POLARIZATION OF RADIATION EXCITED BY ELECTRON IMPACT[1]

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ABSTRACT

Polarized radiation following electron impact.—If a unidirectional beam of electrons, of velocity slightly in excess of the resonance potential, is projected through a vapor at a very low pressure so that effects due to atomic collision and resonance radiation are negligible, and in the absence of an applied field and resulting Larmor precession, there is reason to suspect that the radiation emitted perpendicular to the electron beam should be partially polarized, especially for lines corresponding to $\Delta j=1$.

Polarization in mercury and sodium vapor.—Experiment showed a polarization of about 30 percent for $\lambda 2537$ with the greatest intensity of the electrical vibration having a direction perpendicular to the electron beam. No polarization was detected for the unresolved sodium D-lines, confirming the recent observation of Kossel and Gerthsen.

Polarization in mercury with field of 3 gauss.—A field parallel to the electron beam produced no effect. With the field perpendicular to the beam the radiation along the field was unpolarized while that perpendicular to the field was reduced in polarization to 13 percent. These results suggest that the atom radiates with the same distribution of polarization and intensity as in zero field but with the atom rotated through an angle determined by the time of excitation and the precessional velocity.

IN the complete absence of an electric or magnetic field, the atoms of a gas at very low pressure are oriented at random. Let j_0 represent the number of units $(h/2\pi)$ of angular momentum characterizing each atom in the normal state. The effect of an inelastic impact with an electron is the production of an atom in an excited state having an increased amount of energy and an angular momentum j. In collisions at a velocity only slightly greater than that corresponding to the resonance potential, the final velocity of the electron is practically zero. Under these conditions it would appear that the vector representing the angular momentum transferred to the atom should be directed perpendicularly to the velocity of the electron before the collision.

Let us consider the case when the atom absorbs one unit of angular momentum $(j=j_0+1)$ which is subsequently radiated as a quantum of circularly polarized light. The axis of the circular vibration coincides in direction with j. For a uniform distribution of the j_0 vectors the statistical

[1] Published by permission of the Director of the National Bureau of Standards of the U. S. Department of Commerce.

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distribution of the j vectors, following collision with a unidirectional, univelocity beam of electrons, is readily obtained from simple geometrical relations. The j axis of any atom should remain fixed in direction since the assumption of no external field precludes precession during the time of excitation. The circular vibration emitted, as viewed by an observer looking perpendicularly to the electron beam, appears in general elliptically polarized. The elliptical vibration may be resolved along the directions parallel and perpendicular to the beam and the sums $I_{\parallel}$ and $I_{\perp}$ of the corresponding intensities for the circularly polarized radiations from all of the atoms representing the various orientations of j, may be calculated. The following formula for the resulting polarization of the radiation is obtained in the above described manner.

$$\text{Polarization} = P = \frac{I_{\parallel} - I_{\perp}}{I_{\parallel} + I_{\perp}} = \frac{3(1 - j_0^2/j^2)}{9 - j_0^2/j^2}. \tag{1}$$

The experiment therefore appeared to afford a direct means for differentiating between the three systems of inner quantum numbers proposed by Sommerfeld, Landé and Bohr. Thus for the λ2537 line of mercury, as shown in Table I, the assumption of 0, 1/2 and 1 unit of angular momentum for the normal state of the mercury atom leads to values of the polarization which are readily distinguishable experimentally. Unfortunately these considerations fail entirely to explain the results obtained.

TABLE I

Percent of polarization computed from Eq. (1)

j_0	j	$I_{\parallel}/I_{\perp}$	P
0	1	2.00	33.3%
1/2	3/2	1.86	30
1	2	1.69	25.7
3/2	5/2	1.57	22.2

The experiment has been carried out with the λ2537 line of mercury and the sodium D-lines. Several different forms of discharge tube were employed, one found quite satisfactory for mercury being shown in Fig. 1. The hot wire source was a narrow platinum ribbon with a small spot of calcium-barium mixture directly opposite the pair of diaphragms of 3 mm opening. On making the focusing cylinder slightly positive relative to the activated spot on the platinum, a well defined beam of electrons could be projected into the observation chamber. By means of a quartz-glass re-entrant graded seal with a plane quartz window fused in the end, the scattering effect of the vapor surrounding the beam was reduced to a minimum. The chamber through which the beam passed was a platinum cylinder cut away in front for the observation window and in back so that the line of sight passed into the horn on the left. The entire tube was painted on the outside with lamp black, so that the horn made a very effective light trap for scattered radiation from the filament. The mercury vapor was at a pressure corresponding to $-18°C$, the lower part of the tube being immersed in an ice-salt bath. The vapor pressure on the mercury pump side was reduced by a liquid air trap. At this low mercury pressure the effect of secondary resonance radiation is practically negligible. For example, a beam of $\lambda 2537$ radiation projected through a bulb of mercury vapor at $-18°C$ is sharply defined, whereas at $0°C$ the

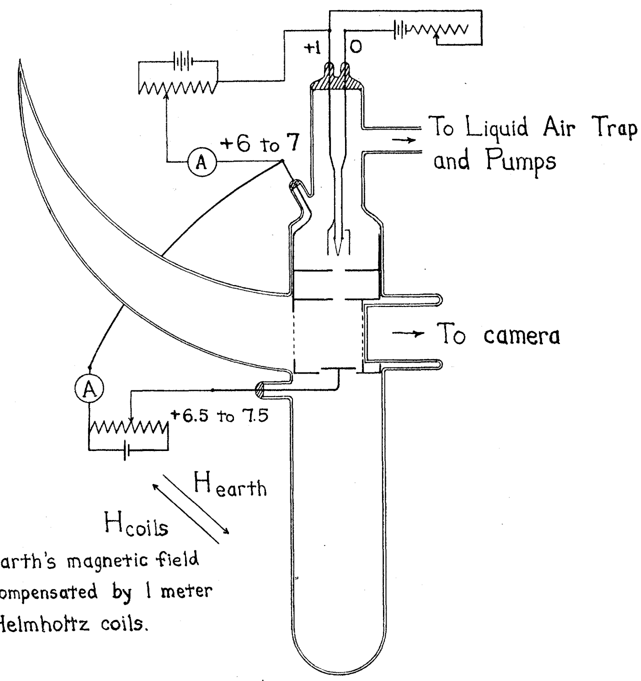

Fig. 1. Diagram of tube used for mercury vapor. The radiation produced by the beam of electrons was photographed through a quartz window by a camera with quartz lens and quartz Wollaston prism.

scattered resonance radiation diffusely fills the bulb. The portions of the discharge chamber which were cut away for the observation window and horn were covered with a very coarse grid of two or three fine platinum wires to reduce electrostatic effects. The wires by the window served as fiducial marks defining different sections of the beam.

The potential required to excite the $\lambda 2537$ line of mercury is 4.9 volts. However the next line $1S-2P$ is not produced below 6.67 volts, and since the quartz observing system was opaque to this line, fields up to 7 volts introduced no spectroscopic complications even in the excitation of λ2537 as a two-stage process. In general, the field employed was around 6 to 7 volts. A few exposures at somewhat lower voltage showed no pronounced differences. It was found necessary to use an additional electrode at the bottom of the cylinder at a potential a few tenths of a volt positive to the cylinder. In this way the effect of space charge in the beam was partially neutralized. With proper care the beam could be limited to the geometrical projection of the diaphragms and extended for about 2 cm, well past the observation window. The current represented by the beam was of the order 5 to 20 μ-amp.

The beam was photographed by means of a camera with a quartz objective. Between the objective and the tube was mounted a large quartz Wollaston prism so oriented that one image represented the intensity of the radiation polarized with the electric vector parallel to the beam and the other perpendicular. Plate I illustrates several typical exposures. The plates were photometered and a rough estimate of the intensity ratio was made on the assumption of a gamma value of 0.8 for the plate characteristic. This value is probably a fair assumption for λ2537 and the type of development employed, although of course it cannot be considered as quantitatively correct. Exposures were usually of about two hours. With mercury it was necessary to compensate for the earth's magnetic field by a pair of large Helmholtz coils since the vapor is extremely sensitive to the depolarizing action of a field. Lead-in wires for the filament current of about 5 amperes were twisted together and every precaution was taken to eliminate stray fields. Nothing but platinum was used in the construction of the discharge chamber and heavy platinum wires extended well back to the tungsten seals. These precautions were not necessary with sodium as is shown by the behavior of the resonance radiation in fields of one gauss or less. The usual high vacuum technique was employed. The tube was well baked at 360°C and, upon cooling, a drop of metal, after several distillations, was condensed in the bottom. The pressure on the fore-pump side was below that readable on a McLeod gage.

In order to be certain that the beam in mercury vapor represented true electron impacts and was not resonance radiation excited by the 2537 radiation produced between the filament and the diaphragm system, a weak magnetic field, perpendicular to the beam, was introduced by a second pair of Helmholtz coils. The beam was bent into a circular arc well out of the geometrical projection of the filament, proving the effect to be due to electrons.

Sodium. Since the beam in sodium is visible, photographic difficulties may be eliminated. The observing device consisted of a quartz wedge and nicol prism oriented for the production of fringes. No polarization was observed although a polarization of 2 percent could have been readily detected. It does not seem likely that the vapor pressure at 150°C was sufficient to have caused any depolarizing action by atomic collision. This experiment, which was made about a year ago, is an independent confirmation of the recent work by Kossel and Gerthsen.[3] They were

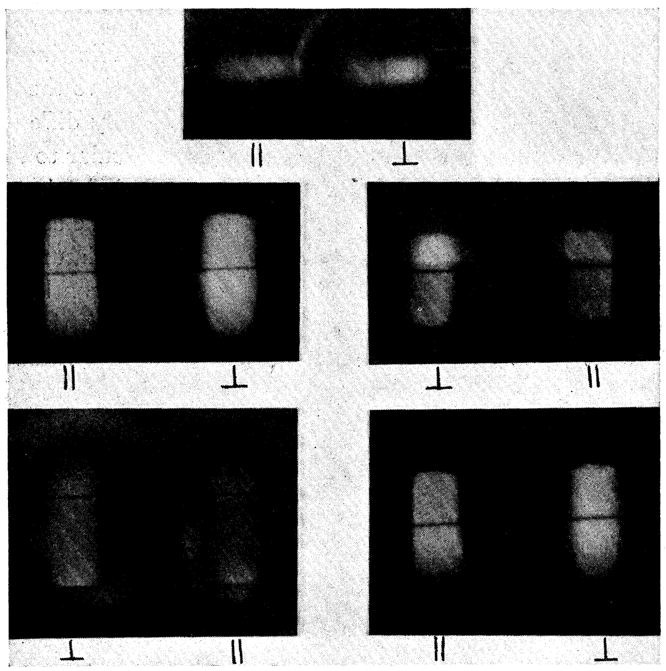

Plate 1. At −18°C the beam of λ2537 radiation from mercury vapor is sharply defined by the geometrical projection of the diaphrams limiting the beam of electrons. The width of the beam is about 3 mm. The ends of the beam are limited by the re-entrant quartz tube and window. The component of the radiation polarized with the electrical vibration perpendicular to the electron beam is about twice as intense as the parallel component. Densitometer measurements on the original negatives were made at corresponding points of the two images as determined in reference to the wire marker reproduced as a black line. Since the difference in densities of the two images is only 0.2 to 0.3 the contrast is not striking. The upper photograph was made with a tube of different design and considerable scattered radiation from the hot wire is present.

led to the experiment by theoretical considerations quite different from those proposed above. Thus, according to their theory, the predicted

[3] Kossel and Gerthsen Ann. d. Physik, *77* pp. 273-86 (1925).

polarization is about 60 percent for 3 volt impacts. Since two lines are emitted, with $\Delta j=0$ and $\Delta j=1$ respectively, in the intensity ratio 1:2 we should expect, on the basis of Sommerfeld's quantum numbers, a polarization of 20 percent.

Mercury. With mercury vapor in the absence of any applied magnetic field, we find a polarization of about 30 percent with the greatest intensity of the electrical vibration having its direction perpendicular to that of the electron beam. The polarization therefore is in the opposite direction to that predicted by the theory outlined above and by that of Kossel and Gerthsen.

Using a uniform magnetic field of about 3 gauss, the following observations were made with mercury vapor. (1) A field parallel to the direction of motion of the electrons produced no effect perceptibly different from that without the field. (2) When the field was perpendicular to the direction of motion of the electrons, the radiation emitted along the field was unpolarized and that emitted perpendicular to both the electron beam and the field showed a polarization of 13 percent, the maximum intensity of the electric vibration being perpendicular to the electron beam.

These effects with the field are in the proper direction if the field produces a Larmor precession in the excited atom so that it radiates with the same distribution of polarization and intensity as it would in the absence of the field, but with the atom rotated through some angle determined by the time of excitation and the precessional velocity.

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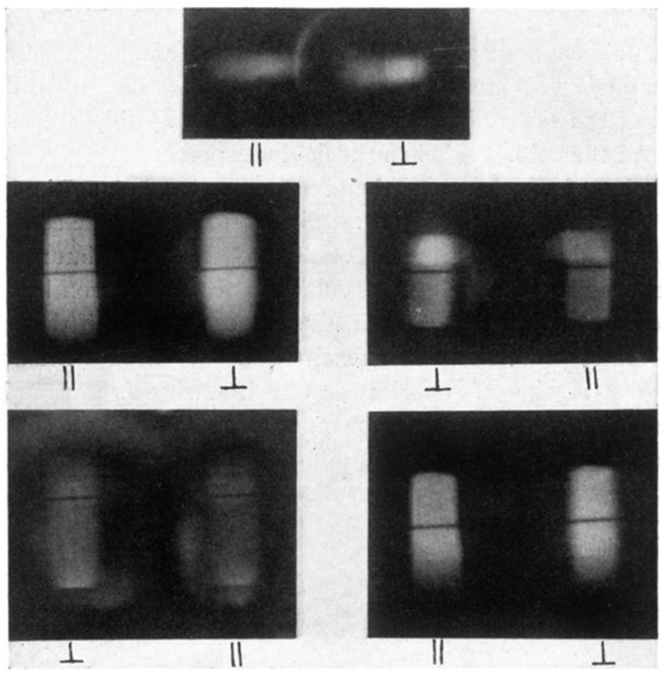

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