with matter; this is the case in all the static, spherically symmetric solutions in Einstein's form of the theory.[2,3]

[1] B. Kurşunoğlu, Phys. Rev. **88**, 1369 (1951).
[2] W. B. Bonnor, Proc. Roy. Soc. (London) **209**, 353 (1951).
[3] W. B. Bonnor, Proc. Roy. Soc. (London) **210**, 427 (1951).

The de Haas-van Alphen Effect in Arsenic

TED G. BERLINCOURT
United States Naval Research Laboratory, Washington, D. C.
(Received September 30, 1953)

THE de Haas-van Alphen effect (periodic dependence of magnetic susceptibility upon magnetic field) has been observed in a single crystal of arsenic. The torsion balance method[1] was used, the crystal being suspended in a horizontal magnetic field with a binary axis vertical and its trigonal axis horizontal. The measurements were carried out at liquid helium temperatures in magnetic fields between 22 and 25 kilogauss. The specimen, which exhibited good crystal development, was cleaved perpendicular to its trigonal axis from a large crystalline mass of Fisher A892 "Purified Arsenic." Earlier failure to observe any effect in arsenic[2] can probably be ascribed to poorer crystal quality and the unavailability of sufficiently high fields.

The nature of the de Haas-van Alphen effect in arsenic is illustrated in Fig. 1, where CH^{-2}, the couple per unit mass (in dyne-cm per gram) acting on the crystal divided by the square of the magnetic field (a quantity proportional to the difference in magnetic susceptibility along and at right angles to the trigonal axis) is plotted against the reciprocal of the magnetic field for an angle of $\phi=-56.3°$ between the trigonal axis and the magnetic field. (The sign of ϕ was determined according to the convention adopted by Shoenberg[1] in his study of antimony.) The data presented in Table I for the angular dependence of the period β/E_0 of the oscillations suggest that the constant energy surfaces for the de Haas-van Alphen electrons in arsenic probably fit the general scheme proposed by Shoenberg for bismuth and antimony. The amplitude a of the oscillations in CH^{-2} at 24 390 gauss is also listed in Table I. The degeneracy parameter E_0 for the de Haas-van Alphen electrons was calculated from the temperature dependence of the amplitude and was found to be $E_0=26\times10^{-14}$ erg. From the field dependence of the amplitude, the value for the temperature damping parameter x was found to be approximately 6°K at $\phi=-56.3°$ indicating high impurity content in the crystal. A spectrochemical analysis of fragments from the same batch of arsenic revealed impurities of approximately 1 percent Sb, 0.1 percent Bi, 0.1 percent Pb, and traces of Cu, Mg, Si. However, since addition of comparable amounts of impurities to tin,[1,3] which has parameters β and E_0 comparable with those of arsenic, had the effect only of increasing x (and consequently decreasing a), while leaving β and E_0 unaltered; the values quoted here for the latter parameters are probably also characteristic of pure arsenic.

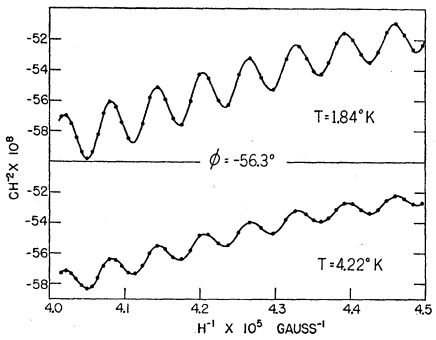

FIG. 1. Arsenic: CH^{-2}, the couple per unit mass in dyne-cm per gram acting on the crystal divided by the square of the magnetic field, *versus* the reciprocal of the magnetic field.

TABLE I. Angular dependence of the period β/E_0 and the amplitude a of the oscillations in C/H^2 at 24 390 gauss.

ϕ	$(\beta/E_0)\times10^{7}$ (gauss^{-1})	$a\times10^{8}$ 4.22°K	$a\times10^{8}$ 1.84°K
−71.7°	5.34	0.21	0.59
−56.3	6.27	0.72	1.59
−41.0	6.81	0.37	
−26.4	6.73	0.56	
−11.9	6.27	0.57	
−0.7	5.44	0.38	
16.2	5.79		0.46
30.7	5.85		0.74
45.6	5.28		1.00
60.7	4.52		0.34
76.2	~3.9		~0.05

It should be pointed out that the slow shift of the mean of the oscillations (See Fig. 1) cannot as yet be explained. It seems unlikely that ferromagnetic impurity could account for the shift, since it should presumably be saturated at fields well below 25 kilogauss, and since a broad maximum in this shift was observed for two different orientations. It would be tempting to attribute the shift to a very long period de Haas-van Alphen term, but the presence of such a term was not at all obvious in a graph of CH^{-2} *versus* ϕ. Since such a long period term would likely be more dependent upon purity,[4] investigation of this feature is being reserved for experiments on high purity arsenic.

[1] D. Shoenberg, Trans. Roy. Soc. (London) **245**, 1 (1952).
[2] Ted G. Berlincourt, Phys. Rev. **88**, 242 (1952).
[3] T. Croft, Annual Project Report, University of Pennsylvania, 1953 (unpublished).
[4] D. Shoenberg and M. Z. Uddin, Proc. Roy. Soc. (London) **A156**, 701 (1936).

Paramagnetic Resonances in Irradiated Glasses

E. L. YASAITIS AND B. SMALLER
Chemistry Division, Argonne National Laboratory, Lemont, Illinois
(Received October 2, 1953)

PARAMAGNETIC resonances have been detected in glasses which had been exposed to gamma radiation. The experimental data were taken over a frequency range of 18 to 375 Mc/sec. The equipment used was $\frac{1}{4}$-λ coaxial line regenerative detector developed for the 100- to 375-Mc/sec frequency range while the 18- to 100-Mc/sec range was covered by a cathode-above-ground regenerative detector with conventional tank coil wound around the sample. Both circuits were used in conjunction with a dual field modulation technique[1] designed for previous experiments. The detection limit was 2×10^{14} spins, requiring a 10^3 r exposure. The free radical diphenyl picryl hydrazyl was used both for intensity and field calibration.

The glass samples used fell into two groups: those containing borosilicate, and the boron-free glasses. The non-boron glasses, lead, lime, vitreous silica, and boron-free Pyrex (Corning No. 728) showed a prominent resonance at a gyromagnetic ratio of $g=2.0$, with minor differences in their subsidiary spectra. While the boron-free Pyrex spectra consisted of a singlet line, the lime and lead glasses at 375 Mc/sec showed doublet structure centered at $g=2.00$. A detailed study of the vitreous silica resonance yielded a precise value of g of 2.004 ± 0.004, independent of frequency. Subsidiary resonances were noted at lower g values.

The borosilicate glasses, Pyrex, Kovar, Vycor, Nonex, and uranium glass, when irradiated and investigated at 375 Mc/sec, displayed four distinct resonances having line widths of 1 to 2 gauss separated by 10 to 15 gauss. The complex structure may be presumed to be due to the presence of B^{11}, with $I=3/2$. However, although the strong field spectra correspond to a splitting constant of 80 Mc/sec, at weak fields anomalous effects remain to be explained.

All glasses except the vitreous silica showed a strong irradiation-independent resonance at $g=4.00\pm0.20$ and this is presumably due to some paramagnetic impurity.

Measurement of the optical densities of a series of gamma-irradiated samples of lime glass revealed that the paramagnetic resonance amplitude varied linearly with optical density. Likewise, with annealing at 200°C, the signal amplitude decreased proportionately with bleaching. For the gamma-ray excitation, the dependence of spin concentration on total radiation showed a saturation characteristic with an initial efficiency of, roughly, 20 ev per spin created.

Further studies on the processes involved will be published more completely in the near future.

[1] B. Smaller and E. Yasaitis, Rev. Sci. Instr. **24**, 991 (1953).

Visible Light from Localized Surface Charges Moving across a Grating

S. J. Smith* and E. M. Purcell
Lyman Laboratory, Harvard University, Cambridge, Massachusetts
(Received September 25, 1953)

It occurred to one of the authors (EMP) that if an electron passes close to the surface of a metal diffraction grating, moving at right angles to the rulings, the periodic motion of the charge induced on the surface of the grating should give rise to radiation. A simple Huygens construction shows the fundamental wavelength to be $d(\beta^{-1}-\cos\theta)$, in which d is the distance between rulings, β stands for v/c as usual, and θ is the angle between the direction of motion of the electron and the light ray. If $d=1.67$ microns, as in a typical optical grating, and if electrons of energy around 300 kev are used, the light emitted forward should lie in the visible spectrum. As for intensity, if we assume that the surface charge traversing the hills and dales is equivalent to a point charge e oscillating with an amplitude $d/10$, we find that in the forward direction the radiation (in laboratory coordinates) should amount to 40×10^{-12} erg (about ten photons) per sterad per millimeter of electron path. Only if the electron path lies within perhaps $d/2$ of the grating will the surface charge be so well localized. Nevertheless, with a reasonable electron current density over the surface an easily detectable amount of light should be produced. In fact, under the assumed conditions, the total radiation per cm² of grating surface, in milliwatts, should be about four times the electron current density parallel to the surface in amp/cm².

We have tried the experiment, using a small pressure-insulated Van de Graaff generator and electron accelerator tube. A 5-microampere beam, focused electrostatically and magnetically to a diameter of 0.15 mm and diverging less than 0.004 radian, is adjusted by deflection coils to pass over a flat grating,[1] just grazing its surface. The 48-mm long path across the grating, viewed from a forward position 10 or 20 degrees off the beam, appears as a sharp, luminous, colored line on the surface of the grating. The color of the light changes with angle of observation and beam voltage in the manner expected. The light is strongly polarized with the electric vector perpendicular to the grating. The effect of varying d can be investigated by rotating the grating in its own plane (a test suggested by E. H. Land) and here, too, the color changes as predicted.

The spectrum of the light has been recorded at low dispersion by photographing the source through a transmission grating. Light from the electron track is collected by a collimating lens, where an arc-shaped aperture restricts the range of angles θ, passed through the analyzing grating and received by a 35-mm camera ($f=90$ mm) focused for infinity. With this arrangement only one point on the line source is in good focus. Figure 1 shows a sequence of such photographs in which only the electron velocity was varied. Within the accuracy of our still rather crude measurements of wavelength and voltage, the predicted dependence of wavelength on v, d, and θ is quantitatively confirmed by the spectrograms. On spectrograms taken at $\theta=30°$, radiation of half the fundamental wavelength is detectable. Higher harmonics appear in considerable intensity at 90°, where we find radiation of one-third, one-fourth, and one-fifth the fundamental wavelength.

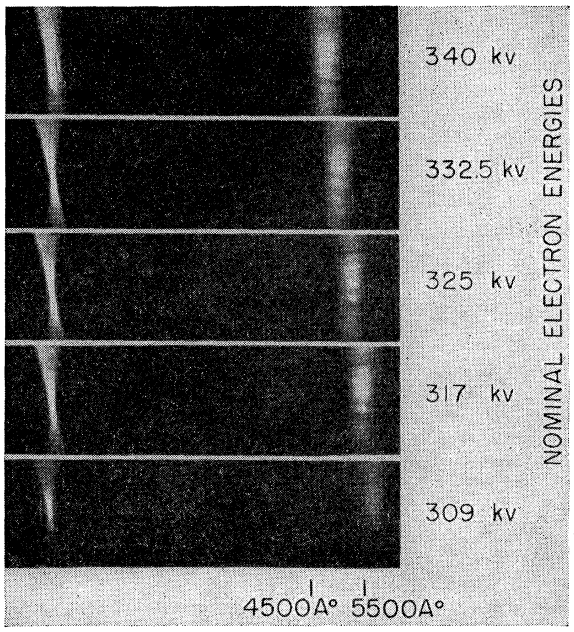

FIG. 1. Spectrogram of the light emitted from the grating surface at $\theta=20°$. Central images are vertically aligned on the left. First-order spectra appear on the right. Light was accepted over an interval of 3.5° in θ; this corresponds to a spread in wavelength of about 350° and accounts for the width of the first-order line. Striations in the first-order line are presumably due to vertical irregularities on the surface of the grating. The exposure time for each spectrum was about 60 seconds, on Linagraph Pan.

Although many details remain to be studied, we believe these observations establish the reality of the effect and suggest that it may have interesting applications.

* Recipient of a General Electric Fellowship in Applied Physics for 1952–53.

[1] Obtained from Baird Associates, Cambridge, Massachusetts.

Derivation and Renormalization of the Tamm-Dancoff Equations*,†

Behram Kurşunoğlu
Laboratory of Nuclear Studies, Cornell University, Ithaca, New York
(Received August 10, 1953)

In this note we show that (1) the derivation of Tamm-Dancoff (T.D.) equations for two nucleons (as well as for meson-nucleon scattering) from the covariant Bethe-Salpeter[1] (B.S.) equation can be simplified to a remarkable degree, and (2) the renormalizations in the T.D. method can be achieved in a covariant manner without having the difficulties presented by the original T.D. method.

We introduce the spinor function $\psi(12)$ by the relation

$$\chi(12)=\int S_{F'a}(11')\beta_a\psi(1'2)d1'+\int S_{F'b}(22')\beta_b\psi(12')d2', \quad (1)$$

where $\chi(12)$ is the B.S. wave function for two nucleons. By using (1) in the B.S. equation we obtain

$$[(\beta\gamma_\mu\partial_\mu+\beta M)_a+(\beta\gamma_\mu\partial_\mu+\beta M)_b]\psi(12)$$
$$=-\int g(121'2')\psi(1'2')d1'd2', \quad (2)$$