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XV. *The Magnetic and Electric Deviation of the easily absorbed Rays from Radium.*

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RADIUM gives out three distinct types of radiation:—

(1) The α rays, which are very easily absorbed by thin layers of matter, and which give rise to the greater portion of the ionization of the gas observed under the usual experimental conditions.

(2) The β rays, which consist of negatively charged particles projected with high velocity, and which are similar in all respects to cathode rays produced in a vacuum-tube.

(3) The γ rays, which are non-deviable by a magnetic field, and which are of a very penetrating character.

These rays differ very widely in their power of penetrating matter. The following approximate numbers, which show the thickness of aluminium traversed before the intensity is reduced to one-half, illustrate this difference.

Radiation.	Thickness of Aluminium.
α rays	·0005 cm.
β rays	·05 cm.
γ rays	8 cms.

In this paper an account will be given of some experiments which show that the α rays are deviable by a strong magnetic and electric field. The deviation is in the opposite sense to

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[*] Communicated by the Author.

that of the cathode rays, so that the radiations must consist of positively charged bodies projected with great velocity. In a previous paper[*] I have given an account of the indirect experimental evidence in support of the view that the α rays consist of projected charged particles. Preliminary experiments undertaken to settle this question during the past two years gave negative results. The magnetic deviation, even in a strong magnetic field, is so small that very special methods are necessary to detect and measure it. The smallness of the magnetic deviation of the α rays, compared with that of the cathode rays in a vacuum-tube, may be judged from the fact that the α rays, projected at right angles to a magnetic field of strength 10,000 C.G.S. units, describe the arc of a circle of radius about 39 cms., while under the same conditions the cathode rays would describe a circle of radius about ·01 cm.

In the early experiments radium of activity 1000 was used, but this did not give out strong enough rays to push the experiment to the necessary limit. The general method employed was to pass the rays through narrow slits and to observe whether the rate of discharge, due to the issuing rays, was altered by the application of a magnetic field. When, however, the rays were sent through sufficiently narrow slits to detect a small deviation of the rays, the rate of discharge of the issuing rays became too small to measure, even with a sensitive electrometer.

I have recently obtained a sample of radium[†] of activity 19,000, and using an electroscope instead of an electrometer, I have been able to extend the experiments, and to show that the α rays are all deviated by a strong magnetic field.

Magnetic Deviation of the Rays.

Fig. 1 A shows the general arrangement of the experiment. The rays from a thin layer of radium passed upwards through a number of narrow slits, G, in parallel, and then through a thin layer of aluminium foil ·00034 cm. thick into the testing vessel V. The ionization produced by the rays in the testing vessel was measured by the rate of movement of the leaves of a gold-leaf electroscope B. This was arranged after the manner of C. T. R. Wilson in his experiments on

[*] Phil. Mag. Jan. 1903, p. 113. It was long ago suggested by Strutt (Phil. Trans. Roy. Soc. 1900) that the α rays consist of positively charged particles projected from the active substance. The same idea has lately been advanced by Sir Wm. Crookes (Proc. Roy. Soc. 1900).

[†] The sample of radium of greater activity than that usually sold was obtained from the Société Centrale de Produits Chimiques, through the kindness of M. P. Curie.

the spontaneous ionization of air. The gold-leaf system was insulated inside the vessel by a sulphur bead C, and could be charged by means of a movable wire D, which was afterwards earthed. The rate of movement of the gold-leaf was observed by means of a microscope through small mica windows in the testing vessel.

Fig. 1 A.

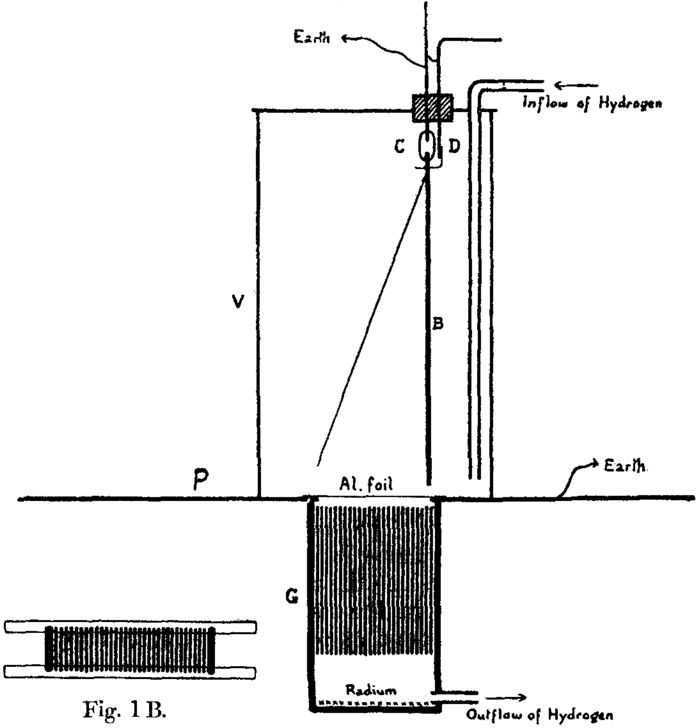


Fig. 1 B.

In order to increase the ionization in the testing vessel, the rays passed through 20 to 25 slits of equal width, placed side by side. This was arranged by cutting grooves at regular intervals in side-plates into which brass plates were slipped. A cross section of the system of metal plates and air-spaces is shown in fig. 1 B.

The width of the slit varied in different experiments between 042 and 1 cm.

The magnetic field was applied perpendicular to the plane of the paper and parallel to the plane of the slits.

The testing vessel and system of plates were waxed to a lead plate P so that the rays entered the vessel V only through the aluminium foil.

It is necessary in these experiments to have a steady stream of gas passing downwards between the plates in order to prevent the diffusion of the emanation from the radium upwards into the testing vessel. The presence in the testing vessel of a small amount of this emanation, which is always given out by radium, would produce large ionization effects and completely mask the effect to be observed.

For this purpose a steady current of dry electrolytic hydrogen of 2 c.c. per second was passed into the testing vessel, streamed through the porous aluminium foil, and passed between the plates, carrying with it the emanation from the apparatus.

The use of a stream of hydrogen instead of air greatly simplifies the experiment, for it *increases* at once the ionization current due to the α rays in the testing vessel, and (at the same time) greatly *diminishes* that due to the β and γ rays.

This follows at once from the fact that the α rays are much more readily absorbed in air than in hydrogen, while the rate of production of ions due to the β and γ rays is much less in hydrogen than in air. The intensity of the α rays after passing between the plates is consequently greater when hydrogen is used; and since the rays pass through a sufficient distance of hydrogen in the testing vessel to be largely absorbed, the total amount of ionization produced by them in hydrogen is greater than in air.

With the largest electromagnet in the laboratory I was only able to deviate about 30 per cent. of the α rays. Through the kindness of Professor Owens, of the Electrical Engineering Department, I was, however, enabled to make use of the upper part of the field-magnet of a 30 kilowatt Edison dynamo. Suitable pole-pieces are at present being made for the purpose of obtaining a strong magnetic field over a considerable area; but with rough pole-pieces I have been enabled to obtain a sufficiently strong field to completely deviate the α rays.

The following is an example of an observation on the magnetic deviation:—

Pole-pieces 1·90 × 2·50 cms.

Strength of field between pole-pieces 8370 units.

Apparatus of 25 parallel plates of length 3·70 cms., width 70 cm., with an average air-space between plates of ·042 cm.

Distance of radium below plates 1·4 cm.

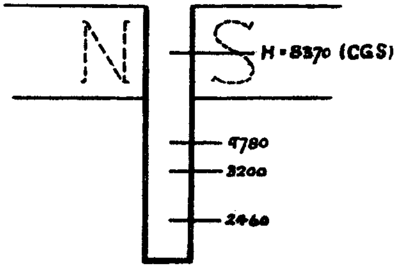
	Rate of Discharge of Electroscope in volts per minute.
(1) Without magnetic field	8·33
(2) With magnetic field	1·72
(3) Radium covered with thin layer of mica to absorb all α rays ...	0·93
(4) Radium covered with mica and magnetic field applied	0·92

The mica plate, ·01 cm. thick, was of sufficient thickness to completely absorb all the α rays, but allowed the β and γ rays to pass through without appreciable absorption. The difference between (1) and (3), 7·40 volts per minute, gives the rate of discharge due to the α rays alone; the difference between (2) and (3), 0·79 volt per minute, that due to the α rays not deviated by the magnetic field employed.

The amount of α rays not deviated by the field is thus about 11 per cent. of the total. The small difference between (2) and (4) includes the small ionization due to the β rays, for they would have been completely deviated by the magnetic field. It is probable that the ionization due to the β rays without a magnetic field was actually stronger than this; but the residual magnetic field, when the current was broken, was large enough to deviate them completely before reaching the testing vessel. (4) comprises the effect of the γ rays together with the natural leak of the electroscope in hydrogen.

In this experiment there was a good deal of stray magnetic field acting on the rays before reaching the pole-pieces. The distribution of this field at different portions of the apparatus is shown graphically in fig. 2.

Fig. 2.

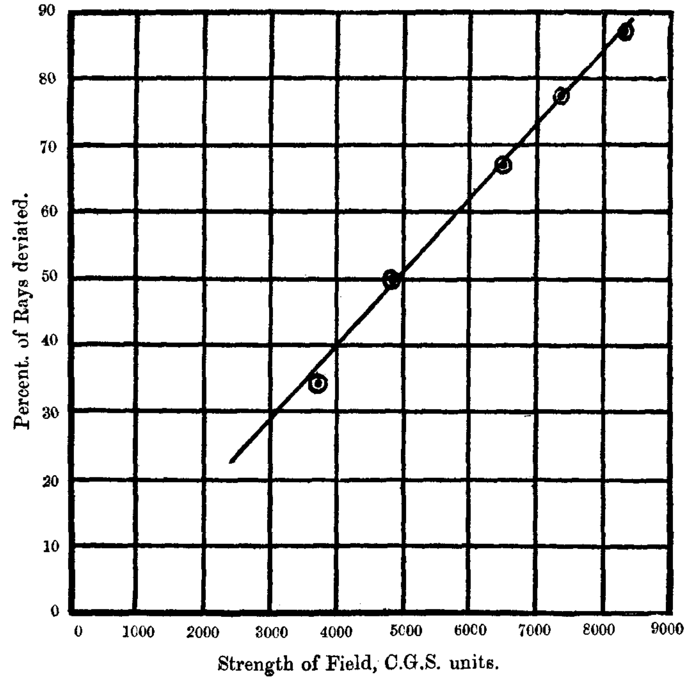


The following table shows the rate of discharge due to the α rays for different strengths of the magnetic field. The maximum value with no magnetic field is taken as 100. These results are shown graphically in fig. 3.

Magnetic field between pole-pieces.	Rate of discharge due to *a* rays.
0	100
3720 C.G.S. units	66
4840 " "	50
6500 " "	33
7360 " "	23
8370 " "	11

The curve (fig. 3) shows that the amount deviated is approximately proportional to the magnetic field.

Fig. 3.

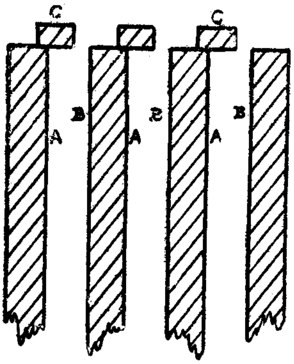


With another apparatus, with a mean air space of ·055 cm., the rays were *completely* deviated by a uniform magnetic field of strength 8400 units extending over the length of the plates, a distance of 4·5 cms.

Direction of the Deviation of the Rays.

In order to determine the direction of the deviation, the rays were passed through slits of 1 mm. width. Each slit was about half covered by a brass plate in which air-spaces were cut to correspond accurately with the system of parallel plates. Fig. 4 represents an enlarged section of three of the plates, with the metal plate C half covering the slit AB. If a magnetic field is applied, not sufficiently great to deviate all the rays, the rate of discharge in the testing vessel when the rays are deviated in the direction from A to B should be much greater than when the magnetic field is reversed, *i. e.* when the rays are deviated from B to A. This was found to be the case, for while the rate of discharge was not much diminished by the application of the field in one direction, it was reduced to about one quarter of its value by reversal of the field.

Fig. 4.



In this way it was found that the direction of deviation in a magnetic field was *opposite* in sense to the cathode rays, *i. e.*, the rays consisted of positively charged particles.

Electrostatic Deviation of the Rays.

The apparatus was similar to that employed for the magnetic deviation of the rays with the exception that the brass sides, which held the plates in position, were replaced by ebonite.

Twenty-five plates were used of length 4·50 cms., width 1·5 cm., and average air-space of ·055 cm. The radium was 85 cm. below the plates. Alternate plates were connected together and charged by means of a battery of small accumulators to a potential-difference of 600 volts. A current of hydrogen was used as in the case of the magnetic experiment.

With a P.D. of 600 volts, a consistent difference[*] of 7 per cent. was observed in the rate of discharge due to the α rays with the electric field off and on. A larger potential-difference could not be used as a spark passed between the plates in the presence of radium.

The amount of deviation in this experiment was too small to determine the direction of deviation by the electric field.

Determination of the Velocity of the Rays.

It is difficult to determine with certainty the value of the curvature of the path of the rays in a given magnetic field from the percentage amount of rays deviated, on account of the fact that some of the rays which strike the sides of the parallel plates are deviated so as to pass into the testing vessel.

From data obtained, however, by observing the value of the magnetic field for *complete deviation* of the rays, it was deduced that

$$H\rho = 390{,}000,$$

where H = value of magnetic field,

ρ = radius of curvature of path of the rays.

This gives the higher limit of the value $H\rho$.

By using the usual equations of the deviation of a moving charged body it was deduced that the velocity V of the rays was given by

$$V = 2{\cdot}5 \times 10^9 \text{ cms. per sec.},$$

and that the value $\frac{e}{m}$, the ratio of the charge of the carrier to its mass, was given by

$$\frac{e}{m} = 6 \times 10^3.$$

These results are only rough approximations and merely indicate the order of the values of these quantities, as the electric deviations observed were too small for accurate observations. The experiments are being continued with special apparatus, and it is hoped that much larger electrostatic deviations will be obtained, and in consequence a more accurate determination of the constants[†] of the rays.

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[*] In later experiments, which are not yet completed, I have been able to deviate about 45 per cent. of the α rays in a strong electric field.

[†] The α rays are complex, and probably consist of particles projected with velocities lying between certain limits; for the radiations include the α radiations from the emanation and excited activity which are distributed throughout the radium compound.

The α rays from radium are thus very similar to the *Canal Strahlen* observed by Goldstein, which have been shown by Wien to be positively charged bodies moving with a high velocity. The velocity of the α rays is, however, considerably greater than that observed for the *Canal Strahlen.*

General Considerations.

The radiations from uranium, thorium, and radium, and also the radiations from the emanations and excited bodies, all include a large proportion of α rays. These rays do not differ much in penetrating power, and it is probable that *in all cases* the α radiations from them are charged particles projected with great velocities.

In a previous paper* it has been shown that the total energy radiated in the form of α rays by the permanent radioactive bodies is about 1000 times greater than the energy radiated in the form of β rays. This result was obtained on the assumption that the total number of ions produced by the two types of rays when completely absorbed in air, is a measure of the energy radiated. The α rays are thus the most important factor in the radiation of energy from active bodies, and, in consequence, any estimate of the energy radiated based on the β rays alone leads to much too small a value.

Experiments are in progress to determine the charge carried by the α rays, and from these it is hoped to deduce the rate of emission of energy in the form of α rays from the active substances.

The projection character of the α rays very readily explains some of their characteristic properties. On this view the ionization of the gas by the α rays is due to collisions of the projected masses with the gas molecules. The variation of the rate of production of the ions with the pressure of the gas and the variation of absorption of the rays in solids and gases with the density at once follows. It also offers a simple explanation of the remarkable fact that the absorption of the α rays in a given thickness of matter, when determined by the electrical method, *increases* with the thickness of matter previously traversed. It is only necessary to suppose that as the velocity of the projected particles decreases in consequence of collision with the molecules of the absorbing medium, the ionizing power of the rays decreases rapidly. This is most probably the case, for there seems to be no doubt that the positive carrier cannot ionize

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* Rutherford and Grier, Phil. Mag. Sept. 1902.

the gas below a certain velocity, which is very great compared with the velocity of translation of the molecules.

It is of interest to consider the probable part that the α rays play in the radioactive bodies on the general view of radioactivity that has been put forward by Mr. Soddy and myself in the Phil. Mag. Sept. and Nov. 1902. It is there shown that radioactivity is due to a succession of chemical changes in which new types of radioactive matter are being continuously formed, and that the constant radioactivity of the well known active bodies is an equilibrium process, where the rate of production of fresh active matter is balanced by the decay of activity of that already produced. Some very interesting points arose in the course of these investigations. It was found that the residual activity of uranium and thorium when freed from UrX and ThX by chemical processes consisted entirely of α rays. On the other hand, the radiation of UrX * consisted almost entirely of β rays, while that of ThX † consisted of both α and β rays. Similar results probably hold also for radium, for the Curies have shown that radium dissolved in water and then evaporated to dryness temporarily loses to a large extent its power of emitting β rays.

It thus appears probable that the emission of α rays goes on quite independently of the emission of β rays. There seems to be no doubt that the emission of β rays by active substances is a secondary phenomenon, and that the α rays play the most prominent part in the changes occurring in radioactive matter. The results obtained so far point to the conclusion that the beginning of the succession of chemical changes taking place in radioactive bodies is due to the emission of the α rays, *i.e.* the projection of a heavy charged mass from the atom. The portion left behind is unstable, undergoing further chemical changes which are again accompanied by the emission of α rays, and in some cases also of β rays.

The power possessed by the radioactive bodies of apparently spontaneously projecting large masses with enormous velocities supports the view that the atoms of these substances are made up, in part at least, of rapidly rotating or oscillating systems of heavy charged bodies large compared with the electron. The sudden escape of these masses from their orbit may be due either to the action of internal forces or external forces of which we have at present no knowledge.

It also follows from the projection nature of the α rays that the radioactive bodies, when inclosed in sealed vessels

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* Soddy, Proc. Chem. Soc. 1902.

† Rutherford and Grier, Phil. Mag. Sept. 1902.

sufficiently thin to allow the α rays to escape, must *decrease in weight*. Such a decrease has been recently observed by Heydweiler* for radium, but apparently under such conditions that the α rays would be largely absorbed in the glass tube containing the active matter.

In this connexion it is very important to decide whether the loss of weight observed by Heydweiler is due to a decrease of weight of the radium itself or to a decrease of weight of the glass envelope; for it is well known that radium rays produce rapid colourations throughout a glass tube, and it is possible that there may be a chemical change reaching to the surface of the glass which may account for the effects observed.

McGill University,
Montreal, Nov. 10, 1902.

XVI. *On Vector Differentials.* *By* FRANK LAUREN HITCHCOCK.—Second Paper †.

1. THE calculus of Quaternions enables us to represent a vector, or directed quantity, by a single symbol, and to work with it easily and compactly. We are not obliged to resolve into components, nor do we arbitrarily introduce any lines or planes of reference.

One of the simplest vectors is that of a point in space, represented by the symbol ρ. If we have a vector function of ρ continuously distributed throughout a portion of space, we may differentiate it: the result is a linear and vector function of $d\rho$, closely analogous, in a mathematical sense, to a homogeneous strain. Any such strain is fully determined if we know the roots of the strain-cubic, and the three directions which correspond to them.

In an introductory paper on this subject (Phil. Mag. June 1902, p. 576) it was shown that if ν be a vector of unit-length normal to any family of surfaces, and if its differential be $\chi d\rho$, then one of the roots of the cubic in χ is always zero.

The other two roots give directions tangent to the lines of curvature. For a line of curvature may be defined as one such that normals at contiguous points intersect, that is, such that the three vectors ν, $\nu+d\nu$, and $d\rho$ are coplanar; but because ν is a unit-vector $d\nu$ is at right angles to ν, and therefore parallel to $d\rho$. Accordingly $(\chi-g)d\rho=0$, g being a root of the strain-cubic.

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* *Phys. Zeit.* 1902.

† Communicated by the Author.