pressure field). However, as with sound waves, it is thought possible to transmit and focus variations in the electrostatic field. Means of intensifying, transmitting, and pulsing oscillating electrostatic field variations have been demonstrated. The successful electrostatic propulsion system will need to have the ability to set up an intense electrodynamic field around the craft. This field will have a sharp, transient electrostatic field gradient capable of being propagated. In some instances, the intense charging of remote objects might be used for action-reaction force. Pertinent craft components will need to be sized so as to be resonant with each other and the surrounding fields. A means of adjusting the field on the craft must be employed to maintain resonance at differing velocities and differing distances from the craft. Thus, a method of pulsing, phasing, and directing electrostatic influence may be possible; and is preferable to forcing motion of the atmosphere at large, as is typical of ion propulsion. In any case, care must be taken to prevent voltage breakdown from shorting out and defeating the intense, oscillating field.

If the earth were to be oscillated at its resonant frequency, then a craft might be propelled by self-modulating its polarity to interact with the earth's alternating coulomb attractions and repulsions. The ability of air to behave as a conductor for high-voltage, high-frequency fields might assist in this endeavor (Yost-1996). Standing wave resonant fields would need to be developed, somewhat in the fashion described by Tesla in his early experiments to produce earth electrical resonance. This technique might be limited to altitudes within the extent of the earth's atmosphere.

In another means of propulsion (Yost-1996), an ambient electrostatic field of an oscillating polarized nature might be developed in the medium surrounding a craft. A ground transmitter might establish such an ambient field, which would be neutral for most purposes, but propulsive close to a craft capable of alternating its polarity in proper phase with the surrounding longitudinal polar oscillation (Yost-1992a). It may also be possible that the craft itself could induce a resonant polarization on its surroundings, with which it would react repulsively (Yost-1997b).

Another propulsion mechanism would involve intense static potential transients built up on the craft (Yost-1997b). The pulses could be of the same or alternating polarities. The craft would be powered by discharges that would polarize its lower side. A series of pulses would set up a train of gradually-dissipating potential waves. Should the waves be near the ground, they would set up a polarization field in the ground molecules. It may be possible that shifted-phase polarization of boundary surface molecules in the immediate vicinity of the ship will provide a repulsive thrust. There appears some possibility that a sufficiently-intense pulse of nonlinear electrostatic fields will cause nearby molecules to assume an inverted polarity, opposite to the polarity they normally would assume in response to the charge on the bottom of the craft. If this is the case, intense pulsing may simply produce a repulsion force against the surroundings.

CONCLUSIONS:

Even with field propulsion techniques, the principles of action/reaction and conservation of momentum still apply. However, with field propulsion techniques, it is not necessary to throw away mass to achieve action and reaction. To develop fields, generators still require the expenditure of large amounts of energy. The energy must be converted into an electric force field which can react against the surrounding medium or objects. Thus, masses are moved relative to one another in accordance with established Newtonian principles, which state that the center of mass of a system remains constant. The only way to move, according to this hypothesis, is to react against the surrounding medium (objects, fields). The motion of one object in this space requires the rearrangement of other objects.

For liftoff, a repulsive force is required to act against the immediately surrounding objects, like the earth or the atmosphere. The critical issue is whether or not the electric fields (charges) can be manipulated in order to produce an interacting repulsive/attractive force at a distance to propel a craft. This might be accomplished by charging the craft and surroundings with like charges. Repulsion might also be accomplished by polarizing the craft out of phase with its surroundings using oscillating fields. The latter technique is most desirable.

The prospective system will require a lightweight craft with a large surface area to accommodate electrical storage and interactions. Some means of on-board capacitive discharge will be employed to transfer a large potential difference (energy density gradient) to and from the ship's surface. The medium surrounding the craft will require an electrostatic field against which the ship may react. The field in the medium may be generated by the craft or a ground transmitter. Strong, pulse discharges will probably be the best technologically feasible method of creating the necessary field intensities and gradients. The frequency of the dc pulses will need to be brief to prevent the propagation of electrical breakdown. To overcome inverse-square energy losses, the field interactions will need to occur in close proximity to the ship. It is possible that focusing techniques may be developed with the ability to direct intensities over extended distances. At least one field must be oscillated to be continually pulled by the polarities of the other field. The phased oscillation of the fields must be continually modulated in order to coordinate all the constantly-changing, interactive variables involved in this attractive/repulsive thrust mechanism.

Individual components of the envisioned electrostatic propulsion systems have been demonstrated to work on a small scale. These include the generation of electrostatic fields capable of levitating small objects and thrusting with small forces, the existence of a beam of electricity capable of producing mechanical force, the transmission of charge to conductively isolated objects in the laboratory, the intensification of longitudinal electrostatic fields by means of Tesla magnifiers, and the oscillation of these fields by various means. The next step in experimentation will be to perform tests

on a larger scale with more powerful equipment. The implementation of full-scale potential field propulsion systems is dependent on the affirmative answers to the following questions:

• Can the conversion of Tesla coil magnifier oscillations to electrostatic charge be made sufficiently efficient?
• Can the longitudinal electrostatic forces be intensified, directed, and extended?
• Can they be asymmetrically directed?
• Can polar fields between separated objects be phased to set up continuous mutual repulsion against surrounding objects, fluids, gases, or space fields?

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Can a "Hyperspace" really Exist?

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Abstract

The idea of "hyperspace" is suggested as a possible approach to faster-than-light (FTL) motion. A brief summary of a 1986 study on the Euclidean representation of space-time by the author is presented. Some new calculations on the relativistic momentum and energy of a free particle in Euclidean "hyperspace" are now added and discussed. The superimposed Energy-Momentum curves for subluminal particles, tachyons, and particles in Euclidean "hyperspace" are presented. It is shown that in Euclidean "hyperspace", instead of a relativistic time dilation there is a time "compression" effect. Some fundamental questions are presented.

1. INTRODUCTION

In the George Lucas and 20th Century Fox Production of STAR WARS, Han Solo engages a drive mechanism on the Millennium Falcon to attain the "boost-to-light-speed". The star field visible from the bridge streaks backward and out of sight as the ship accelerates to light speed. Science fiction writers have fantasized time and time again the existence of a special space into which a space ship makes a transition. In this special space, objects can exceed the speed of light and then make a transition from the special space back to "normal space". Can a special space (which I will refer to as hyperspace) exist? Our first inclination is to emphatically say no! However, what we have learned from areas of research such as Kaluza-Klein theory[1], Grand Unified supersymmetry theory [2], and Heterotic string theory [3] is that there indeed can be many types of spaces. Quantum Geometrodynamics indicates (as a theory) that space-time geometry may be fluctuating at distances within the Planck length [4]. Moreover, not only can space have different geometries but it can have enormous virtual energy content as a result of the zero-point quantum fluctuations of the electromagnetic field of the vacuum. [5] *Thus, it is not unreasonable to at least explore the possibility that nature may provide a four-dimensional or higher dimensional space-time which exists throughout the universe and is physically accessible for the motion of particles (such as electrons, protons, photons, or neutrinos) at speeds beyond the speed of light.* This subject would tantamount to an investigation of enormous scope, but here the author will present a brief discussion of one of the simplest space-time geometries in which he is particularly interested.

2 THE EUCLIDEAN-FOUR SPACE

Consider a Euclidean four-space geometry [6] expressed by the line element:

$$(ds)^2 = (dt)^2 + \sum_{\mu=1}^{3} (dx^\mu)^2 \tag{1}$$

The coordinates of a space-time point in this space , (x^0, x^1, x^2, x^3), are defined as cartesian coordinates (t, x, y, z). Here, the temporal coordinate x^0, is really ct, where t is time as measured on a clock by an observer in an inertial reference frame S, and c (the speed of light) has been set equal to one. We can ask the question Is there a set of coordinate transformations $S \rightarrow S'$ (where S' is moving at a speed v relative to S) that leaves $(ds)^2$ invariant? The answer is yes. Such a set of transformations is given by:

$dt' = \gamma (dt + v\,dx)$ (2)

$dx' = \gamma (dx - v\,dt)$ (3)

$dy' = dy$ (4)

$dz' = dz$ (5)

$\gamma = (1 + v^2)^{1/2}$ (6)

Here v is really the relative speed of S' with respect to S expressed as a fraction of the speed of light. Although the above transformation equations look very similar to the Lorentz transformations they are not. Equation (2) has a plus sign where the corresponding Lorentz transformation has a minus sign. The factor γ has a plus sign, whereas Lorentz transformations would have a minus sign. Note that the set of transformations (2) through (5) do *not* go undefined as $v \to c$.

3. ELECTROMAGNETIC FIELD THEORY IN EUCLIDEAN FOUR-SPACE

Now [6] has found that a complete set of covariant electromagnetic field equations can be formulated for this Euclidean four-space representation of Minkowski space-time. It appears superficially on the surface as though there is a parallel space with Maxwell-like fields. But we can write the "new" field equations in their 3-space plus time representation and get the following:

$\nabla \bullet E = 4\pi\rho$ (7)

$\nabla \bullet B = 0$ (8)

$\nabla \times E = \partial B/\partial t$ (9)

$\nabla \times B = 4\pi J + \partial E/\partial t$ (10)

The obvious change is in (9) where there is a sign modification on the differential equation that expresses "Faraday's Law". This sign modification is all-important. It changes all of electrodynamics as we know it. Firstly, there is a reverse of Lenz's Law. The magnetic field produced by an induced current is in a direction such as to *reinforce* the original change in magnetic flux that produces it. This would increase the total magnetic flux through a loop, which, in turn, would increase the emf. This would lead to a "run-away" magnetic flux and emf. Secondly, it is shown in [6] that there will be a self-damping of mono-chromatic electromagnetic waves in the vacuum. Thirdly, the electromagnetic wave-equations in the presence of sources (charge density or current density vector) have a general solution that looks like an "advanced" and "retarded" time solution. However, this is a Euclidean-four space "analog" of classical electrodynamics since it contains imaginary terms. Specifically, the two solutions are:

$$\Psi(x,t) = \alpha \int d^3x' \; \frac{f(x', t - i|x-x'|)}{|x'-x|}$$ (11)

$$\Psi(x,t) = \alpha \int d^3x' \; \frac{f(x', t - i|x-x'|)}{|x-x'|}$$ (12)

where $\Psi(x,t)$ is either the scalar potential or a component of the magnetic vector potential. The " f " function represents the source density (either charge density or the current density vector respectively). The factor α is a constant.

Question 1: The E and B fields do not appear to be the electric and magnetic fields we know. Could we "fix-up" the Maxwell-like equations (7) through (10) so that the difficulties are surmounted but the Euclidean four-space retained? What type of electrodynamics would emerge? This is a formidable problem and is yet to be solved.

Question 2. What equations of relativistic dynamics would hold for particles moving within Euclidean four-space? Some progress can be made on question (2).

4. EFFECT ON TIME MEASUREMENTS IN EUCLIDEAN FOUR SPACE

Consider a pair of events such as the emission and detection of an atomic particle. Suppose that an observer in a reference frame S' moves along with the particle at the same velocity so that the particle is observed to be "at rest" with respect to the observer in S'. We can re-introduce "c" in the line-element (1), so that dx^0 is given by cdt. For the observer co-moving with the frame S', $v' = 0$, and the observer may define a proper time so that $c\,d\tau = ds$. This leads directly to the result that .

$$dt = d\tau\,(1 + v^2/c^2)^{-1/2} \tag{13}$$

This result is strange indeed since there is now a *time compression* effect from relative motion rather than a time dilation effect as in Special Relativity. Equation (13) means the following:

The apparent time interval dt (the interval between the two events as measured by an observer in the S reference frame) appears to be shortened with respect to the time interval (dτ) as measured in the S' frame that is co-moving with the particle. Another way to interpret this result is to say that clocks appear to speed up when they are in relative motion within Euclidean hyperspace.

5. MOMENTUM AND ENERGY

We can derive the formulas for total Relativistic Momentum and Energy of a free particle in "Hyperspace" by calculating the components of the covariant four-momentum vector. [7] If m is the rest mass,

$$P^\mu = m\,dx^\mu/d\tau$$
$$= m(dx^\mu/dt)(dt/d\tau)$$
$$= mv^\mu(1 + v^2/c^2)^{-1/2} \tag{14}$$

$$E = cP^0 = mc\,(dx^0/dt)(dt/d\tau)$$
$$= mc^2(1 + v^2/c^2)^{-1/2} \tag{15}$$

Resulting in:

$$E^2 + c^2p^2 = m^2c^4 \tag{16}$$

The speed of light has been explicitly represented as c to show similarity to the formulas of Special Relativity. Note that the momentum and energy analogs in Euclidean hyperspace do not go unbounded at the point v=c. Moreover, E and P remain real and bounded as $v \to \infty$, specifically, $P \to mc$, and $E \to 0$. No hypothesis of imaginary rest mass (as in tachyon theory [8]) is required for P and E to remain real as $v \to \infty$.

At this point the reader may ask what is the graph of equation (16) ? For the purpose of easy comparisons and graphing ease, once again we set c equal to one. Equation (16) becomes:

$$E^2 + p^2 = m^2 \tag{17}$$

which is the equation of a circle. Where is this circle found?

Graphs of: $F^2 - p^2 = m^2$ Minkowski space-time version (massive particle)   (18)

           $E^2 - p^2 = -m^2$ (m→im)   Version of above relation for Tachyons   (19)

           $E^2 + p^2 = m^2$ Euclidean Representation of space-time ("Hyperspace") (20)

           $E^2 - p^2 = 0$ Minkowski space-time version (for photons)   (21)
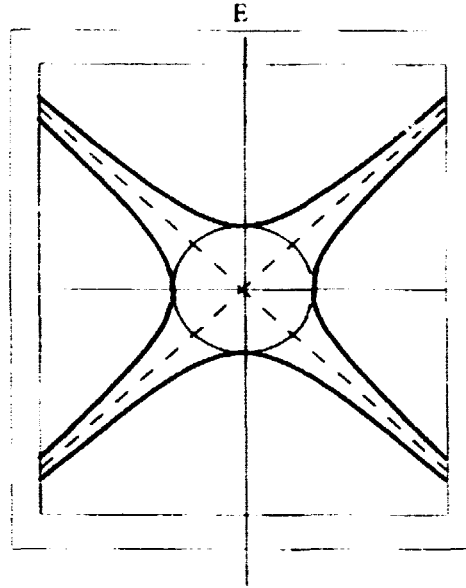
The diagonal asymptotes (dotted lines [9]) are the graphs of the energy-momentum equation for photons, since for photons, the "rest mass" is zero, or m=0, leaving us with the equations of lines.

For photons,

$$E^2 - p^2 = 0 \tag{22}$$

Which implies,

$$E = -p \tag{23}$$

and,

$$E = -p \tag{24}$$

The graph for E in the two equations intersects the origin at a 45 degree angle. There are four hyperbolas. The upper hyperbola represents particles of positive rest mass and positive relativistic energy moving at subluminal speeds. The hyperbola to the right represents tachyons of either positive or negative relativistic energy, whereas the lower hyperbola (on the bottom) represents particles of negative relativistic energy at subluminal speeds. The hyperbola to the left represents tachyons with either positive or negative relativistic energy. The tachyons are a class of particles that must always move at a speed greater than the speed of light in order to exist and have imaginary rest mass. However, at the center of the graph is the circle which is the plot of equation 17. It touches all of the E vs. P hyperbolas at exactly one point. Imagine sub-atomic particles moving in Euclidean "hyperspace". Such particles will have strictly bounded relativistic momentum and energy for each value of proper mass m. (rest mass) However, particle speed is free to assume values anywhere within the interval $[0, \infty)$.

The particle speed can exist anywhere within [0, ∞) without creating infinities in the coordinate transformations, relativistic momentum or relativistic energy. Moreover, when v > c, momentum and energy remain real valued. There is, however, a notable exception to the rule, namely the case of photons.

Note the interesting property of Euclidean four space when m=0. This leads to the solutions for E given by:

$$E = - i\,p \qquad (17)$$

and

$$E = + i\,p \qquad (18)$$

Photons (particles with zero rest mass) would have imaginary total relativistic energy in Euclidean four-space.

6. FINAL REMARKS

More study is needed in "superluminal physics" to understand it at a level deeper level. Profound questions await an answer. Can we re-formulate the theories of electromagnetism and gravitation to be consistent with the Euclidean representation of space-time? Would major paradoxes remain or could they be eliminated? What physical principle would have to be operable in nature so that particles could make transitions into and out-of hyperspace? The following hypothesis is put forth by the author:

It is believed that there exists a "unified theory" of superluminal physics in flat space-time which can contain the theory of Tachyons, complex speed [10], and Euclidean four-space. But what is it?

ACKNOWLEDGEMENTS

REFERENCES & NOTES

[1] E. David Peat, "Superstrings and the search for the Theory of Everything", Contemporary Books, Chicago/New York, 1988. (See Chapter titled "Closed or Open Loops", pg.115, Para.3)

[2] See Ref.[1], pg.113, "How many dimensions does a theory need?"

[3] See especially Ref.[1], "The shadow universe", pg.147.

[4] C.W. Misner, K.S. Thorne, J.A. Wheeler, GRAVITATION, W.H. Freeman & Co., 1970 & 71, Sec.43.4, pp. 1190-1194. "Fluctuations in Geometry"

[5] For a very good tutorial on zero-point fluctuations of the elect omagnetic field and its basis in theory, See: R.L. Forward, "Mass Modification Experiment Definition", PL - TR - 96-3004. Phillips Laboratory Propulsion directorate, USAF Materiel Command. Feb. 1996.

[6] Zampino,E., "A Brief Study on the Transformation of Maxwell Equations in Euclidean Four-Space", In Journal Math Physics, Vol.27, N.5,, p.1315-1318, (May 1986).

[7] Keith R. Symon, MECHANICS. Addison-Wesley Publishing Co., Sec.14.2, pg.548 & 550.

[8] G.Feinberg, "Possibility of Faster-than-light particles", Phys. Rev., Vol. 159, No.5, 1089-1105, (1967)

[9] The dotted lines which denote the diagonal asymptotes for E vs. P do not imply discontinuity of the function and have been dotted simply to distinguish curves visually.

[10] C. Asaro, "Complex speeds and special relativity", Am. J. Phys. 64, (4), April 1996, pp. 421-429.