THE EFFECT OF EXTERNAL FIELDS ON THE POLARIZATION OF THE LIGHT IN HYDROGEN CANAL RAYS

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Abstract

Hydrogen canal rays were allowed to pass through a cathode so constructed that the light of the canal particles could be observed in the 6 mm length of the canal, for a distance of 5 mm below the canal, and for several cm in the high vacuum chamber above the canal in which the intensity of the light falls off exponentially. The light of the canal rays in the canal and below it is partially polarized with the amount of polarization depending on the material of the cathode. The ratio of the intensity of the light vibrating in the direction of motion of the particles to that perpendicular to the motion is 1.20 for brass and only 1.09 for aluminum. Beyond the canal the polarization falls rapidly and completely disappears in a distance of 6 mm. When electric fields are applied to the canal ray, the dying out of the polarization is disturbed and fluctuations of the degree of polarization occur which are nearly periodic along the length of the beam. With fields perpendicular to the ray the number of these changes in the polarization in a given length increases slightly with increase of field strength. The wave-length of one of these changes varies almost directly with the velocity of the rays. For electric fields parallel to the beam the wave-lengths are constant for all field strengths and decrease with increase of velocity. Weak magnetic fields applied perpendicular to the canal ray reduce the polarization of the light in the canal and below it. These results are in agreement with the effect of magnetic fields on the polarization in resonance radiation. In the high vacuum chamber the magnetic fields also produce periodic changes in the polarization. The variation of the wave-length with increasing fields depends on the orientation of the field.

The polarization of the light emitted by canal rays was first observed by Stark[1] and quantitatively studied in 1915 by Stark and Luneland.[2] Lately observations have been extended to include the light emitted by canal rays in a high vacuum, where the total intensity of the light from the bundle was shown by Wien, and Dempster to fall exponentially. The polarization has been shown in this case to disappear a short distance from the end of the canal. The distance is given as 5–15 mm by Hertel[3] depending on the potential across the discharge tube, while Rupp[4] obtains no polarization at 3 mm from the canal, and Stark[5] at about 1 mm. A similar fall in the polarization near the end of the canal was also found by von Hirsch and Döpel.[6] The polarization is expressed as the ratio of the electric component vibrating in the direction of the motion of the particles to that vibrating at right angles to the motion, and its possible cause may be the orientation of the molecules in the canal ray in the direction of its motion due to frequent

[1] Stark, Verh. d. D. Phys. Ges. **8**, 104 (1908).
[2] Stark and Luneland, Ann. d. Physik **46**, 68 (1915).
[3] Hertel, Phys. Rev. **29**, 848 (1927).
[4] Rupp, Ann. d. Physik **79**, 1 (1926); **85**, 515 (1928).
[5] Stark, Die Axialität d. Lichtemission u. Atomstruktur, Berlin, (1927).
[6] R. v. Hirsch and R. Döpel, Ann. d. Physik **82**, 16 (1927).

collisions with the molecules of the rest gas, or to the influence of their ionic fields.

The effect of a magnetic field applied to the canal ray has been described by Rausch von Traubenberg and Levy[7] who obtained results analogous to those obtained by Hanle, Wood and others for the polarization of resonance radiation in mercury vapor. For canal rays in a high vacuum chamber Hertel and Rupp have investigated the effect of applying a transverse electric field and have found that the dying out of the polarization is disturbed and regular periodic variations of the polarization occur along the length of the canal ray. In the following experiments the effect on the polarization of the light in canal rays is described when electric and magnetic fields were applied in different directions.

Apparatus

Hydrogen canal rays were obtained through a cathode having a rectangular canal 6 mm long (Fig. 1). The cathode was constructed so that the light from the canal rays could be observed for a length of 5 mm before it entered the canal, then throughout the 6 mm length of canal, and finally in the high vacuum chamber beyond the canal. It consisted of two parts fastened together by screws. The back half had one plane face in which a slit was cut 6 mm long and of rectangular cross section measuring 0.46 mm wide and 1 mm deep. Below this was a large chamber communicating with the discharge tube and at the same pressure. Immediately below the slit a thin metal strip was placed at a distance of 1 mm back from the plane face, so that the light seen in the lower chamber was only slightly more intense than that seen in the slit. The slit in the back half was covered by a microscope cover glass which was kept in place by the front half. The front half of the cathode was as high as the back half and itself had a slit of 0.7 mm wide and 11 mm long exactly facing the slit and the metal strip in the back half, to allow observations of the light in the canal. The plane faces of the two parts of the cathode were ground flat in the optical shop of the laboratory so that no gas should pass through the interface when these were in contact. The microscope cover glass was cut to shape and placed between the two parts which were then fastened together with screws. The bottom surface of the assembled cathode was ground flat and placed on a ground glass joint separating the discharge tube from a high vacuum chamber, so that diffusion

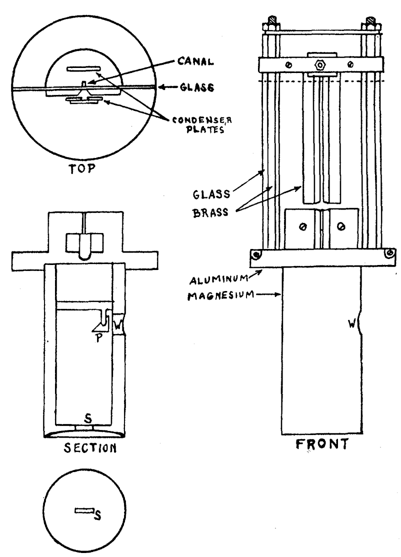

Fig. 1. Diagram of apparatus.

[7] Rausch von Traubenberg and Levy, Zeits. f. Physik **44**, 549 (1927).

of hydrogen gas from the discharge tube to the high vacuum observation chamber could only take place through the top of the slit in the back half of the cathode. A magnesium cup collimating the canal beam was fastened to the cathode. A totally reflecting prism P was held in the cup so that it reflected the light from the collimating slit S through a window W into the slit of a spectroscope for observing the Doppler effect.

The discharge tube was 50 cm long and 2.5 cm in diameter. Hydrogen was generated electrolytically from barium hydroxide solution, passed through platinized asbestos and phosphorus pentoxide for removal of oxygen and water vapor and stored in a reservoir. From the reservoir it flowed into the discharge tube through a capillary in which was inserted a glass rod. The rod was attached to a piece of iron and by moving the iron with a magnet the rod was adjusted so that the rate of inflow gave the desired pressure in the discharge tube. The gas which passed through the slit in the cathode into the high vacuum observation chamber was rapidly removed by a three stage Gaede all-steel mercury diffusion pump which was connected to it through a large liquid air trap. The pressure in the discharge tube was measured by a McLeod gauge, and that in the observation chamber by an ionization gauge previously calibrated with the McLeod gauge. The pressure ratio between the discharge and observation chamber was about 200 to 1. An alternating current transformer rectified with one kenetron thus giving only half of the cycle was used to supply the current for the discharge tube. The voltage across the discharge tube was measured by an electrostatic voltmeter. The cathode was always grounded.

For the experiments on the effect of magnetic fields on the polarization, Helmholtz coils were placed outside the observation chamber. The coils were 16 cm in diameter and placed so that the canal ray was in the uniform part of the field. One pair of coils was oriented so as to compensate for the earth's magnetic field throughout all the experiments. Electric fields were obtained by condenser plates supported on glass rods fastened to the cathode. Fig. 1 shows the condenser used to apply an electric field perpendicular to the canal ray but in the direction of the line of vision. The front condenser plate had a slit 0.7 mm wide through which the canal ray was viewed. For applying successive fields in opposite directions two condensers were used, both connected to the same source of potential but having the directions of their fields opposite in sense. The condenser plates were joined to a potentiometer for applying the required voltage. They were always placed symmetrically with respect to the canal beam and the potential on each adjusted so that the grounded cathode was midway between the two. To apply an electric field along the ray, a piece of brass gauze of fine mesh was stretched across the glass supports a distance of 3 cm above the canal end as indicated by the dotted line in the diagram of the cathode Fig. 1. All condensers were made of brass which was blackened with a solution of silver nitrate in nitric acid. The velocity of the rays was obtained by photographing the lines Hβ and Hγ and their Doppler components through a Steinheil three prism spectrograph. The light for this was reflected by the prism W in the magnesium cup of the cathode into the slit of the spectroscope.

Method of Photometry and Intensity Measurements

Observations were made through a calcite crystal cemented with Canada balsam to a good piece of plate glass which was fastened with wax to an opening in the observation chamber. Photographs of the bundle were obtained through an ordinary camera placed near the calcite crystal. The calcite crystal was oriented to produce two images of the canal beam side by side, one image of the light vibrating parallel to the motion of the particles and the other of the light vibrating perpendicular to it. The camera gave a magnification of the image of 1.5. On each photographic plate a series of intensity spots were placed on both sides of the canal-ray images. This was obtained by placing the plate in a sensitometer consisting of a series of 10 holes of various diameters uniformly illuminated by a milk glass screen. The holes were all at a distance of 7 cm from the plate and the light from each passed through a separate tube blackened on the inside and fell on the plate. The intensity of the light from each hole was proportional to the area of the hole. The milk glass screen was illuminated by the light from the hydrogen discharge tube immediately below the cathode so that the quality of the light producing the intensity spots was the same as that producing the images of the canal beam; the blackenings of the intensity spots on the plate could be interpreted as relative intensities and a calibration curve was thus obtained for each plate. Cramer Hi-Speed plates were used so that the measurements pertain mainly to $H\beta$ and $H\gamma$ which predominate in the canal-ray spectrum. Exposures of the canal ray were taken for 20 minutes and immediately after that the intensity spots were photographed on the same plate for the same length of time. Separate exposures of 3 minutes each were taken of the beam in the slit of the cathode and below. The plates were developed in strong contrast Glycin developer.

Measurements of the blackening on the plates were made with a Moll microphotometer. For the image of the beam in the slit of the cathode and below it, a photographic register of the intensity was obtained by reducing the length of the image of the illuminating slit of the microphotometer to less than the width of the canal beam image. First one of the two images produced by the calcite crystal and then the other was moved past the illuminating slit. The intensity spots were also registered on the photographic trace. A different procedure was used for measuring the intensities of the images of the bundle in the high vacuum chamber. The slit of the microphotometer was removed and the filament of the lamp was focussed on the photographic plate. The opening to the thermopile was then reduced so that only the light from a region $\frac{1}{4}$ mm$\times\frac{1}{2}$ mm on the plate entered the thermopile. The Moll galvanometer was replaced by a Leeds and Northrup high sensitivity galvanometer giving large deflections which were observed visually. The canal-ray images were placed horizontally and the plate holder given a slow vertical motion so that first one beam then the second moved past the illuminating cone of light and the galvanometer deflections were observed for the maximum blackening in the center of each beam. Such pairs of readings were taken at points 1 mm apart or less along the length of the canal beams. With the same arrangement the deflections produced by the intensity spots were also measured. From these a calibration curve was drawn for each plate and the deflections of the canal beam images could then be changed into intensity readings. These were plotted for each beam and a smooth curve drawn. The ratio of the intensities as read from these curves was then plotted as the polarization. By taking the readings from a smooth curve any local imperfection in the plate which may cause a wrong reading in any of the beams will not affect the final polarization curve.

Experiments were first carried out with a cathode and condenser plates made of iron. With this cathode it was found that the fall of intensity of the light along the canal bundle was not purely exponential. For a distance of 1 mm from the canal end the intensity fell rapidly, after which it changed but little for a distance of 1–1.5 mm. From there on the intensity fell exponentially. When the separate curves for the intensity of the light parallel and perpendicular to the direction of motion of the canal rays were plotted, these deviations from exponential fall were much more marked for the intensity perpendicular to the beam than that for the intensity parallel to it. Departures of this type from the exponential fall of the total intensity near the canal end were also observed by Wien[8] and have lately been shown by Port[9] to be due to a constant outgassing by the material of the cathode. Port has obtained an exponential curve for the intensity right up to the canal end. This he achieved by heating the cathode for a long time using a high voltage discharge. In these experiments the discharge was maintained for 11 hours at 8000 volts and 6 milliamperes without much change in the deviations from the exponential fall. The iron cathode was abandoned due to the influence of the residual magnetism in the iron on the polarization of the canal ray.

The cathode described above and shown in Fig. 1 was then constructed of brass. The polarization ratio in the canal was found to be about 1.20. The brass, however, sputtered strongly and the cover glass in front of the slit of the cathode became almost opaque after 10 or 15 minutes. An aluminum cathode of the same design was then made which removed the difficulty of sputtering. With both the brass and the aluminum cathodes a discharge was run through the tube for an hour or two before exposures were taken, and as a result it was found that the deviations from the exponential fall of intensity observed with the iron cathode were quite inapparent with the brass and aluminum ones. However, in all the photographs with aluminum the initial polarization ratio was never more than 1.09. This reduction in the polarization would have to be entirely ascribed to the metal as no changes were made in the optical system when the brass cathode was replaced

[8] Wien, Ann. d. Physik **60**, 597 (1919); **66**, 229 (1921).

[9] Port, Ann. d. Physik **87**, 581 (1928).

by the aluminum one. According to Baerwald[10] the electron emission when a metal is bombarded by canal rays is greater for the component elements of brass than for aluminum. The stream of emitted electrons can cause additional polarization as has been shown by Skinner[11] and others and this may account for the polarization in the brass cathode being greater than in the aluminum one.

Three potentials were used across the discharge tube in the following experiments, viz., 5000, 10000, and 15000 volts. The Doppler effect at these potentials indicated that the rays had velocities 4.9×10^7, 7.0×10^7 and 8.1×10^7 cm/sec respectively. In the following figures the ratio I_p/I_n is plotted along the length of the canal ray, where I_p is the intensity of the electric vector parallel to the motion of the canal beam and I_n the intensity at right angles to the motion. In Curves 1 and 2 (Fig. 2) the exponential fall of intensity of the canal ray is shown in dotted line, and the changes in the polarization ratio in heavy line. In the chamber below the slit the polariza-

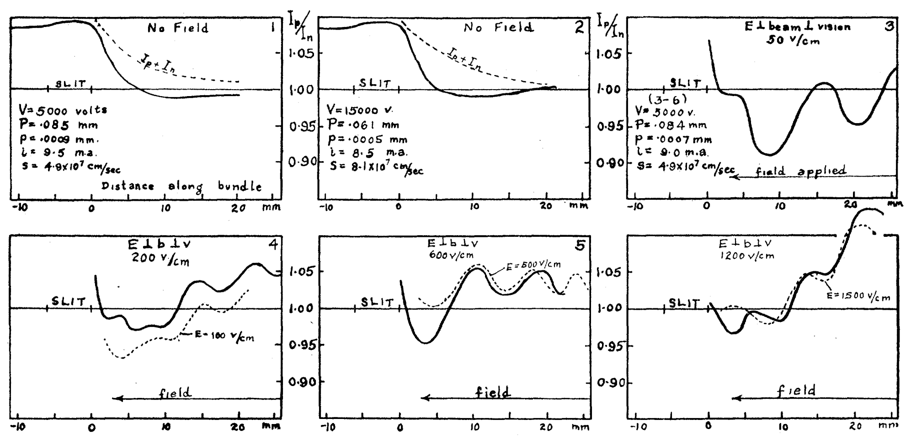

Fig. 2. Curves 1–2, no field, fall of total intensity in dotted lines. Curves 3–6, electric fields perpendicular to beam, and perpendicular to vision. E, electric field applied to canal beam, in volts per cm. H, magnetic field applied to canal beam, in gauss. V, Potential across discharge tube, in volts. P, pressure in discharge tube, in mm of mercury. p, pressure in observation chamber, in mm of mercury. i, current through discharge tube, in milliamperes. s, velocity of canal-ray particles, in cm per second.

tion was found to be constant and the ratio I_p/I_n was 1.08. At the beginning of the slit a slight rise in the polarization was observed and a value of the ratio of 1.09 prevailed throughout the length of the slit. This value was unchanged as the potential across the discharge tube was raised from 5000 to 15000 volts. When the bundle leaves the slit and enters the high vacuum chamber there is a rapid decrease in the polarization, the ratio falling from 1.09 to 1.0 in about 6 mm from the end of the canal. This decrease is seen to be more rapid than that observed by Hertel and to agree better with the observations of Rupp. As the potential in the discharge tube is increased

[10] Baerwald, Ann. d. Physik **41,** 662 (1913).
[11] Skinner, Nature **117,** 418 (1926).

from 5000 volts to 15000 volts the curve of the fall of polarization is not changed appreciably. In the case of the Stark effect, Bloch[12], Rausch v. Traubenberg and Gebauer,[13] have shown that as soon as the radiating atoms pass out of the electric field they no longer emit the Stark effect components of the spectral lines. In these experiments the gas diffusing from the discharge chamber into the observation chamber is reduced to the pressure of the observation chamber within 1 mm (equal to the width of the canal) from the canal end. After this the canal-ray particles can no longer be affected by the electric fields of neighboring rest gas molecules as is the case in the canal and below it. The radiation however, unlike the case of the Stark effect does not become unpolarized immediately but retains some degree of polarization for a short time corresponding to 4 or 5 mm path after the atoms in the moving canal beam have escaped the influence of neighboring rest atoms.

Effect of Electric Fields on Polarization

Field, canal beam and direction of vision at right angles to each other. Curves 3–6 (Fig. 2) indicate the change produced in the polarization when an electric field perpendicular to the canal ray and the line of vision is applied. This field began at a distance of 3 mm from the canal end. The curves show that the dying out of the polarization observed with no electric field is disturbed, and periodic variations in the polarization are introduced. If we call the distance from the maximum of one of the variations to the maximum of the next a "wave-length" then the curves indicate that as the field strength is increased the "wave-length" gets shorter, but no direct proportionality is seen. The dotted curves 3,4,5, are the curves obtained by Hertel at slightly different field strengths The agreement is very close except at the beginning of the beam where no diminution of the initial polarization as indicated by Hertel's curves was noted.

Successive fields in opposite directions. To observe whether the direction of the field has an effect on the polarization two condensers were set up one above the other whose fields were of the same strength but opposite in sense. The lower condenser was 7 mm long and placed at a distance of 1.5 mm above the cathode and the second condenser was 3 mm above the first. Curves 7–13 (Fig. 3) give the results for this directional change in the field. Curve 8 has the same type of periodicity as the corresponding curve 4 except that the part of the curve in the second condenser has a downward trend instead of continuing up as in 4. The same effect is observed on comparing curve 9 with curve 6, and curve 10 with Fig. 5*F* of Hertel, viz., a trend of the polarization in the second field opposite to that in the first but with same periodic variation. Curves 11–13 taken with a discharge potential of 10000 volts indicate very similar variations except that the wave-lengths are longer than in the case of 5000 volts. Comparison of curves 12 and 8 yields a ratio of

[12] Bloch, Zeits. f. Physik **35,** 894 (1926).
[13] Rausch v. Traubenberg and Gebauer, Zeits. f. Physik **44,** 762 (1927).

the wave-lengths almost equal to the ratio of the velocities of the canal rays used in the two cases. This indicates that the changes in the polarization occupy the same time in both cases.

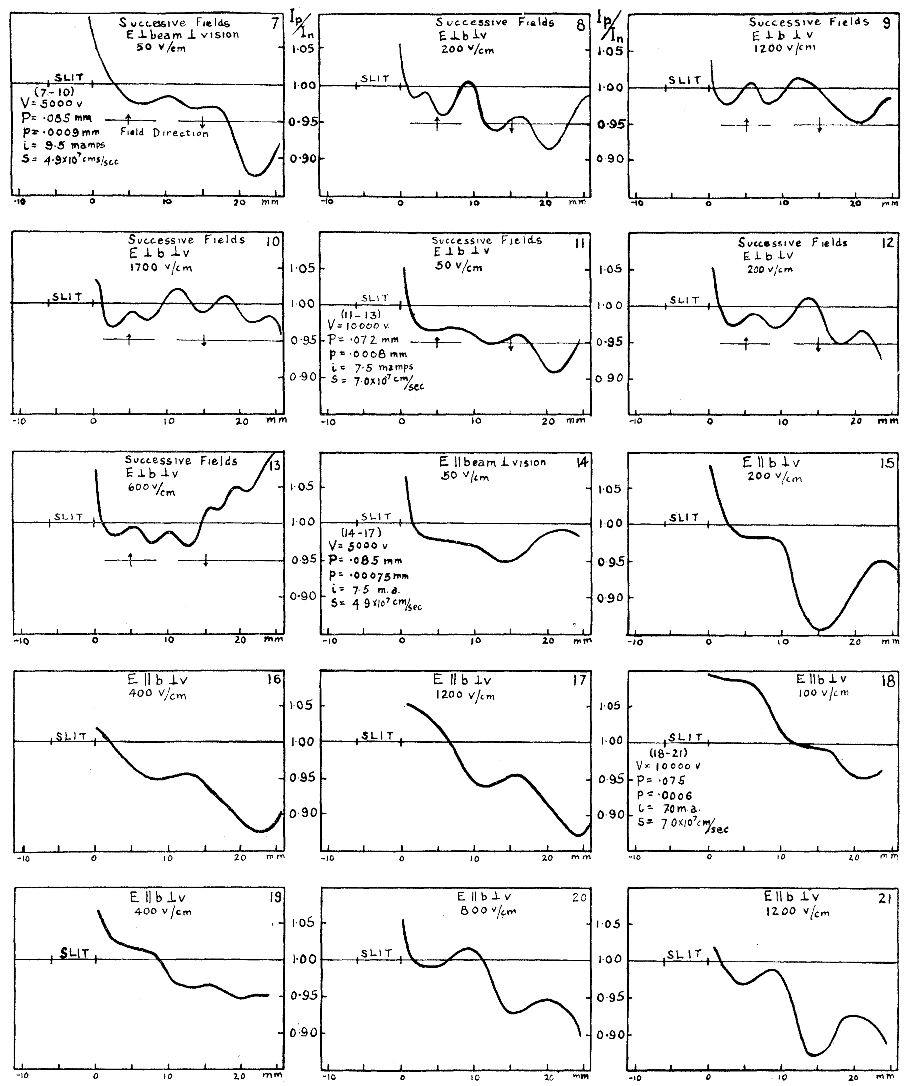

Fig. 3. Curves 7–13, successive electric fields in opposite directions. Curves 14–21, electric fields parallel to beam, and perpendicular to vision.

Field along the direction of vision and at right angles to the beam. The condenser used was that shown in the diagram of the cathode. The results obtained are collected in curves 22–30 (Fig. 4). It will be noticed as the strength of the applied field is increased the initial polarization is decreased, the ratio becoming less than 1.0 for a field greater than 200 volts per cm.

The decrease in the wave-length is noticeable up to 200 volts per cm after which it remains constant. However, the amplitude of the waves is increased with the field and the maximum of the first wave approaches the end of the slit. Comparison of curves 29, 27 and 23, and 30 and 28 indicates that as the velocity of the rays is increased the wave-length of the variations is also changed, although not in the same proportion as the increase in the velocity of the rays.

Electric field along the direction of the beam and perpendicular to the direction of vision. To obtain this field a metal gauze placed 3 cm above the canal

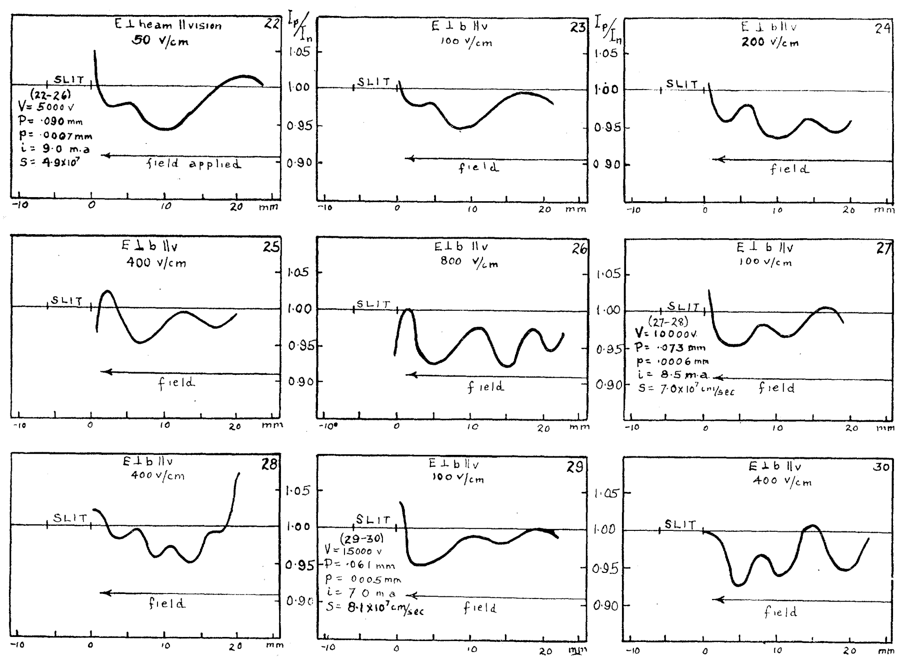

Fig. 4. Curves 22–30, electric fields perpendicular to beam, parallel to line of vision.

was joined to a set of B batteries connected in series which were capable of giving an electric field of 1200 volts per cm. A general downward trend of the polarization is observed in all curves (14–21) with this field, and this decrease of I_p/I_n becomes more marked for strong fields. The effect is at first not recognized as a periodic variation but with field strengths of over 400 volts per cm this becomes clear. Unlike the effect of the fields transverse to the beam the wave-length here does not decrease with larger fields but is practically constant. The increased field strength again seems to have the effect of causing more accentuated wave forms rather than changes in the wave-length. As the potential across the discharge tube is raised from 5000 to 10000 volts the wave-length for any given field strength is shortened. This may be seen on comparing directly curve 19 with 16 and 21 with 17, or even curve 18 for 100 volts per cm with either 14 or 15. This stands in contrast to the effect of transverse electric fields on the beam where the wave-length of the change in polarization for any field strength was increased when the velocity of the rays was made greater, although the increase was not always proportional to the increase in velocity.

If the periodic variations in the polarization described above are due to modified radiation produced by the applied electric field then one should be able to deduce the period of the variation from the formula for the Stark effect. Kramers[14] has derived such a formula for the Stark effect in weak fields for spectral lines which have a fine structure. He obtained

$$\Delta\nu=-\frac{9}{4}\left(\frac{h}{2\pi}\right)^8\frac{c^2E^2}{e^{10}m_0^3}\,\frac{n^5k}{h}(n^2-2k^2+m^2)$$

for the additional frequency of the Stark component. For a field of 50 volts per cm this would give for the first component of $H\beta$ a frequency of 2×10^7 sec^{-1} which is of the same order of magnitude as that represented by the period of the variation in the polarization produced by such a field (cf. graphs 4, 8, 24). The formula moreover requires that the imposed frequency should increase according to the square of the applied field. The graphs for applied electric fields do in general indicate an increase in the number of waves but the increase is not very rapid. With fields perpendicular to the beam the number of waves increases until fields of about 400 volts per cm are reached, while with fields parallel to the beam the number of waves remains constant. The requirement for the increase in the number of waves with the square of the velocity is certainly not fulfilled. The period for each wave is also found to vary with the velocity of the canal ray, a variation not indicated by the Kramers theory. The results of Rupp although varying in certain details from those found by Hertel, or given here, do not agree with the Kramers theory either.

Hanle[15] in his experiments on the effect of electric fields on the polarization of resonance radiation of mercury makes use of the theory of the anharmonic oscillator to give a "classical" explanation to his results. The effect of an electric field on an anharmonic oscillator vibrating along a line inclined to the direction of the field is to produce a difference in the frequency between the component of the vibration along the field and the component perpendicular to the field. In time there ensues a phase difference between the two components which changes the original linear oscillation into an elliptic motion. The ratio of the minor axis to the major axis of the ellipse constantly increases until the motion again becomes linear for a phase difference of π. The motion then reverses and is repeated back and forth while at the same time the amplitude is being reduced due to the damping of the oscillation.

In the canal ray the initial polarization may be considered to be due to a large number of anharmonic oscillators vibrating along directions making an angle of less than 45° with the direction of the ray, and a lesser number

[14] Kramers, Zeits. f. Physik **3**, 214 (1920).
[15] Hanle, Zeits. f. Physik **35**, 346 (1926).

at angles greater than 45°. When an electric field is applied these inclined oscillators become elliptically polarized and their major axis vibrates about the direction of the field. As the particles move along in the canal beam one observes at successive points in space successive states of the ellipticity of the oscillator and when viewing through a fixed calcite crystal this produces different ratios of the intensities in two perpendicular directions; as the ellipticity repeats itself it will produce waves in the polarization. The theory of the anharmonic oscillator also requires an increase in the number of waves proportional to the square of the field applied as well as no change in the number of waves per second with the velocity of the rays. Dependence of the number of waves on the square of the field strength signifies an independence on the direction of the field. The results with successive fields in opposite directions do give practically the same wave-lengths as a unidirectional field but at the same time the general trend of the polarization is shown to be reversed when the direction of the field is reversed.

Effect of Magnetic Fields on Polarization

The application of magnetic fields to the canal rays should affect not only the canal ray in the high vacuum chamber but also the light in the slit and in the discharge tube below the slit. The change in the polarization of this light is also indicated in all the curves with magnetic fields.

Experiments on the depolarization of the light from a canal-ray bundle caused by a magnetic field, where the pressure was the same as that of the discharge tube, have recently been carried out by Rausch v. Traubenberg and Levy.[7] The observations reported here agree in general with their results.

Below the slit where the pressure is high the polarization was found to be constant and decreased with greater field strengths. For any value of the magnetic field strength the polarization remains the same as the velocity of the rays is increased. The polarization of the light in the slit is slightly higher than that below the slit and remains constant along the length of the slit except near the end where there is a slight fall in the polarization. The polarization falls with increase of the magnetic field the same amount as that of the light below the slit. Near the canal end, however, the polarization falls more rapidly.

The experiments on the effect of magnetic fields on the polarization of resonance radiation of mercury have been fully explained by Breit[16] and others on the classical theory of the behavior of a linear oscillator in a magnetic field. The oscillator performs a Larmor precession in the magnetic field while at the same time the damping reduces the amplitude of the oscillation. When the Larmor precession and the damping factor are of the same order of magnitude then the resultant light is seen to be partly depolarized, and the plane of polarization is inclined at an angle of less than 45° to the original plane of polarization of the oscillator. All the predictions

[16] Breit, Jl. Opt. Soc. **10**, 439 (1925).

of this theory have been experimentally verified by Ellett,[17] Hanle[18] and Fermi and Rasetti.[19]

If the fall in the polarization of the light in the canal rays with magnetic fields is also due to the depolarization produced by the precession of an oscillator in a magnetic field, then the values of the polarization can be calculated for different field strengths. For a field applied along the direction of vision Breit has shown that the resulting degree of polarization is

$$P_l' = P_0 \cos 2\phi$$

where P_0 is the degree of polarization with no field defined as $(I_p - I_n)/(I_p + I_n)$, and ϕ is the angle through which the plane of polarization was rotated by the field; it is given by

$$\tan 2\phi = L/k$$

where L is the Larmor precession $\frac{1}{2}(e/mc)H$, and k the damping factor which is given for hydrogen as 3×10^7 sec^{-1} by Wien. In our case where the calcite crystal is held in one position and the components I_p and I_n are always measured along the line of motion of the particles and perpendicular to it

$$P_l = P_0 \cos^2 2\phi .$$

Expressed in the ratio of I_p/I_n this becomes

$$\frac{I_p'}{I_n'} = \frac{(I_p/I_n)(1+\cos^2 2\phi)+\sin^2 2\phi}{(I_p/I_n)\sin^2 2\phi+(1+\cos^2 2\phi)} .$$

The polarization in the slit and below it as taken from the curves 31–40 (Fig. 5) is given in Table I. A value for the polarization is also given which

TABLE I

H (gauss)	5	15	20	25	30
I_p/I_n below slit	1.08	1.04	1.03	1.02	1.01
Calculated	1.07	1.04	1.03	1.02	1.01
I_p/I_n in slit	1.08	1.04	1.03	1.02	1.01
Calculated	1.08	1.04	1.03	1.02	1.01

is calculated on the basis of $k = 15 \times 10^7$ sec^{-1} which was found to give agreement with the experiments on taking a value of I_p/I_n for zero magnetic field of 1.09. The reason for the high value assumed for k may be that in the high pressure that exists below the slit and for some distance in it the damping factor is large, due to additional damping introduced by collisions. The theory of the collision damping factor was worked out by Wien and its magnitude under different conditions determined by Dasanacharya.[20] For potentials of 10000 volts and 15000 volts on the discharge tube and a pressure

[17] Ellett, Jl. Opt. Soc. **10**, 427 (1925).
[18] Hanle, Ergebnisse de. Exakten Naturwiss. **4**, 214 (1925).
[19] Fermi and Rassetti, Zeits. f. Physik **33**, 246 (1925).
[20] Dasanacharya, Ann. d. Physik **77**, 697 (1925).

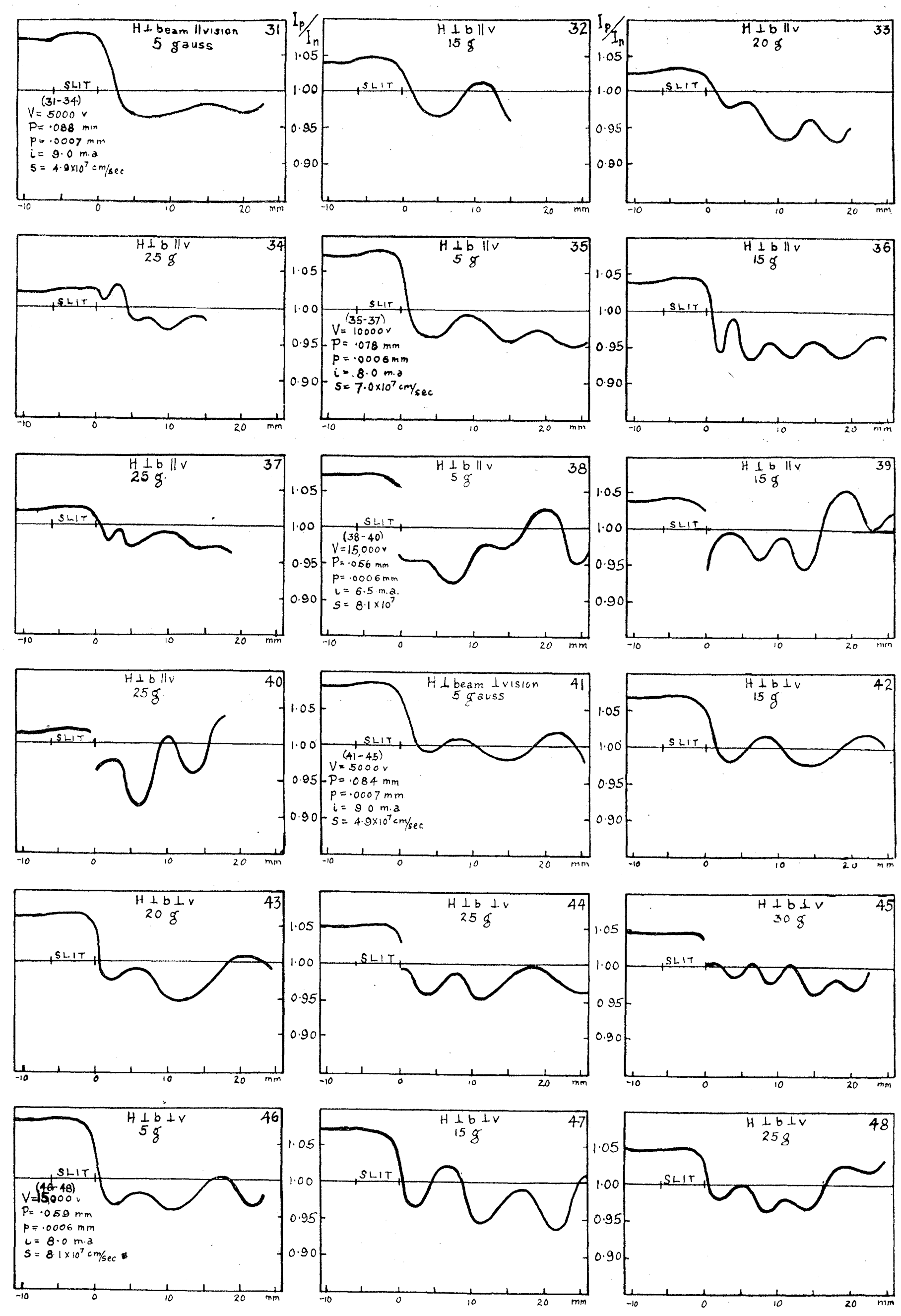

Fig. 5. Curves 31–40, magnetic fields perpendicular to beam and parallel to line of vision. Curves 40–48, magnetic fields perpendicular to beam and to line of vision.

of 0.078 mm and 0.059 mm respectively, the value of $k = 15\times 10^7$ sec^{-1} agrees closely with the results of Dasanacharya as well as those of Rausch v. Traubenberg and Levy. The collision damping factor would also qualitatively explain the more rapid fall of the polarization near the end of the slit where the pressure is lower and the damping factor smaller. With a fixed orientation of the calcite crystal it was not possible to tell whether there was also a rotation of the plane of polarization so that the proof that the results are due to a Larmor precession is not complete.

The observations of the polarization in the high vacuum chamber show a regular increase in the number of waves in the polarization curve beyond the slit. This might also be connected up with the Larmor precession, as the time of one revolution is of the same order of magnitude as the "period" represented by one of the waves. As the magnetic field is increased the "period" should decrease. This is qualitatively shown in all the curves, the exact ratio however is only approached in the curves for 5000 volts discharge potential. In the graphs for 5000 and 10000 volts the curve in the slit is shown as joined up with the curve in the high vacuum, although the photographs of the light in the slit were taken on different plates from those of the light in the canal. For 15000 volts the initial polarization ratio in the high vacuum measured near the slit was always found to be less than 1.0 indicating a very rapid change of the polarization at the end of the slit.

Magnetic field at right angles to the beam and to the line of vision. In the slit and below it there is again a depolarization as the magnetic field is increased. Using Breit's formula for the degree of polarization in a transverse field we have

$$P_t = \frac{P_0(2+L^2/k^2)}{2+(L^2/k^2)(2-P_0)}$$

or

$$\frac{I_p''}{I_n''} = \frac{1}{2}\,\frac{(I_p/I_n)(2+L^2/k^2)+L^2/k^2}{1+L^2/k^2}.$$

Table II gives the calculated values again using $k = 15\times 10^7$ sec^{-1} and the observed values give good agreement with the theoretical ones. No rotation of the plane of polarization is required by theory.

TABLE II. *Observed and calculated values of I_p/I_n.*

H (gauss)	5	15	20	25	30
I_p/I_n (obs.)	1.08	1.06	1.05	1.05	1.05
Calculated	1.083	1.069	1.063	1.057	1.051

In the high vacuum there seems to be a constant number of waves for fields up to 25 gauss with 5000 volt discharge potential. Extremely rapid changes in polarization at the end of the slit are found with 25 and 30 gauss. A slight decrease in the wave-length is observed with higher fields with 15000 volt discharge potential, while in general the wave-length is smaller for the 15000 volt discharge than for the 5000 volt discharge.

Conclusion

Application of electric or magnetic fields to a canal ray in high vacuum causes a periodic variation of the polarization along the length of the beam. Strong fields usually increase the number of changes in the polarization in the length observed, but sometimes only increase the amplitude of the variation. The effect of magnetic fields on the polarization of the canal rays before entering the high vacuum is that which would be expected from the theory of the Larmor precession of a harmonic oscillator.

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Note added in proof. In a recent paper, Ann. d. Physik **87**, 285 (1928), Rupp finds periodic changes in the polarization in a distance of 5 mm from the canal end only when a field is applied at 45° to the ray. His previous results with transverse and longitudinal electric fields he ascribes to inhomogeneity in the field. The results described above, however, were taken for a distance of 2.5 cm in the homogeneous part of the field.