N 69 10524
NASA CR 97482

UNIVERSITY OF HOUSTON

DEPARTMENT OF PHYSICS

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PROGRESS REPORT

March 1, 1968 - October 1, 1968

SPACE RELATED

TECHNICAL INVESTIGATIONS

NASA GRANT NGR-44-005-022

OFFICE OF GRANTS & RESEARCH CONTRACTS

NASA - OSSA

October 1968

Alvin F. Hildebrandt

This progress report constitutes both a supplement to the final progress report submitted by Dr. John W. Kern and a continuing progress report of present work with Dr. Alvin F. Hildebrandt, Principal Investigator. Since the issuance of the final report under Dr. Kern, M.S. thesis and Ph.D. thesis have been completed under the program. An up-dated summary of all publications of work performed under the grant is attached. Ten copies of reprints of each paper not submitted previously will be transmitted with this report.

The bulk of the work now in progress is that concerned with the study of Atomic Processes and Solid State Physics and the Plasma Studies. This work is outlined in the accepted proposal covering the present period. The work is well under way as the remainder of the report will show and results of the new work are already being written up for publication. The funds are being spent as outlined in the proposal and no major adjustments are anticipated.

Questions regarding the work described in this grant may be directed to Dr. Alvin F. Hildebrandt, Associate Professor, Department of Physics, University of Houston, Houston, Texas 77004, (713) 748-6600, extension 697 or 691. The investigators named in the body of the report may be contacted individually regarding their work at the same address.

1. Low Temperature Physics, Dr. Alvin F. Hildebrandt, Associate Professor of Physics.

a) Critical Velocities in Superfluid Helium Flow. H. E. Corke and A. F. Hildebrandt.

Much critical velocity data reported has been only a side light from other investigations, and there is wide differences as to the values and to the conditions under which the fluid goes critical. This is especially true in wide channels (10^{-3}cm). A good study of critical velocities has been performed by Van Alphen[1] where he reports a critical velocity dependence upon channel width of $d^{-1/4}$ and no temperature dependence below about 2.14°K. His explanation for previous discrepancies is that in other experiments there was not pure isothermal flow and the normal fluid becoming turbulent was mistaken for superfluid critical velocity. This could be true in some cases; however, other critical velocity measurements reported for isothermal flow experiments differ somewhat from his results, and include temperature dependence. Our previous data, from pressure measurements in pure superfluid helium flow,[2] suggests some temperature dependence for critical velocities and indicate a lower critical velocity than Van Alphen for comparable channel widths. A comprehensive experimental study is under way to determine critical velocities in wide channels as a function of temperature, channel geometry, channel endeffects, flow conditions (acclerations etc.), time dependence, and normal fluid velocity from zero to above turbulance.

The apparatus will utilize a thin ($\sim 10^{-4}$cm) aluminum foil pressure detector. The aluminum foil is stretched over an aluminum base with about 10^{-3}cm clearance to form a capacitor. This capacitor is part an L-C tank circuit in a back diode oscillator. Fluid flowing over the outside of the foil reduces the outside pressure ($P=1/2\ \rho_s V_s^2$) lifting the foil away from the aluminum base and decreasing the capacitance, which changes the oscillator frequency. Calculations indicate that a pressure sensitivity of better than 10^{-5}dynes/cm^2 can be obtained, or less than .05 cm/sec flow velocity can be detected. An initial foil velocity detector has been tested (using a previous oscillator[2] which is not as stable as the back diode osc.) and velocities below 1 cm/sec were detected. The back diode oscillator has now been built and initial testing indicates it will be stable, when at liquid helium temperatures, to within a few cycles/sec for five or ten minutes. With this oscillator and a refined foil pressure detector now under construction it is anticipated that velocities below .1 cm/sec will be detectable, which meets our sensitivity requirements to measure critical velocities. Rectangular and round critical velocity channels are being built for an initial check on critical velocity versus channel geometry for a channel characteristic depth of .05 cm.

b) Entrainment of Second Sound in Steady State Counter Flowing Normal and Superfluid Helium II. Earl M. Johnson and A. F. Hildebrandt.

Modification of the experimental apparatus was completed such that data could be obtained at lower temperatures.

Additional data was obtained and this data was included in a manuscript that has been sent to the Physical Review for publication. The abstract follows:

The velocity dependence of second sound in liquid helium was measured as a function of the relative velocity ($\vec{v}_n - \vec{v}_s$), where $\vec{v}_n$ is the normal fluid velocity and $\vec{v}_s$ is the superfluid velocity. The experimental technique consisted of measuring the time of flight of a second sound pulse in steady state counter flowing normal and superfluid for subcritical velocities. The results are in agreement with the theoretical predictions of Khalatnikov.

c) Flux Quantization and the Vector Potential. Thomas N. C. Tsien and A. F. Hildebrandt.

Research effort has been directed in the past few months in studying induction phenomena in rotational frames. Voltages observed in a unipolar are found to be explainable in terms of a non-local vector potential description. This involves a reconsideration of the Lagrangian of a charged particle in a magnetic field. Two manuscripts are in preparation for publication.

References

1. W. M. Van Alphen, G. J. Van Harsteren, R. De Bruyn Ouboter and K. W. Taconis, Physics Letters 20, 474 (1966).

2. H. E. Corke and A. F. Hildebrandt, Physics of Fluids, Vol. II No. 3, 465, Mar. (1968).

2. Solid State Physics. Dr. D. C. Rich, Professor of Physics

Theory[1,2] predicts that the strong interaction between the conduction electrons and phonons in a semimetal manifests itself as changes in the velocity of sound as well as in the attenuation coefficient of the wave. In particular, if the electrons are given a drift velocity in the direction of sonic propagation greater than the velocity of sound, then acoustic amplification should occur. Simultaneously, large changes in the velocity of sound should also be observable.

The following report discusses the theoretical bases for these effects, and presents the results of an attempt to measure the predicted velocity shift experimentally. Although positive results were not achieved, the experimental results are interpreted within the existing theory. Further, a detailed description of the experimental apparatus and technique is presented.

During the current contract period, work on the properties of metals has continued using magnetoacoustic techniques. The electronic contribution to the acoustic properties of a medium can be calculated by writing the equation of motion for the medium and solving for the dispersion relation. The basic equation of motion is

$$\rho \frac{d^2\xi_i}{dt^2} = \partial T_{ij}/\partial x_j \qquad (1)$$

where ξ_i is the elastic displacement and T_{ij} is the stress tensor. In the absence of phonon-electron interaction,

$$T_{ij} = C_{ijk\ell} S_{k\ell} \qquad (2)$$

where

$$S_{k\ell} = \frac{\partial \xi_k}{\partial x_\ell} \qquad (3)$$

is the strain tensor. In the simple case of an isotropic medium the dispersion relation is

$$\omega = ks \qquad (4)$$

where

$$s = (c/\rho)^{1/2} \qquad (5)$$

is the velocity of the wave.

Electron-phonon interactions are inserted into the equations by appropriately altering the stress-strain relations, eq. (2). Where the electron-phonon coupling is via a deformation potential, eq. (2) has the form[1]

$$T_{jk} = C_{jk\ell m}S_{\ell m} - \sum_i n_i C^i_{jk} \tag{6}$$

where C^i_{jk} is the deformation potential tensor for carriers of type i and carrier density n_i.

The equation of motion is then, for a one-dimensional medium,

$$\frac{d^2\xi}{dt^2} = S^2 \frac{d^2\xi}{dx^2} - \sum_i C_i \frac{\partial n_i}{\partial x} \tag{7}$$

This can be solved by noting that $\xi \propto \exp[i(qx-\omega t)]$, where ω, q are the frequency and wave number of the sound wave and by setting

$$n_i = n_i^o + n_i^1 \tag{8}$$

where n_i^o is the density of carriers in the absence of the sound wave and n_i^1 is a perturbation, also assumed proportional to $\exp[i(qx-\omega t)]$. The carrier densities are written in terms of the respective current densities by means of the equations of continuity and the current densities can be related to externally applied electric and magnetic fields by means of constitutive relations derived from manipulation of the Boltzman transport equation. When this complicated process is carried through[2], the desired dispersion relation is obtained for longitudinal waves:

$$\omega^2 = q^2 s^2 \left[1 + \frac{iq^2(C_e+C_p)^2}{2\rho e^2 \omega s^2}\sigma'_{11}\right] \tag{9}$$

where σ'_{11} is an effective conductivity in the direction of propagation and includes effects of external fields. The velocity of sound is the real part of ω/q; this gives[3] for the normalized charge in s,

$$\frac{\Delta s}{s_o} = \frac{q^2(c_e+c_p)^2}{\rho e^2 \omega s_o^2}\,\mathrm{Im}(\sigma'_{11}) \tag{10}$$

Substitution of σ_{11}' into eq. (10) yields

$$\frac{\Delta s}{s_o} = \frac{1}{4}\,\frac{N_o m}{\rho}\,\left(\frac{v_F}{s_o}\right)^2\left(\frac{C_n+C_p}{mv_F^{\,2}}\right)^2 (q\ell)^2 \times \left[\frac{\mu^2(\omega_c\tau)^2 + 1/3\,(v_F/s_o)^2}{\mu^2(\omega_c\tau)^4 + 1/9\,(q\ell)^2(v_F/s_o)^2}\right] \qquad (11)$$

where ρ = density of material

s_o = velocity of sound in absence of strong interaction

N_o = carrier density

m = effective mass of electron

v_F = Fermi velocity

τ = relaxation time of electron in material

ℓ = mean free path of electron in material

$\omega_c = eB/mc$ = cyclotron frequency of electron in field B

q = sound wave number = $2\pi/\lambda$

$\mu = 1 - v_D/s_o$

C_n, C_p = deformation potential of electron, hole.

Inserting values of the parameters appropriate for bismuth gives $s/s_o \sim 10^{-1}$ at $v_D = s_o$, so the effect should be easily observable. As an example, figure 1 is a plot of the relative velocity change as a function of v_D/s for X = 0.1 and $\omega_c\tau = 100$.

During the current reporting period, work has continued on an experiment to measure the velocity of sound of ultrasonic pulses in bismuth single crystals using the pulse interferometry technique of McSkimin[3], when $v_D \approx s_o$. (v_D is the drift velocity of conduction electrons.)

The necessary high drift velocity of the electrons in the sample can be established by imposing mutually perpendicular D.C. electric and magnetic fields in the sample. To establish the necessary electric field it is necessary to pass large currents through the sample, while limiting power dissipation in the crystal to levels which can be tolerated in an experiment performed in liquid helium necessitates pulsing these large currents. The current pulse generator in Fig. 2 was designed and constructed for this purpose; it will furnish 45 ampere pulses of duration up to 400 μsec at repetition rates up to 40 pulses/sec. This current capability is also adequate for ultrasonic amplification experiments, which require $v_D >> s_o$. Characteristic performance curves for this apparatus are shown in Fig. 3.

A block diagram of the assembled equipment is shown in Fig. 4. A very stable oscillator (General Radio 1330-A) whose frequency is monitored continuously by a frequency counter, issued as a trigger for the Simpson 2620 pulse generator, the output of which is used to gate the RF generator of the previous section. The trigger output from the Simpson pulse generator is fed into a scalar. The register output from the scalar is converted into a trigger signal for the current pulse generator described previously. In operation the scalar is set to put out a pulse for every 4096 input pulses. This scheme synchronizes the current pulse with the RF pulses applied to the sample, and thereby allows the stable display on an oscilloscope of those RF pulses which are received at the transducer during the current pulse, while rejecting display of those RF pulses which do not occur during the current pulse.

The display on the 545 scope is used to monitor the amplitude of the current pulse by means of a 1/2 ohm resistor in series with the sample.

Macroscopic crystals of bismuth[6] were grown using a Bridgman technique from 99.9999% pure bismuth supplied by Cominco, Inc. Single crystals were produced about 75% of the time by using the soft mold technique[5] with the furnace heater at about 400°C and liquid nitrogen flowing through the cooling coils. The aluminum oxide powder around the sample allows for the expansion of bismuth upon freezing, and has the additional advantage of preserving the shape of the sample during the growing process; i.e., a single crystal of any reasonably simple shape can be produced by machining the material before placing it in the furnace.

Bismuth crystals grown from the melt show a strong preference for growing with the trigonal axis perpendicular to the growth axis[6]. A total of about fifteen single crystals were grown, of which only three were oriented with the growth axis near the trigonal direction.

An attempt was made to machine the first eleven single crystals grown on a spark planner, but ten of these showed macroscopic recrystallization when etched after planning. The reason for this is not understood, as it proved to be impossible to reproduce the effect outside of the spark machine either by subjecting a single crystal to strain or shock, or by pulsing large currents through a crystal.

To avoid the problem of recrystallization, a grinding apparatus was constructed employing a goniometer crystal mount. The goniometer can be used with an X-ray camera to allow alignment of the sample by Laue back-scattering methods. Two crystals, here labeled A and B, were prepared in the shape of flat rectangles. The dimensions of the two crystals are .467 cm X .852 cm X .917 cm and .402 cm X .861 cm X .962 cm respectively.

Crystal A has x_1 parallel to the trigonal axis, x_2 parallel to the binary axis, and x_3 parallel to the bisectrix. Crystal B was cut with the faces of the sample nearly parallel to the faces of the pseudo-cubic unit cell of bismuth. Use of this orientation complicates the spectrum of the expected velocity change by introducing phonon interactions with electrons of various effective masses, so the $\Delta s/s_o$ curve would have several peaks instead of the single peak of Fig. 1. This effect does not occur for sound propagation in the trigonal direction.

The transducer to crystal bond consisted of a sheet of lens paper soaked in stopcock grease sandwiched between the transducer and crystal. The lens paper was used to provide electrical insulation between the gold plating on the transducer and the crystal; this electrical isolation was necessary to prevent the gold film from shorting the current pulse applied to the crystal, since the conductivity of gold is about fifty times that of bismuth. Electrically isolating the crystal from the transducer also removed the necessity of keeping the crystal grounded, which was an aid in monitoring the amplitude of the current pulse.

The direction of propagation of the sound pulse was along the shortest crystal dimension (along the trigonal axis in the case of crystal A).

The current pulse was introduced into the sample by means of brass electrodes soldered to the crystal with Wood's metal. The electrodes were attached to those faces of the crystal having the smallest area, since this arrangement achieved the highest current density for a fixed total current. In the case of crystal A the applied current pulse was in the bisectrix direction. In each crystal the maximum current density achieved was about 100 amp/cm^2.

Experimental runs were made, at 4.2°K, in the following way: Longitudinal RF sound pulses were introduced into the crystal at intervals of twice the round trip transit time of the sound pulse (i.e., p = 2 in the discussion of Section II). The frequency of the sound pulse was near 13Mc, the resonant frequency of the transducers used. The signal at the transducer was amplified and displayed on an oscilloscope and the pulse repetition rate adjusted for maximum amplitude of the summed reflections. The current pulse amplitude was set at 40 amperes (100 amp/cm^2 in the crystal). The magnetic field was then slowly swept from zero to 50 kg as the RF pulse interference pattern was monitored. Any change in the velocity of sound greater than one part in 10^4 would manifest itself as an observable change in the interference pattern.

No effect could be seen. Since the magnitude of the expected change in velocity when $v_D = s_o$ is about a thousand times greater than the minimum change which could be detected, the necessary conclusion is that a sufficiently high electron drift velocity in the direction of sound propagation was not achieved. This implies a short relaxation time in the sample. An upper limit for τ can be deduced from the following consideration:

The expression relating the applied current density, J_x, to the current density in the direction of sound propagation, J_y, is

$$J_x = \frac{1}{\omega_c \tau} J_y \qquad (12)$$

Now, J_y is given in terms of the drift velocity in the y direction by

$$J_y = ne\bar{v}_y \qquad (13)$$

The negative result in the experiment indicates that $v_y < s_o$, so that

$$J_y < nes_o \qquad (14)$$

But

$$J_y = \omega_c \tau J_x \qquad (15)$$

so

$$\omega_c \tau J_x < nes_o \qquad (16)$$

or

$$\tau < \frac{nes_o}{\omega_c J_x} \qquad (17)$$

using $\omega_c = eB/mc$ this gives

$$\tau < \frac{mncs_o}{B J_x} \qquad (18)$$

Inserting the values $m = .01\ m_e$, $n = 5 \times 10^{17}\ cm^{-3}$, $s_o = 10^5$ cm/sec, $B = 50$ kg, and $J_x = 100$ amp/cm^2 gives

$$\tau < 10^{-12} \text{ sec}$$

This is certainly plausible, in view of the large strains which may be induced in the crystal because of differential expansion of bismuth and the brass electrodes during cooling to liquid helium temperatures.

For $\tau = 10^{-12}$ sec, $\tau\omega_c$ is about 10^2 at $B = 50$ kg; using this in Eq. (4) along with $\Delta s/s_o = 10^{-3}$ and solving (11) for v_D/s_o gives

$$\frac{v_D}{s_o} \sim .99$$

indicating that the above evaluation of an upper limit for τ is not inconsistent with the fact that no change in velocity was seen.

Note: The single experimental difficulty which could be responsible for an ambiguous result was that the thinness of the crystal used resulted in poor differentiation of the individual reflections as viewed on the oscilloscope--the null areas between reflections were definite but very short. This meant that it was possible that the pattern which was seen was due to electrical interference in the electronics and cables (instead of acoustic interference in the sample). However, any such electrical interference would have been a very sharp function of frequency, and over the (small) range of frequencies at which it was possible to obtain reflections the pattern was found to be independent of frequency.

The preliminary results of this investigation were reported at the Beaumont, Texas meeting of the AAPT, March 16, 1968. The completed work was submitted as a thesis in partial fulfillment of the requirement for the degree of Master of Science by Nicholas P. Thiessen in August, 1968.

REFERENCES

1. H. N. Spector, Solid State Phys. 19, 291 (1966), Academic Press, New York.

2. H. N. Spector, Phys. Rev. 125, 1880 (1962).

3. H. J. McSkimin, J. Acoustical Soc. Am. 33, 12 (1961).

4. H. N. Spector, Phys. Rev. 134, A507 (1964).

5. T. S. Noggle, Rev. Sci. Inst. 24, 184 (1953).

6. J. J. Gilman (ed.), The Art and Science of Growing Crystals (1963) John Wiley & Sons, New York.

3. Atomic Physics. Dr. R. H. Walker, Associate Professor of Physics.

NASA support has resulted in three completed M.S. theses and one paper submitted to the Physical Review for publication. The title of the submitted paper is "Spin Exchange Cross Sections of Alkali Atoms." The topics investigated in the these for which M.S. degrees were awarded were: "Models for Phonon Dispersion Relations in Simple Metals," "The Electromagnetic Fields of Dipoles in Arbitrary Relativistic Motion," and "The Influence of Rotation on the Low Temperature Thermal Properties of Crystals." A brief description of the work carried out is given below.

a. Spin Exchange Cross Sections of Alkali Atoms.

Calculations were performed for low energies so that the Born-Oppenheimer Approximation was valid. The potentials determining the scattering were obtained by adding a phenomenological core-core potential to a scaled hydrogen-hydrogen potential. The resulting potentials compared quite well with results obtained from band spectra. Potentials were obtained for the diatomic systems corresponding to Li, Na, K, R_b, and C_s. Scattering phases were obtained as a function of energy for each system to allow thermal averages of various scattering cross sections to be calculated. In all four different energy dependent cross sections were calculated for each system. Below is a graphical representation of the results of this work. Figure I shows the potentials used in the calculation. Figures II-V show the various cross sections evaluated together with their thermal averages.

b. Models for Phonon Dispersion Relations in Simple Metals.

Atomic interactions necessary for the description of lattice vibrations were assumed to be described by point coulombic interactions with strength given by the valence of the atom involved. Expressions for the phonon spectrum for such a "coulombic lattice" were obtained in terms of certain lattice sums which could be rendered rapidly convergent by appropriate transformation techniques. The influence of the conduction electrons on the vibration spectrum of the "coulombic lattice" electron scattering leading to an effective, or renormalized, interaction for the lattice charges which was characterized by a wavelength dependent dielectric constant. A final correction to this basic model was the introduction of a short range force to account for the mutual repulsion of the cores of the ions. This term was assumed to be of Yubawa form. The only undetermined parameters of the model were those two that specified the Yukawa potential, providing a strength and a range. All other constants of the theory could be related to the lattice constant, which was taken from X-ray data, and the valence of the atoms which comprised the crystal. The two undetermined parameters were chosen to give agreement with inelastic neutron scattering determination of the phonon spectrum for one particular wavelength. These parameters so chosen were then used for the calculation of the spectrum for all wavelengths. The agreement or lack of agreement was then taken

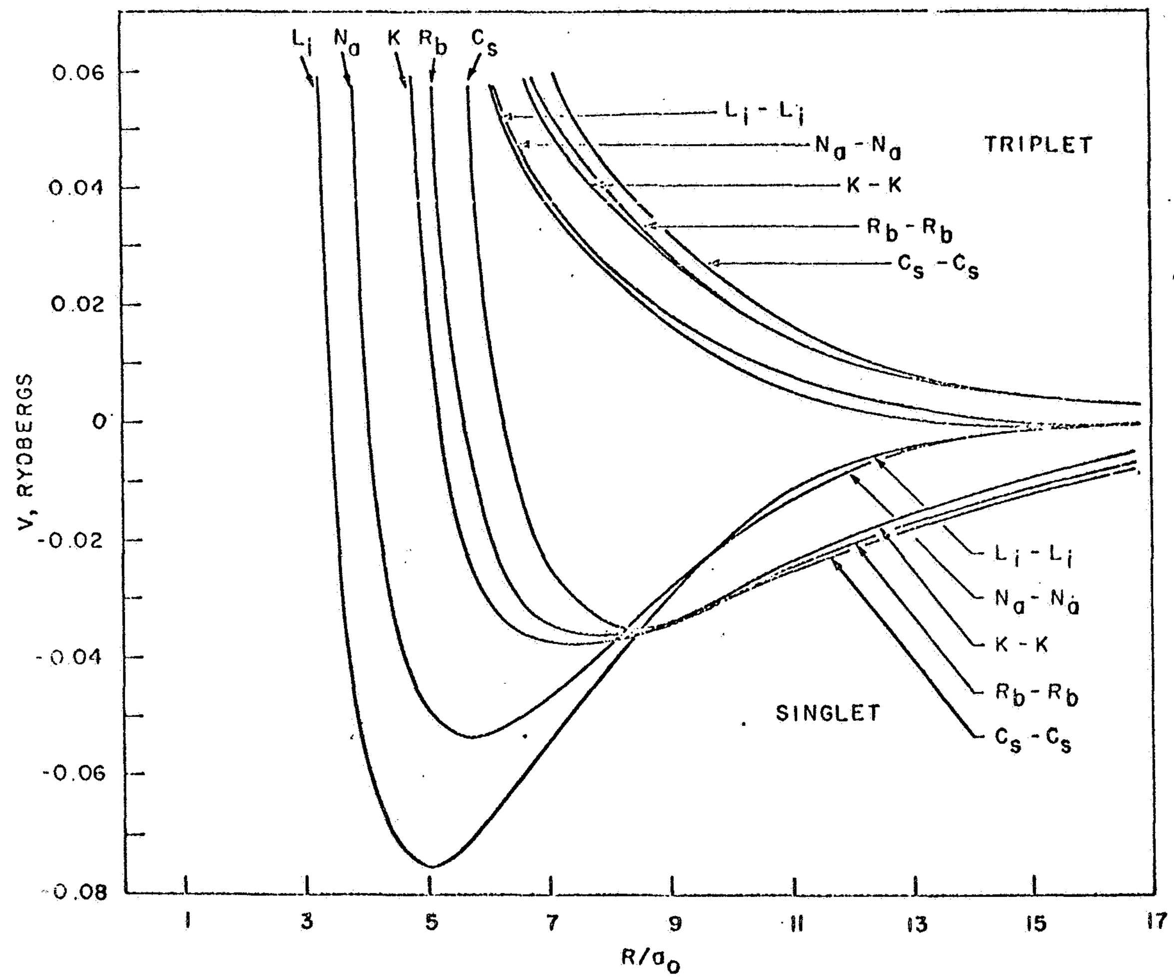

Fig. 1 Interaction potentials of alka... atoms as a ... ...n of the nuclear separation. a_o is the Bohr radius.

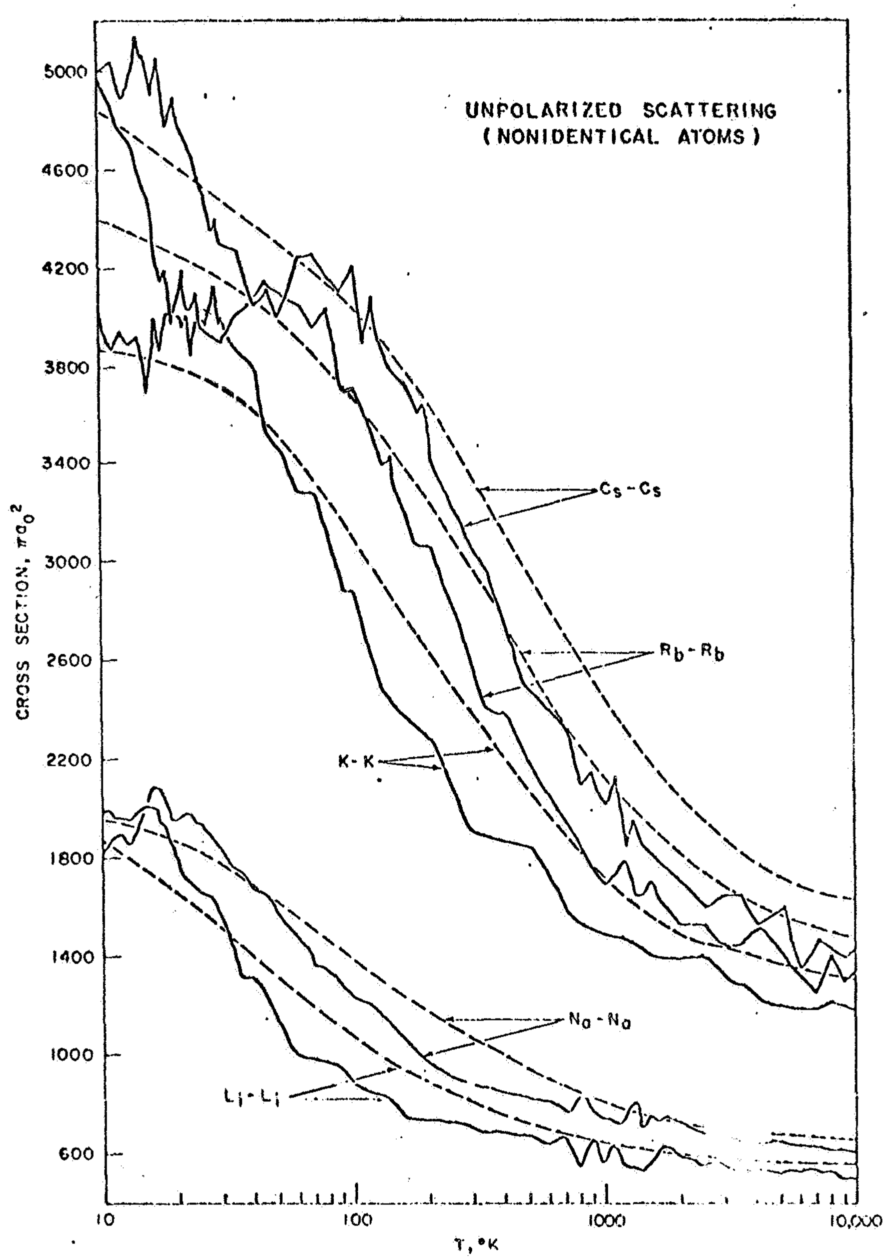

Fig. 2 Unpolarized scattering cross sections of nonidentical alkali atoms as a function of relative kinetic energy E ($= \frac{3}{2}kT$). The dashed curves are thermally averaged cross sections versus the temperature T. a_o is the Bohr radius.

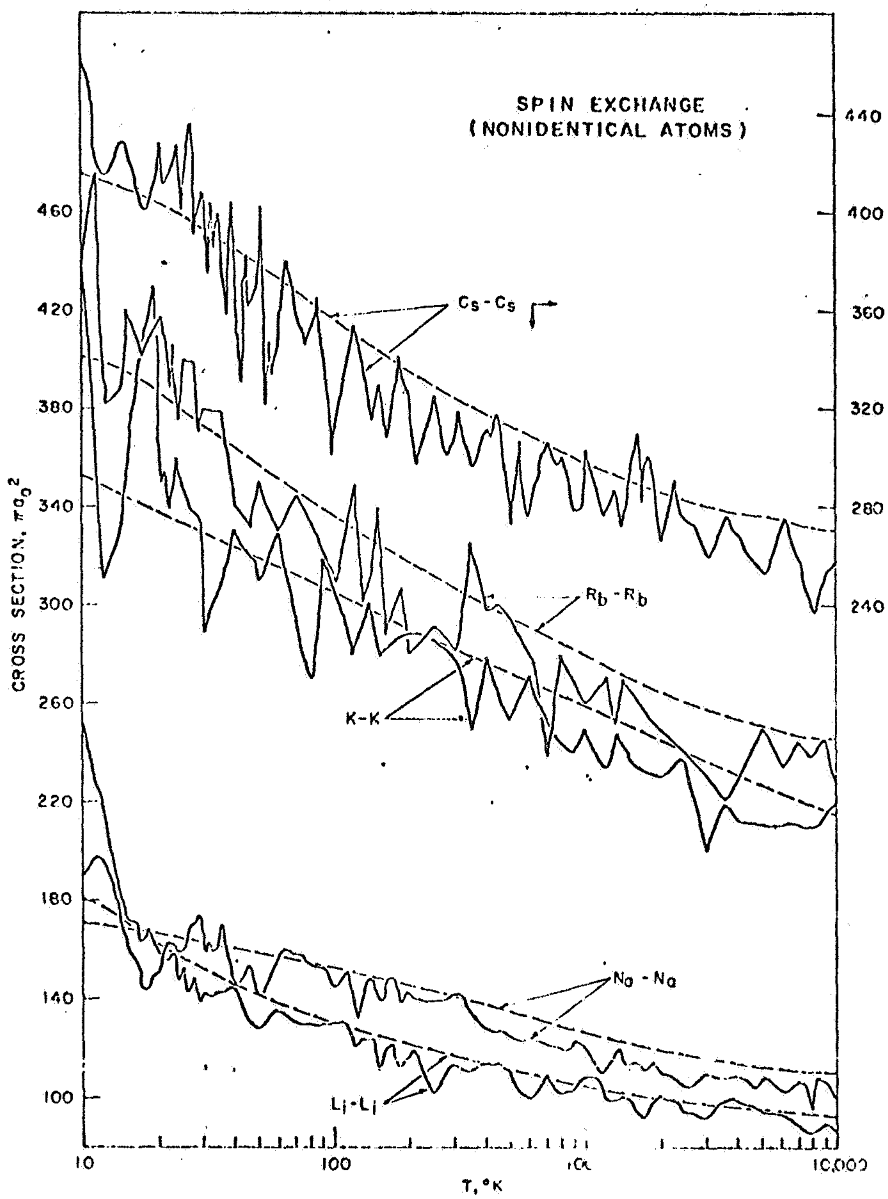

Fig. 3 Spin exchange cross sections of nonidentical alkali atoms as a function of relative kinetic energy E ($= \frac{3}{2}kT$). The dashed curves are thermally averaged cross sections versus the temperature T. a_0 is the Bohr radius. The right hand scale is for Cs - Cs only.

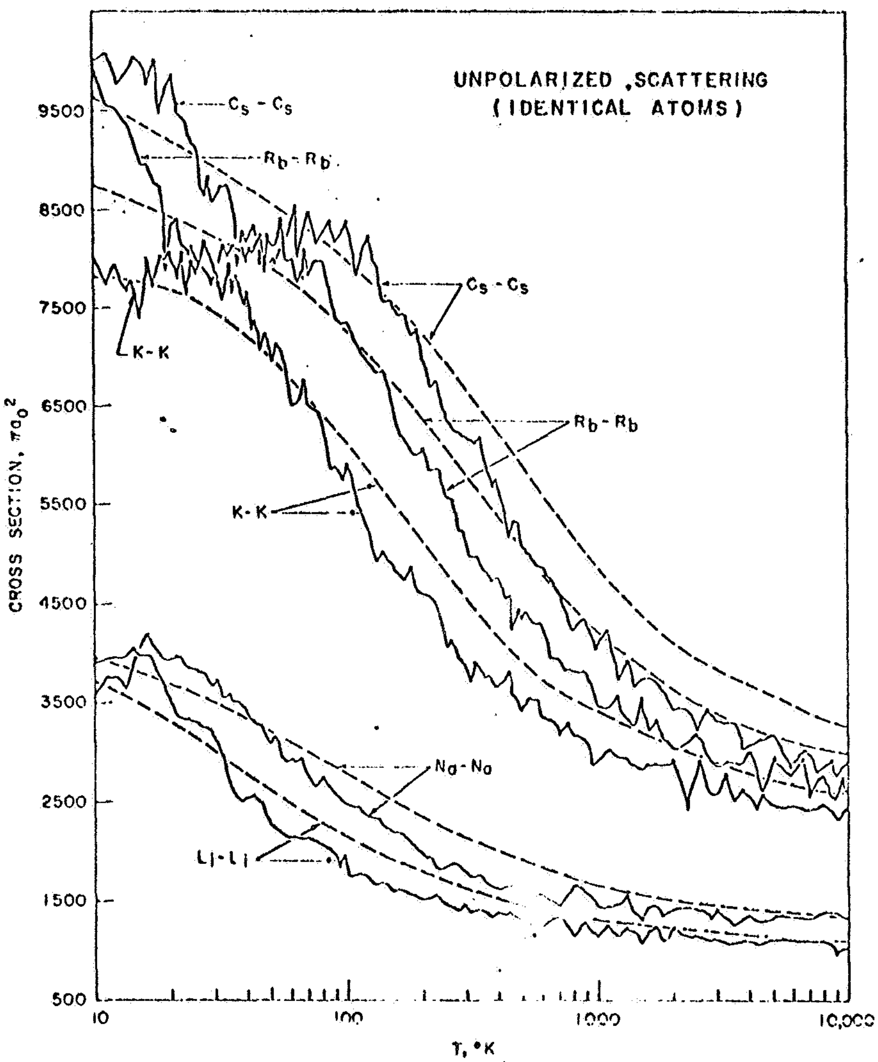

Fig. 4 Unpolarized scattering cross sections of identical alkali atoms as a function of relative kinetic energy E ($= \frac{3}{2}kT$). The dashed curves are thermally averaged cross sections versus the temperature T. a_o is the Bohr radi...

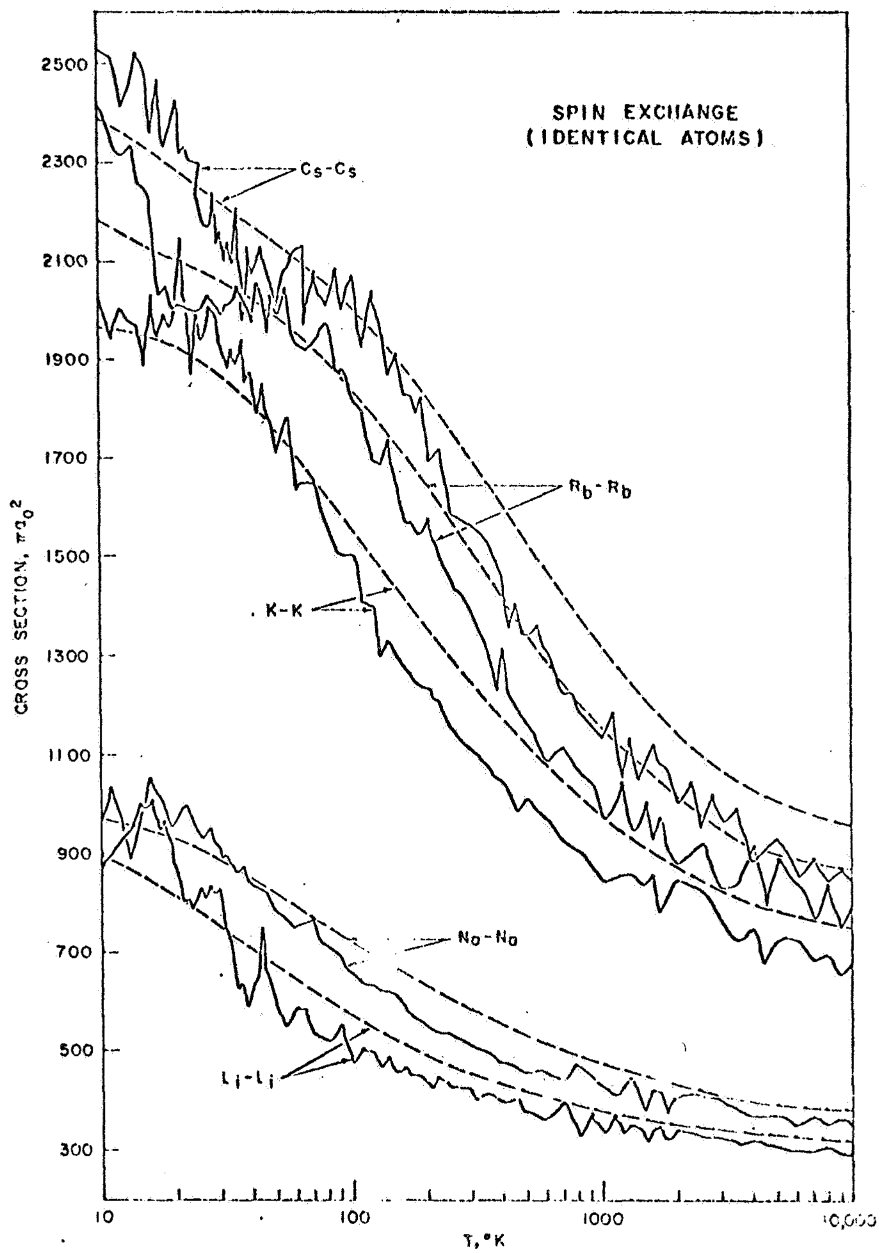

Fig. 5 Spin exchange cross sections of idential alkali atoms as a function of relative kinetic energy E $(= \frac{3}{2}kT)$. The dashed curves are thermally averaged cross sections versus the temperature T. a_o is the Bohr radius

as a measure of the adequacy of this simple model for the description of lattice vibrations in simple metals. Calculations were carried out on copper, aluminum, and lead. Partial results are shown in Figure VI, VII, and VIII where the calculations for copper are compared with experimental results for certain directions of propagation. Considering the crudeness of the model, the results are extraordinarily good.

c. Electromagnetic Fields of Dipoles in Arbitrary Relativistic Motion.

An electromagnetic dipole in motion constitutes a current from which electromagnetic fields arise. A covariant expression for such a current was obtained as the divergence of a suitably defined tensor. This current was then taken as the source term for the inhomogeneous wave equation whose solution provides the analogue for the Lenard-Weichert potentials. These results are valid for the dipole in arbitrary motions. From the 4-potential, the electromagnetic field is determined in the usual way. In particular, general expressions for E, B, and the Poynting vector were obtained and some fifteen special cases discussed. Each case correctly reduces to the appropriate non-relativistic limit. This work is being continued for the purpose of examining the contribution of dipole effects to Syncrotron radiation, radiation reaction, and self-energy of charged particles.

d. The Influence of Rotation on the Low Temperature Thermal Properties of Crystals.

Elementary considerations lead to the conclusion that low frequency vibrational modes of a crystal are effectively frozen out by a macroscopic rotation. Since rotation changes the low energy excitation spectrum, one expects the low temperature thermal properties to likewise be altered. In particular, for non-rotating crystals, the low temperature specific heat is $C_V = AT^3$. One expects that under rotation, the constant A to be temperature dependent. The nature of this temperature dependance has been investigated. The calculation of thermal properties requires the energy spectrum of the system. This was obtained from the microscopic equations of motion for a lattice under rotation. In the long wavelength limit, the microscopic interatomic force constants could be related to the macroscopic elastic constants which then provided a mathematical basis for the description of a rotating elastic medium. Under rotation, a cubic crystal is distorted to one of tetragonal symmetry, and this symmetry is reflected in the symmetry properties of the secular equation determining the frequencies of the normal modes which give the desired energy spectrum $\omega(k)$. Thermal properties are determined by certain weighted averages of this energy spectrum. The inherent symmetry of the rotating crystal was exploited by fitting $\omega(k)$ to the first four tetragonal harmonics. This approximation allowed the three dimensional averages to be calculated in a reasonable amount of time. It was found that the effects of rotation are completely unimportant at any except the lowest of temperatures. For typical crystals, the maximum departure from the T^3 low occurs at $\sim 10^{-3}$°K for rotations at frequencies $\sim 10^5$/sec. It is doubtful that this effect would be observable.

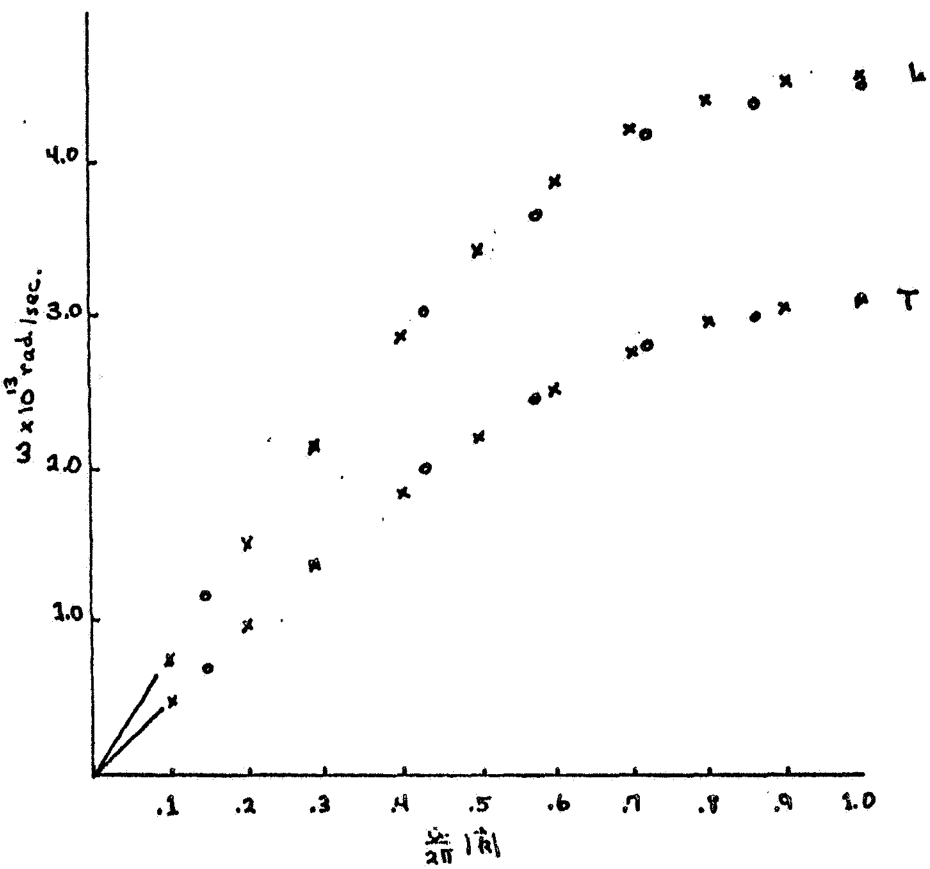

FIGURE 6

COPPER, (1,0,0)
COULOMB AND SHORT RANGE INTERACTIONS
EXPERIMENTAL DATA (15)
CALCULATED POINTS (x)
EXPERIMENTAL POINTS (o)
LONGITUDINAL MODE (L)
TRANSVERSE MODES (T)

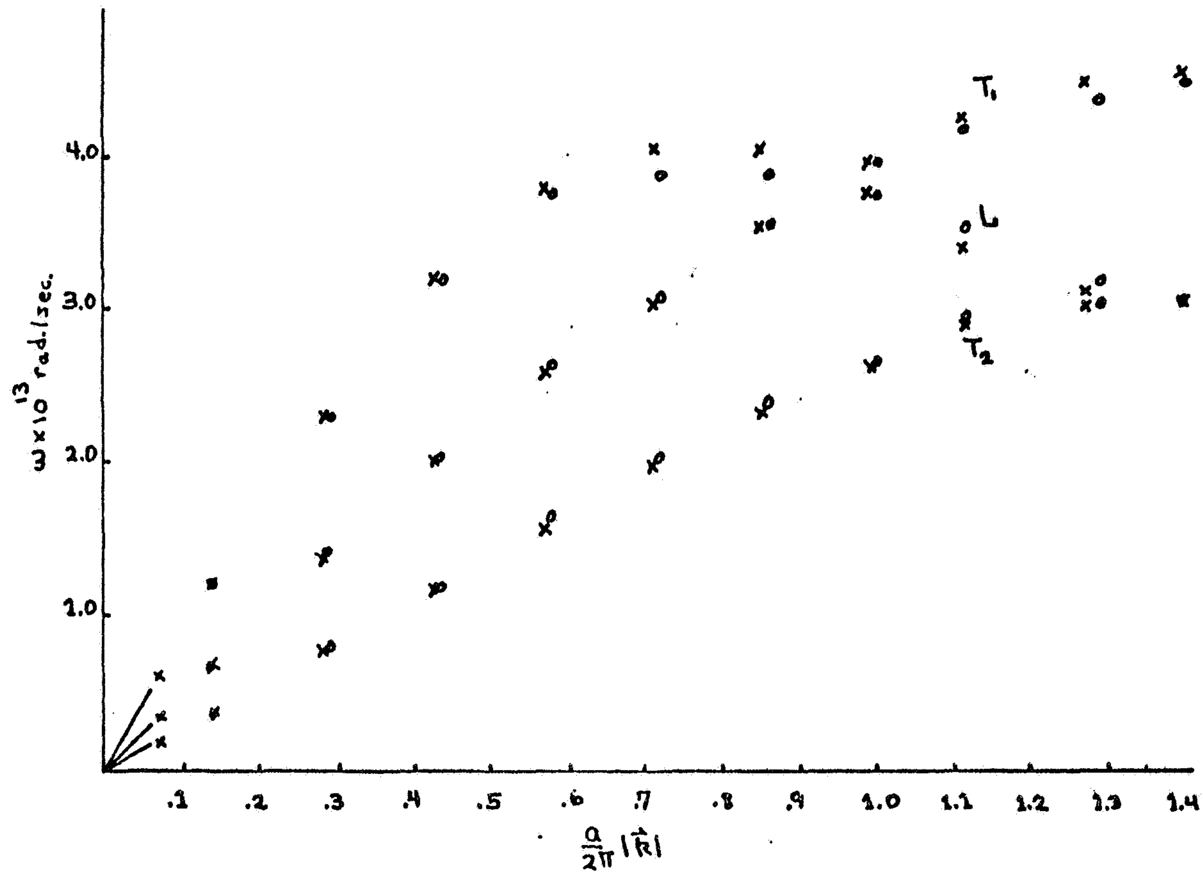

FIGURE 7

COPPER, (1,1,0)
COULOMB AND SHORT RANGE INTERACTIONS
EXPERIMENTAL DATA (15)
CALCULATED POINTS (x)
EXPERIMENTAL POINTS (o)
LONGITUDINAL MODE (L)
TRANSVERSE MODES (T)

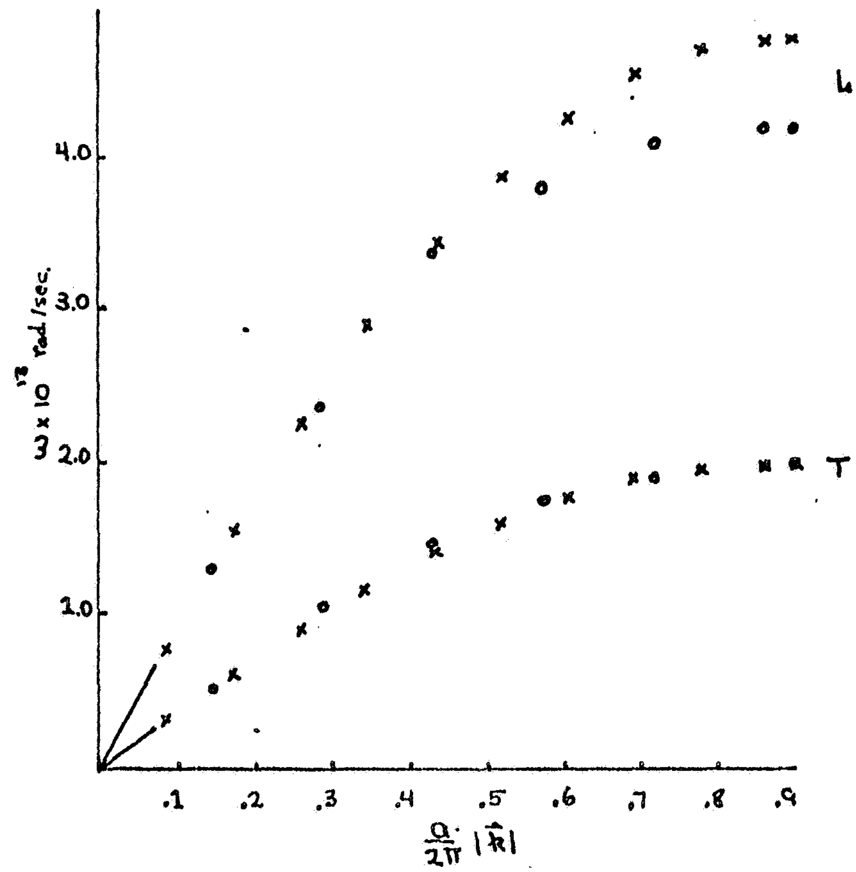

FIGURE 8

COPPER, (1,1,1)
COULOMB AND SHORT RANGE INTERACTIONS
EXPERIMENTAL DATA (15)
CALCULATED POINTS (x)
EXPERIMENTAL POINTS (o)
LONGITUDINAL MODE (L)
TRANSVERSE MODES (T)

4. <u>Astrophysical Research</u>. N. S. Kovar, Assistant Professor of Physics.

During the reporting period the following was accomplished.

1. A paper entitled "Optical Pumping and the D-Line Ratio in Comet 1962 III" appeared in <u>Solar Physics</u>, Vol. 3, April 1968. Ten copies of this paper have been forwarded to NASA headquarters. Briefly, the problem and analysis presented in this paper is as follows.

Spectral observations of Comet 1962-III made prior to perihelion passage revealed a sodium D-line ratio of 2.5. Due to the inadequacy of normal atomic processes in explaining this ratio, an optical pumping process is considered. It is found that such a mechanism can produce the observed D-line ratio if the sodium atoms within the coma were under the influence of a magnetic field and if they were excited by circularly polarized radiation from the sun.

2. A master's thesis entitled "Cometary Plasmas and the Solar Wind" was completed by Mr. Michael Shelby. This work has been fully discussed in previous progress reports. Summarily, however, Mr. Shelby considered the problem of the interaction of the solar wind with the plasma portions (coma and ion tail) of comets. Emphasis was placed upon the magneto hydrodynamic aspects of the solar wind flow past a comet and an attempt was made to determine the shape of the surface which separates the solar wind flow from the outward flow of the cometary plasma. The immediate objective of this thesis was to calculate ion densities in the tail and outer coma. The analysis used was that of specular reflection from the comet boundary without energy loss. Numerical methods were employed to attain the objective. This thesis is part of our ultimate goal of the construction of a model for the formation of plasma comet tails and is part of our program to further our understanding of the interaction of the solar wind and the plasma components of comets.

3. Work has begun, but as yet is not completed, on the general problem of sodium emissions in comets. The lifetime of sodium atoms as a function of comet-sun distance will be computed using the U/H Sigma 7. The formulation of the problem has been virtually completed. Such processes as photo-ionization, proton ionization and excitation as well as recombinations and photo and collisional de-excitations have been considered. However, the actual computer computations have not as yet been carried through.

4. Lastly, this grant has been used to complete work that was primarily supported by NASA Grant No. 44-005-042. In this regard, an invited paper entitled "Space Contamination Due to Manned Vehicles" was presented at the Eleventh Plenary Meeting of COSPAR at Tokyo in May, 1968. The full paper will be published in the proceedings of the meeting.

This paper and those listed below deal with the problem of any possible debris atmosphere surrounding manned spacecraft and with the general problem of space contamination due to the presence of manned vehicles. The effects of this debris atmosphere on the observations of dim light sources such as the solar corona have been examined and evaluated. A discussion of the Apollo program and the effects of contamination were further reported in "Atmospheres Surrounding Manned Spacecraft", Sky and Telescope, Vol. 35, March 1968.

Numerical estimates of light scattering by ice particles originating from the leakage of cabin water vapour were carried through using Mie scattering techniques for particles for which m, the index of refraction, was set equal to 1.3. Scattering functions for a particle distribution, $n(r) \propto r^{-k}$, where $k = 3$ were calculated. The range selected for particle radii was 0.2 to 10 microns. The results of these computations are presented in the paper entitled "Light Scattering by Manned Spacecraft Atmospheres" which has been accepted for publication by Planetary and Space Science.

Furthermore, studies are currently underway on such problems as the contamination by ice particles and silicone polymers of the exposed optical surfaces for the ATM telescope. A paper is currently in preparation which will report on these studies together with the already completed laboratory evaluation of the Gemini window contaminants.

The studies listed under this section will be reported on in more detail in the final report for NASA Grant No. 44-005-042. Ten copies of each of the papers listed under section 4 will be sent to Headquarters according to NASA regulations.

5. Space Related Flow Problems. Dr. R. M. Kiehn and Dr. J. W. Kern, Associate Professors of Physics.

a) Applications of Differential Forms. J. Pierce and R. M. Kiehn.

The following list of French literature on differential forms and their applications has been completely translated:

a) E. Cartan, Lecons sur les Invariants Integraux, Paris, Hermann, 1922.

b) J. Klein, "Espaces Variationels et Mechanique," Annales de L'Institut Fourier, Grenoble 12, 1962, pp. 1-124.

The following works are in advanced stages of translation:

a) J. B. Souriau, Geometrie et Relativite, Paris, Hermann, 1964.

b) E. Cartan, La Theorie des Systems Differentiels Exterieurs, Paris, Hermann, 1945.

c) P. Paquet, "Les Formes Differentielles Exterieures Ω_n dan le Calcul des Variations," Academie Royale des Sciences, des Lettres, et des Beaux Arts de Belgique. Classe de Sciences Bulletins 27, 1941, pp. 65-84.

d) ________, "Sur la Geometrie Differentielle Suivant la Methode de Grassmann et les Integrales du Calcul des Variations," ibid 27, 1941, pp. 148-168.

b) <u>Electrodynamics in Rotating Frames</u>. R. Borochoff, V. Sanders and R. M. Kiehn

A solution to the Maxwell-Einstein equation was obtained, which gave the metric corresponding to a uniform, homogeneous magnetic field in free space. Using the constitutive tensor of E. J. Post, a dielectric constant was obtained corresponding to this field. Although the velocity of a light beam will be reduced by the "effective" dielectric constant, this analysis showed that no optical activity or birefringence resulted from the presence of the magnetic field.

By using the formalism of E. J. Post, it was determined that a normally isotropic optical medium exhibits berefringence under rotation. The birefringence of the medium produces a splitting of a light beam into two orthogonally polarized parts. When the effect is applied to a Sagnac type experiment, it is found that one polarization state of the beam gives the usual value for the Sagnac fringe shift, a value which is independent of the shape of the light path. However, the other polarization state gives a fringe shift that is dependent on the shape of the path, and which differs in value from the usual result. Though this result is novel, it is of third order in v/c and cannot be easily measured.

An attempt was made to determine the principal states of polarization associated with the above rotating frame. Two methods were used. One, an eigenvector formulation, gave the vector states directly. The second method made use of two of the Maxwell equations previously unused in the above work and of the assumption that the electric field is perpendicular to the magnetic field. Although vector states were not obtained explicitly, some rather stringent constraints were obtained which the vectors must satisfy.

The two methods employed gave conflicting results and it was decided that the problem resulted from the assumption that E and B are perpendicular. A further study of this problem is planned.

An investigation was also made to find out if any serious quantitative difference resulted in the calculation of the Sagnac fringe shift when a Lorentz type transformation was applied to the time coordinate. Classically it is assumed that the time is invariant. If the time is multiplied by a Lorentz type factor $1/\sqrt{1 - v^2/c^2}$, it is found that all the previously obtained quantities (velocity, index of refraction, etc.) are simply multiplied by the same quantity. No serious difference thus exists in the non-relativistic approximation.

Apparatus for the construction of a ring laser system has been ordered and partially delivered. An extensive literature search on the applications of ring laser system has been completed.

c) <u>An Intrinsic Theory of Fluids</u>. J. Pierce and R. M. Kiehn

If a physical system admits description in terms of a metric $g_{\mu\nu}$ and covariant vector field of flow, a, then Cartan's methods of exterior differential forms permit the following theorems to be constructed:

1. $d(\beta * a) = 0, \; N \quad 2$

2. $dF = dda = 0$

3. For $H = Z_o * F$, $J = H \wedge d\ell nf$

   $dH = J; \; N \quad 4$

4. $dJ = 0$

5. $\Psi = d(a \wedge H) - F \wedge H + a \wedge J = 0$

6. $\delta\Psi = 0.$

An initial attempt to apply these intrinsic theorems to fluid flow problems indicates that theorems 1, 2, 4, and 6 are tentatively related to the familiar theorems of longitudinal waves, vorticity, current conservation, and Eulerian equations of motion, respectively. The interpretation of theorems 3 and 5 are still open, but the units involved in theorem 5 indicate that it is a statement concerning the transport of angular momentum density, and may be related to problems in turbulent transport theory. The functional Ψ is of extreme interest for it is a first integral of the system of equations describing the "conservation" or transport of energy density and momentum density.

d) Differential Forms. J. Pierce and R. M. Kiehn.

A paper entitled "An Intrinsic Transport Theorem" has been submitted for publication in "The Quarterly of Applied Mathematics."

The six basic theorems in the above paper may be applied to other representations. In particular, the methods are being applied to problems in hydrodynamics. Two of the theorems developed in the above mentioned paper have no known counterpart in the classical theory of fluids. The interpretation of these theorems in terms of dynamical energy storage mechanisms and the transport of angular momentum in turbulent flow is under investigation. A paper entitled "An Intrinsic Theory of Continuous Media" is in the preparation stage.

The following works are in preliminary stages of translation:

a) F. Gallissot, "Application des Forms Exterieures du 2^e Ordre a la Dynamique Newtonienne et Relativiste," Annales de L'Institut Fourier, Grenoble 3, 1951, 278-285.

b) _________, "Les Formes Exterieures en Mechanique" ibid 4, 1952, 145-297.

c) J. Klein, "Les Systemes Dynamiques Abstracts," ibid 13, 1962, 191-202.

d) A. Lichnerowicz, "Les Relations Integrales d'Invariance et Leurs Applications a la Dynamique," Bulletin des Sciences Mathematiques, Series II, 70, 1946, 82-95.

e) _________, Problemes Globaux en Mechanique Relativiste, Paris, Hermann, 1939.

e) Solar-Wind Termination and the Interstellar Medium. J. W. Kern and C. L. Semar.

The formulation of a gas dynamic flow with a distributed mass source was examined. The equation of motion of the medium was constructed, and the correct energy conservation equation for the flow was obtained. It is found that for nearly all situations of physical interest (flow of the solar wind in the vicinity of a comet, flow of the solar wind into the interstellar medium, general hydromagnetic flows in the presence of stationary neutrals, etc.), the kinetic energy density of the flow has an additional source term. That is, the usual relation between pressure and the flow volume element no longer applies. This means that the solutions obtained previously by many workers to the problems of this kind are invalid. The results have been applied to the problem of the flow of the solar wind into the interstellar medium. The results indicate a continuous transition from supersonic flow to subsonic, with the Mach number $M = 1$ at 60 astronomical units for an interstellar neutral hydrogen density of 1 cm^{-3}. The model for the flow and the density of neutral hydrogen inside 100 astronomical units appears quite realistic in view of recent measurements of the local interstellar magnetic field ($B \sim 10^{-6}$ gauss). A portion of this work was supported under the MSC Solar Physics Grant 44-005-041. A paper reporting on the work on the solar wind termination problem was given at the 1968 National Meeting of the American Geophysical Union, April 8-12, Washington D.C., is being incorporated in an M.S. thesis, and prepared for publication in the Journal of Geophysical Research.

6. Plasma Studies. Dr. Melvin Eisner, Professor of Physics.

a) Radiation Energy Spectrum of Plasma Focus.

Studies of the time development of the radiation spectrum of the plasma focus have been initiated. The conditions for obtaining maximum energy transfer from the energy storage band to the pinched discharge have been established for the given geometry. Radiation spectra have been obtained in the soft X-ray region using foil absorbers. Total ionization yields measured with an ionization chamber indicate sufficient ionization to make the device an attractive one for development as a pulsed ionizer in neutral atom diagnostics.

b) Thermalization in Multicomponent Plasmas.

Theoretical studies of the energy exchange through coulomb collisions in non-equilibrium plasmas having light and heavy ion components have revealed some interesting features. For hot ions and cold electrons, the light ions may initially over cool and then heat with the electrons with energy derived from the heavy ions. The bremstrahlung spectrum is being investigated and its application to the modification of the radiation spectrum from the plasma focus is being investigated with the aim of finding means for redistributing the radiation spectrum into the soft X-ray region.

c) Cross Sections for Ion Production in Neutral - Neutral Collisions.

The central problem in the initial stages of this program is the development of an intense source of energetic neutral atoms. A plasmatron ion source has been used with a magnetic confining field to feed a charge-exchange cell whose output of neutrals is then stripped in neutral - neutral collisions. Resulting ions are magnetically analyzed and detected individually. The principal effort so far has been expended in obtaining reliable operation of the ion source and the development of adequate sensitivity in the ion detector. These problems have been solved successfully and effort is now being directed to defining the gas density in the charge exchange and stripping cells. At present, order of magnitude limits have been established for cross sections.

Appendix I

Papers Prepared Under
Space Related Technical Investigations Grant
NGR 44-005-022

1. "Pressure Studies of Pure Superfluid Flow," A. F. Hildebrandt and H. E. Corke presented at A.P.S. meeting June 1967, Toronto.

2. "Pressure Measurements in Subcritical Helium Flow," A. F. Hildebrandt and H. E. Corke, Phy. Fluids, 11 3, March 1968.

3. "Low Field Superconductivity," presented at University of Minnesota January 1968 by A. F. Hildebrandt.

4. "Entrainment of Second Sound in He^2," E. M. Johnson, Master's thesis subject for publication in The Physical Review.

5. "Proposed Hydromagnetic Model for Comets," N. S. Kovar and J. W. Kern presented at 122nd meeting of American Astronomical Society, July 1966.

6. "Optical Pumping and the D Line Ratio of Comet 1962 III," N. S. Kovar and R. P. Kovar, Solar Physics, April 1968.

7. "I(6300/,6363)/I(5577) Ratio of [01] in the Spectra of Comets," N. S. Kovar and R. P. Kovar published abstract in The Astronomical Journal April 1966 - full paper to be submitted to Astronomical Journal.

8. "Spin-Exchange Cross Sections of Alkali Atoms," R. H. Walker and C. K. Chang presented at Austin meeting of A.P.S. February 1967.

9. "Spin-Exchange Cross Sections in Atomic Hydrogen," R. H. Walker and B. M. Mayes presented at Austin meeting of A.P.S. February 1967.

10. "Exterior Forms and Electrodynamics," R. M. Kiehn presented at the Austin Meeting of the A.P.S. February 1967. Bull. A.P.S. 12 2, p. 198 (1967).

11. "Absolute Invariants," John F. Pierce and R. M. Kiehn, Presented at the Austin Meeting of the A.P.S., February 1967. Bull. A.P.S. 12 2, p. 198 (1967).

12. "A Mechanized Approach to Piecewise Potential Problems," J. P. Shores and R. M. Kiehn, Bull. A.P.S. 11 5, p. 749 (1966).

13. "The Relativistic Two State," John F. Pierce and R. M. Kiehn, Bull. A.P.S. 11 5, p. 774 (1966).

14. "Curvature in State Space," R. M. Kiehn and John F. Pierce, presented at the San Antonio Meeting of the Texas Academy of Sciences, November 1966.

15. "The Principle of Integrability," R. M. Kiehn, presented at the San Antonio Meeting of the Texas Academy of Sciences, November 1966.

16. "Mach's Principle and Poincare Stresses," Bull. A.P.S. *11* 5, p. 713 (1966).

17. "An Intrinsic Transport Theorem," John F. Pierce and R. M. Kiehn, submitted for publication in Quarterly of Applied Mathematics.

Translations

E. Cartan, *Lecons sur les Invariants Integraux*, Paris, Hermann, 1922, translated from the French by John F. Pierce and R. M. Kiehn.

J. Klein, "Espaces Variationels et Mechanique," *Annales de L'Institut Fourier, Grenoble* 12, 1962, pp. 1-124, translated from the French by John F. Pierce and R. M. Kiehn.