EVALUATION OF PARAMETERS FOR PARTICLES ACCELERATION BY
THE ZERO-POINT FIELD OF QUANTUM ELECTRODYNAMICS

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1. Preliminaries. That particles may be accelerated by vacuum effects in quantum field
theory has been repeatedly proposed in the last few years\(^1\)-\(^{10}\). A natural upshot of this
is a mechanism for cosmic rays (CR) primaries acceleration\(^2\)-\(^3\),\(^7\)-\(^{12}\). We have been con
cerned with a mechanism for acceleration by the zero-point field (ZPF) when the ZPF is
taken in a realistic sense (in opposition to a virtual field)\(^2\)-\(^3\),\(^7\). Originally
the idea was developed within a semiclassical context\(^2\)-\(^3\). We used the classical Einstein-
Hopf model (EHM) to show that free isolated electromagnetically interacting particles per-
formed a random walk in phase space and more importantly in momentum space when submitted
to the perennial action of the so called classical electromagnetic ZPF\(^1\). The Einstein-
Hopf drag force provided the counteracting dissipation which vanished because of the ZPF
Lorentz-invariance. The model could be applied to polarizable particles like protons and
nuclei. For monopolar particles like electrons it could be shown that there would be a
quenching of the acceleration due to a time dilation effect associated to the ultra-
relativistic oscillation of the center of charge of the particle around the center of mass.
This was reminiscent of zitterbewegung but in the context not of an intrinsic but of a
vacuum effect.\(^5\) Energy spectra of the accelerated particles could be derived assuming
several presumably extant dissipation mechanisms in intergalactic space (IGS) like inter-
particle collisions, bremsstrahlung, inverse-Compton collisions and cosmic expansion (CE)
\(^2\),\(^3\),\(^7\). IGS particle densities were taken at \(10^{-5}-10^{-7} \text{ cm}^{-3}\). The cut-off in the energy
spectrum imposed by CE could be avoided if there was enough magnetic confinement within
the magnetic cavities of superclusters so that particles would not be adiabatically cooled
\(^7\) by CE.

2. Quantum Version of the Einstein-Hopf Model. In order to check if the ZPF acceleration,
originally predicted semiclassically, also occurs within ordinary Quantum Electrodynamics
(QED), one should develop a quantum version of the EHM\(^8\)-\(^{12}\). The original EHM considered
a linear dipolar oscillator, constrained to vibrate parallel to the \(z\) axis, mounted on a
particle restricted to move unidimensionally along the \(x\) axis\(^13\),\(^14\). Such a model was
only good for discussing matters of principle\(^13\),\(^14\). We had to extend the model to three
dimensions in the vibrations and three dimensions in the translations\(^2\). The linearity
assumption could be relaxed\(^15\). Recently we have developed a quantum version\(^8\),\(^{12}\) of the
EHM by means of the Abraham-Lorentz operator equation proposed by Moniz and Sharp\(^16\)
in their nonrelativistic approach to QED. Among several desirable features this approach
has the advantage of being nonperturbative in its approximations, a real advantage when
dealing with the divergent energy spectrum of the ZPF.

3. Acceleration in the Time Symmetric Zero-Point Field. With the quantum model above we
show that if the ZPF is represented as a time symmetric background random field, there is
acceleration\(^12\). The time symmetry of the ZPF suggests itself naturally if one is willing
to preserve the time constancy of Planck's constant \(\hbar\) in an expanding Universe where the
ZPF is a background field tied to particles, i.e., if the ZPF is not a free field but if it
is generated by the motion of charges in the Universe as is usually assumed in Sto-
chastic Electrodynamics\(^17\). So, one constructs the ZPF by superimposing half-advanced
and half-retarded plane wave operators as follows from simple second quantization of Wheeler and Feynman's radiant absorber theory. The resulting average translational energy growth per proton is given by

$$\langle \frac{dE}{dt} \rangle = \frac{15c}{4\pi} \int_0^\infty d\omega \left( \frac{\hbar \omega}{Me^2} \right)^2 \left| \Gamma M \omega \right| \left| \hbar \omega \right| |g|^2$$

(1)

where $\alpha$ is the fine structure constant, $e$ and $M$ are the proton charge and mass respectively, $\Gamma M = 2e^2 / 3Me^3$ is the associated Abraham-Lorentz time parameter, and

$$g = \left( \delta + i\sigma \right)^{-1}$$

(2)

with

$$\delta = \frac{m}{M} \left( \frac{1}{\omega^2/\omega} - \frac{m}{M} \right)^{1/2} - 1$$

(3)

$$\sigma = \left( \frac{\Gamma M}{3} \right) \sum_{s=0}^{\infty} \frac{(8s + 9)(4s + 1)!}{(s + 1)(2s + 3)!(2s)!} \left( \frac{\omega}{\omega_c} \right)^{2s}$$

(4)

where $\Gamma M = \Gamma M (M/m)$, $m$ is the equivalent mass of the entity that oscillates inside the proton. The summation results from going to the point particle limit and $\omega = mc^2/k$ is the corresponding Compton frequency. In practice one may take $mc^2$ to be approximately equal to a few MeV (H. Leutwyler, personal communication), and in principle $m$ cannot be smaller than the quark's rest mass.

4. No Acceleration in the Time-Asymmetric Zero-Point Field. If the ZPF is represented as a time asymmetric expansion of plane waves, it can be rigorously shown at least up to the first iteration in the quantum EHM, that no acceleration takes place and $< dE/dt > = 0$. This result is to be expected if internal thermodynamic consistency of QED is demanded but one has to pay the price of not having a clear origin for the ZPF and of giving up interesting vacuum effects.

5. Evaluation of Parameters. When a Fokker-Planck equation is established for a dilute $(10^{-5} - 10^{-7}\text{cm}^3)$gas of protons under the influence of the ZPF plus a thermal background it can be numerically shown that the ensuing very long relaxation time (much longer than the age of the Universe) implies that the mechanism of Section 3 works efficiently up to inelastic inverse Compton collisions energies $(10^{18} \text{ eV}$, pair production) implying that other dissipation mechanisms like those mentioned above should be invoked to stabilize the energy spectrum of particles. The correspondence between the semiclassical $< dE/dt >$ and the quantum $< dE/dt >$ of Section 3 is quantitatively very good. All the previously proposed preliminary propagation models may then easily be adapted to the quantum case. Numerical evaluation of $< dE/dt >$ has been performed for a wide range of values of $m/M$ (or $\omega$). The fitting of the model to times consistent to expected CR propagation times taking care of the mentioned Greisen-Zatsepin effect is easily done for a rather wide margin of values of $\omega$ (or $m/M$). Unfortunately there is a paucity of data and of theoretical numerically tractable results on the proton polarizability response at the ultrahigh ZPF induced excitations frequencies that are expected.

6. SUMMARY. The acceleration mechanism was originally established semiclassically using the EHM in a classical stochastic version of the ZPF. The acceleration was an
upshot of the Lorentz-invariance of the ZPF spectral energy density. By a quantum version of the EHM we have shown within QED that acceleration occurs for the time-symmetric version of the ZPF\textsuperscript{7,12} but not for the time asymmetric (retarded) version\textsuperscript{12}. We hope this opens the way to an important new class of candidates for sources of acceleration of particles in the IGS, namely vacuum effects in quantum field theory.

7. Postscript. This postscript is written for the theoretically minded reader. We have performed the second quantization of the one half-advanced plus one half-retarded radiation in the Wheeler-Feynman absorber theory.\textsuperscript{16} No attempt however has been made at a full quantization of an action at a distance theory which because of troublesome boundary conditions is not easily quantizable as is well known\textsuperscript{22}.

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References
21. See, e.g., Gasser J. and Leutwyler H., Quark Masses (U. of Bern, 1982) preprint;
Leutwyler H., On the Status of QCD (U. of Bern, 1982) preprint; for a more detailed exposition see Flamm D. and Schöberl F., Introduction to the Quark Model of Elementary Particles (Gordon and Breach, New York, 1982).