The L, M, and N functions are as given in reference 1, but because of the presence of the Dirac matrix β in some of the interactions and not in others, further functions L^-, M^-, and N^- have to be introduced. These are given below, and following the arrow in each case is an approximation good for $\alpha Z \ll 1$.

$$L_0^- = \left(\frac{2\pi}{Fp^2}\right)\frac{g_0^2 - f_{-2}^2}{4\pi} = \frac{S+S^2}{2W} \rightarrow \frac{1}{W},$$

$$L_1^- = \left(\frac{2\pi}{Fp^2}\right)\frac{g_1^2 - f_{-3}^2}{4\pi\rho^2} = \frac{F_1}{F}\frac{p^2}{9W}\frac{2S_1+S_1^2}{8} \rightarrow \frac{p^2}{9W},$$

$$L_2^- = \left(\frac{2\pi}{Fp^2}\right)\frac{g_2^2 - f_{-4}^2}{4\pi\rho^4} = \frac{F_2}{F}\frac{p^4}{225W}\frac{3S_2+S_2^2}{18} \rightarrow \frac{p^4}{225W},$$

$$M_0^- = \left(\frac{2\pi}{Fp^2}\right)\frac{f_0^2 - g_{-2}^2}{4\pi\rho^2}$$

$$= \frac{1}{W}\left[\frac{S-S^2}{2\rho^2} - \frac{\alpha Z W}{\rho}(1-S) + \frac{1}{(2S+1)^2}\{p^2(4S^4-7S^2+2) - \alpha^2 Z^2(4S^2-S-2)\}\right]$$

$$\rightarrow \frac{1}{W}\left[\frac{\alpha^2 Z^2}{4\rho^2} - \frac{p^2}{9}\right],$$

$$M_1^- = \left(\frac{2\pi}{Fp^2}\right)\frac{f_1^2 - g_{-3}^2}{4\pi\rho^4}$$

$$= \frac{F_1}{F}\frac{p^2}{36W}\left[\frac{2S_1-S_1^2}{2\rho^2} - \frac{\alpha Z W}{\rho}(2-S_1) - \frac{1}{(2S_1+1)^2(1+S_1)}\left\{\frac{p^2}{2}(1+S_1)(4+4S_1+3S_1^2-2S_1^3) + \frac{\alpha^2 Z^2}{2}(1+S_1) + \frac{\alpha^2 Z^2 W^2}{2}(8S_1^3-2S_1^2-21S_1-11)\right\}\right]$$

$$\rightarrow \frac{p^2}{36W}\left[\frac{\alpha^2 Z^2}{4\rho^2} - \frac{4p^2}{25}\right],$$

$$N_0^- = \left(\frac{2\pi}{Fp^2}\right)\frac{f_0 g_0 + f_{-2} g_{-2}}{4\pi\rho} = -\left[\frac{\alpha Z S}{2\rho W} - \alpha^2 Z^2\right] \rightarrow -\frac{\alpha Z}{2\rho W},$$

$$N_1^- = \left(\frac{2\pi}{Fp^2}\right)\frac{f_1 g_1 + f_{-3} g_{-3}}{4\pi\rho^3} = -\frac{F_1}{F}\frac{p^2}{36}\left[\frac{\alpha Z S_1}{2\rho W} - \alpha^2 Z^2\right] \rightarrow -\frac{p^2}{36}\frac{\alpha Z}{\rho W}.$$

Work in connection with the comparison of complete correction factors with experimental spectra is proceeding.

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[1] E. J. Konopinski and G. E. Uhlenbeck, Phys. Rev. **60**, 308 (1941).
[2] Longmire, Wu, and Townes, Phys. Rev. **76**, 693 (1949).
[3] L. M. Langer and H. C. Price, Phys. Rev. **76**, 641 (1949).
[4] M. Fierz, Z. Physik **104**, 553 (1936).
[5] H. W. Fulbright and J. C. D. Milton, Phys. Rev. **76**, 1271 (1949).
[6] D. E. Alburger, Phys. Rev. **78**, 629 (1950).

Magneto-Optics of an Electron Gas with Guided Microwaves*

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In recent years the magneto-optics of electromagnetic wave propagation have been extended to guided propagation at microwave frequencies. In particular, Faraday-effect experiments have been made[1-3] in which the plane of maximum E-field of the TE_{11} mode in a circular wave guide is rotated by propagation through a section of the guide filled with a liquid or solid dielectric and located in an axial dc magnetic field. In all the published work to date, very small angles of rotation are obtained per guide wavelength, even at the gyromagnetic resonant field.

We have performed magneto-optic propagation experiments in circular wave guide in the range of frequencies 4600–5500 Mc/sec, employing as the dielectric the decaying plasma from a pulsed dc gas discharge. The main results are as follows:

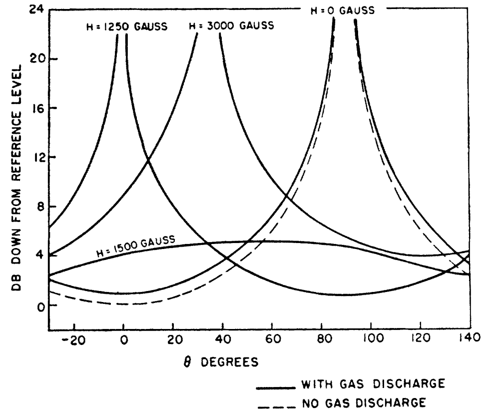

FIG. 1. Relative rf electric field distribution over periphery of circular wave guide. (Signal frequency: 5500 Mc/sec. Gas: Ne+1% at 1 mm Hg.) The reference plane for θ and the reference level for the E-field measurements are the plane and amplitude, respectively, of the maximum E-field with no discharge. Signal pulse 50 sec after 5 sec dc discharge pulse. Pulse voltage: 1050-v peak. Pulse current: 135-ma peak.

(1) Very large angles of rotation, on the order of 90° or more per guide wavelength, exhibiting a pronounced resonance behavior in the region where the gyromagnetic frequency of the electrons approaches the signal frequency.

(2) Departure from linear polarization as resonance is approached. Polarization becomes more broadly elliptical and finally almost purely circular at resonance.

(3) Demonstration of an analogue, for guided microwaves, of the crossed Nicol prisms experiment.

The anisotropic electron gas is produced by a pulsed dc discharge in a hot-cathode tube containing a rare gas, which completely fills a five-inch long section of guide which is enveloped by a solenoid. A signal pulse ten microseconds wide, with variable time delay after the dc discharge pulse, is sampled by a probe in a following section of guide, which can be mechanically rotated about the guide axis.

In Fig. 1 the rf electric field at the guide periphery is plotted as a function of angle for several values of magnetic field. In Fig. 2 the angle of rotation of the plane of maximum E-field is plotted as a function of magnetic field. The experimental conditions are

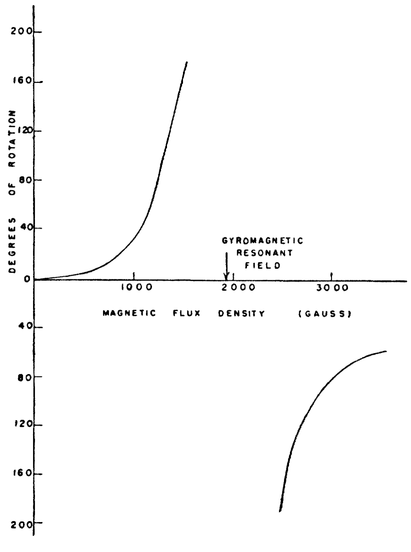

FIG. 2. Rotation of plane of maximum E-field *vs* magnetic field. The experimental conditions are the same as for Fig. 1.

indicated on the graphs. Measurements were made at 4600, 4900, 5200, and 5500 Mc/sec in a guide with cutoff at 4430 Mc/sec, over a range of gas pressures from 0.5 to 100 mm Hg, and at various dc pulse currents and voltages.

The results obtained are readily explained in terms of decomposition of the "linear" TE_{11} wave into two oppositely-rotating circularly-polarized waves, an "anomalous" and a "normal" wave. The "anomalous" wave exhibits, in the region of gyromagnetic resonance, very strong attenuation and a reversal of the sign of its phase shift with respect to propagation in vacuum. The "normal" wave is only slightly attenuated in this region and accounts for the circular polarization observed at gyromagnetic resonance.

The roles of "anomalous" and "normal" waves are interchanged if the sense of the magnetic field is reversed. Consequently, each of the circularly-polarized waves is heavily attenuated by one or the other of two opposing magnetic fields, both at gyromagnetic resonance. This fact enabled the construction, with two independent solenoids, of a microwave analogue of crossed Nicol prisms.

The circularly-polarized waves are not true propagating modes through the plasma in these experiments. Our interpretation remains, however, valid because a short section of plasma was employed. The theoretical details have been worked out for the case of the unbounded anisotropic plasma, including electron collision effects. Further theoretical work remains for the wave guide case.

These results hold promise as a tool for the study of gas discharge phenomena. They are applicable also to switching, amplitude, phase or frequency modulation, and polarization control in an electronically controllable medium.

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[1] P. Keck, Ann. Phys. 5, 15, 903 (1932).

[2] M. C. Wilson and G. F. Hull, Jr., Phys. Rev. 74, 711 (1948). R. G. Barnes and G. F. Hull, Jr., Phys. Rev. 82, 341 (1951).

[3] Mme. Soutif-Guichert and M. M. Lambinet, Compt. rend. 231, 1460 (1950).

Evidence for Ionosphere Currents from Rocket Experiments Near the Geomagnetic Equator*

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RECORDS of magnetic field as a function of altitude have been obtained from total-field magnetometers mounted in two Aerobee sounding rockets which were fired from the seaplane tender USS Norton Sound in March, 1949, off the west coast of Peru. The flights were made 60 miles apart at 89° west longitude, 11° south latitude or geomagnetic longitude 341°, geomagnetic latitude −1°.

The purpose of the flights was to obtain experimental evidence concerning the existence of an ionosphere current system. Harmonic analysis of the diurnal variation of the earth's magnetic field recorded at the earth's surface has shown that it could be represented as the field produced by a current system and that it was largely produced by an external source. It has been generally accepted, although not experimentally verified, that the source was a current system in the upper atmosphere. Several theories of the origin of such a current system have been proposed.[1]

A previous flight at White Sands, New Mexico, had shown the feasibility of the method and instrumentation.[2] The location at the geomagnetic equator was most favorable for detection of the ionosphere currents with a total-field magnetometer which measures the scalar value of the field without regard to direction. The field of the predicted currents in this region is parallel to the main field of the earth; also, the diurnal variation is anomalously large at Huancayo, Peru.

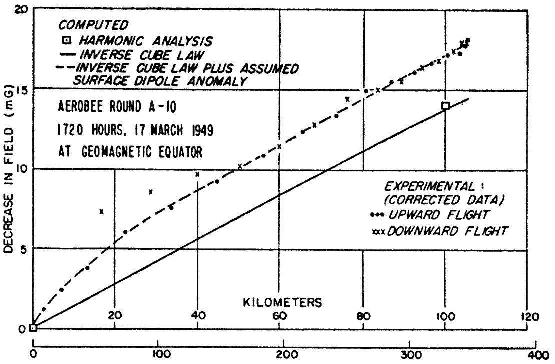

FIG. 1. Decrease of earth's magnetic field (from actual field at sea level) *vs* altitude above sea level for Aerobee A-10 flight.

Aerobee Round A-10 was fired on March 17, at 1720 hours 90th meridian time. Figure 1 shows that the field decreased between 20 km and 105 km, in accordance with the simple dipole field. At that time of day surface measurements show a small value for the diurnal variation, and no evidence of a current layer was obtained in the altitude range covered.

Aerobee A-11 was fired on March 22, at 1120 hours 90th meridian time when the diurnal variation at the surface is near a maximum. Figure 2 shows, in addition to the decrease of the main field of the earth, a decrease of about 4 milligauss between 93 km and 105 km. This decrease at the top of the flight could not be accounted for by sources inside the earth and is attributed to penetration of a current layer by the magnetometer.

Both flights show effects at low altitudes which are attributed to assumed dipole surface anomalies. No other information about surface anomalies in this region is available. The results are, however, consistent with anomalies observed on aerial surveys in other parts of the Pacific.[3]

The estimated accuracy of the decrease in field for the A-10 flight and for the A-11 flight up to 93 km is ±1 milligauss. The decrease in field for the A-11 Flight between 93 km and 105 km is placed at 4±0.5 milligauss.

The expected field discontinuity, if the magnetometer passed completely through the current layer, would be about twice the diurnal variation as measured at the earth's surface. The results of these flights are in reasonable agreement with the magnetograms from the observatory at Huancayo, Peru, for the days of the flights, although accurate correlation is difficult because of a

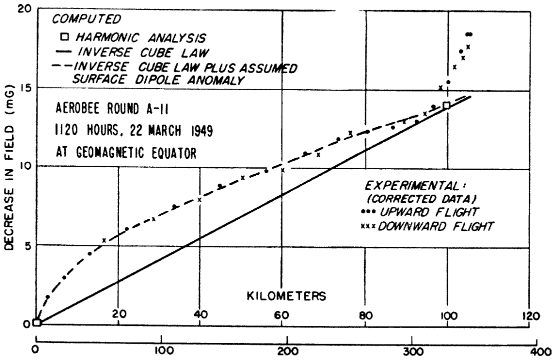

FIG. 2. Decrease of earth's magnetic field (from actual field at sea level) *vs* altitude above sea level for Aerobee A-11 flight.