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Polarised Rontgen Radiation

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XIII. *Polarised Röntgen Radiation.*

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Though many attempts have been made to produce a beam of polarised X-radiation and to detect the polarisation by such methods as are applicable to ordinary light, the experiments have proved unsuccessful, and no evidence of polarity has been obtained. An arrangement of molecules such as occurs in crystals does not appear to affect a beam of this radiation transmitted through the crystalline substance.

The experiments here described were suggested by the results of an investigation of secondary radiation proceeding from gases and certain solids subject to X-rays,* for it was found that the gases experimented upon were the source of a radiation differing little in character from the primary radiation which produced it. In some respects the difference was inappreciable, as, for instance, in the absorbability of the radiations by aluminium. The primary and secondary radiations differed slightly, however, in their ionizing powers in air.† The energy of this secondary radiation was found to be proportional to the mass of gas through which the primary beam of definite intensity passed, and to be independent of the nature of the gas.

This led to the conclusion that this radiation is due to what might be called a scattering of the primary X-rays by the electrons constituting the molecules of the gas.

More recent experiments have shown that from light solids which emit a secondary radiation differing little from the primary, the energy of this radiation obeys the same law.

The phenomenon of secondary radiation from metals, however, is *apparently* much more complex, for in addition to secondary X-rays differing enormously in character from the primary, the metal radiator emits negative corpuscles. The total energy of these secondary radiations and the energy of the secondary X-rays alone are subjects

* C. G. Barkla, 'Phil. Mag.,' pp. 685–698, June, 1903, and pp. 543–560, May, 1904.

† See note, 'Phil. Mag.,' p. 549, May, 1904.

for separate investigation and will not be treated in this paper. It seemed possible that phenomena of exactly the same nature take place in gases, for the fact of ionization implies the emission of negative corpuscles or electrons such as proceed from metals, and, as has been shown, the non-deviable radiation from gases does differ to a small extent from the primary radiation producing it. It had to be proved that the difference in the behaviour of gases and heavy solids is not one of degree merely.

As explained by Professor J. J. THOMSON ('Conduction of Electricity through Gases,' p. 268), on the hypothesis that Röntgen rays consist of a succession of electro-magnetic pulses in the ether, each ion in the medium has its motion accelerated by the intense electric fields in these pulses, and, consequently, is the origin of a secondary pulse, the intensity of electric force in which is given by the expression $\frac{fe \sin \theta}{r}$, where e is the charge on the ion, f its acceleration, r the distance from the point considered in the pulse to the origin of the pulse, and θ the angle which the line joining the point to the origin of the pulse makes with the direction of acceleration of the ion. The direction of electric intensity at a point in a secondary pulse is perpendicular to the line joining the point and origin of the pulse and is in the plane passing through the direction of acceleration of the ion. Thus the secondary radiation is most intense in the direction perpendicular to that of acceleration of the ion and vanishes in the direction of that acceleration.

A secondary beam whose direction of propagation is perpendicular to that of the primary radiation will then on this theory be plane polarised, the direction of electric intensity being parallel to the pulse front in the primary beam.

If a plane-polarised primary beam be used, then the secondary radiation from the electrons has a maximum intensity in a direction perpendicular to that of electric displacement in the primary beam and zero intensity in the direction of electric displacement.

Shortly after I arrived at the conclusion as to the origin of secondary radiation from gases, Professor WILBERFORCE suggested to me the idea of producing a plane-polarised beam by means of a secondary radiator and of testing the polarisation by a tertiary radiator. The secondary radiation from gases under ordinary conditions is, however, much too feeble to attempt the measurement of a tertiary. I hoped by means of some metal which was the source of a much more easily absorbed secondary radiation that this experiment might be performed successfully, but further experiments, which are described later, show that there is another difference between the radiations from heavy metals and those from gases and light solids in addition to those already mentioned, and that evidence of polarisation cannot be expected from experiments with such metals.

A consideration of the method of production of X-rays, however, leads one to expect partial polarisation in a beam of radiation proceeding from the antikathode in a direction perpendicular to the axis of the kathode stream. For the electrons being projected in approximately parallel straight lines from the kathode to the antikathode, there is probably at the antikathode a greater acceleration along the line of propagation of the kathode rays than in a direction at right angles, consequently in a beam of X-rays proceeding in a direction perpendicular to that of the kathode stream it might reasonably be expected there would be greater electric intensity parallel to the stream than in a direction at right angles to that.

Such a beam was used as the primary radiation, and the intensity of secondary radiation proceeding in a direction perpendicular to that of the propagation of the primary beam from different radiators placed successively in the primary beam was studied by means of an electroscope.

In preliminary experiments the intensity of secondary radiation in a direction perpendicular to the axis of the primary beam was compared with that in a direction making a small angle with the axis of the primary beam, while the bulb was turned round that axis.

The intensity in the second direction named, according to theory, should not vary. Using this to standardize the intensity of primary radiation, the intensity of the other was found to reach a maximum when the direction of the kathode stream was perpendicular to that of propagation of the secondary beam and a minimum when these two were parallel.

In other experiments the intensity of secondary radiation in a direction perpendicular to the axis of the primary beam was compared with that of a small pencil of the primary beam itself when the bulb was rotated as before. The results were similar to those in the final experiment, the arrangement of apparatus in which will be described more fully. It was as follows:—

An X-ray bulb was contained in a large lead-covered box, in one side of which was a rectangular aperture, C_1, through which a beam of Röntgen rays passed. The size of this aperture was adjustable by lead shutters, S_1, placed just outside. Large screens, S_2, of thick sheet-lead were placed at a distance of 25 centims. from this aperture and parallel to the side of the box, so that the width of aperture between them was also adjustable. The primary beam studied was that passing through the second rectangular aperture. Beyond S_2 were two parallel lead screens, S_3 and S_4, 8 centims. apart, placed in vertical planes perpendicular to the screens S_1 and S_2. Each contained a square aperture, C_3 and C_4, 5 centims. square, in positions so that lines joining corresponding points were approximately perpendicular to the planes of both. No primary rays were incident upon them, but secondary rays proceeding from a radiator in the primary beam passed through both apertures. Those passing through the second aperture, C_4, were approximately horizontal and perpendicular to the direction of propagation of the primary beam. They then entered an electroscope, A_1, immediately behind the aperture C_4 through a thin paper and aluminium face. Similar lead plates containing square apertures were placed in horizontal planes above the primary beam in such a position that lines joining corresponding points were vertical. Both were screened from the primary radiation, but secondary radiation proceeding in a vertical direction from the radiator in the primary beam passed

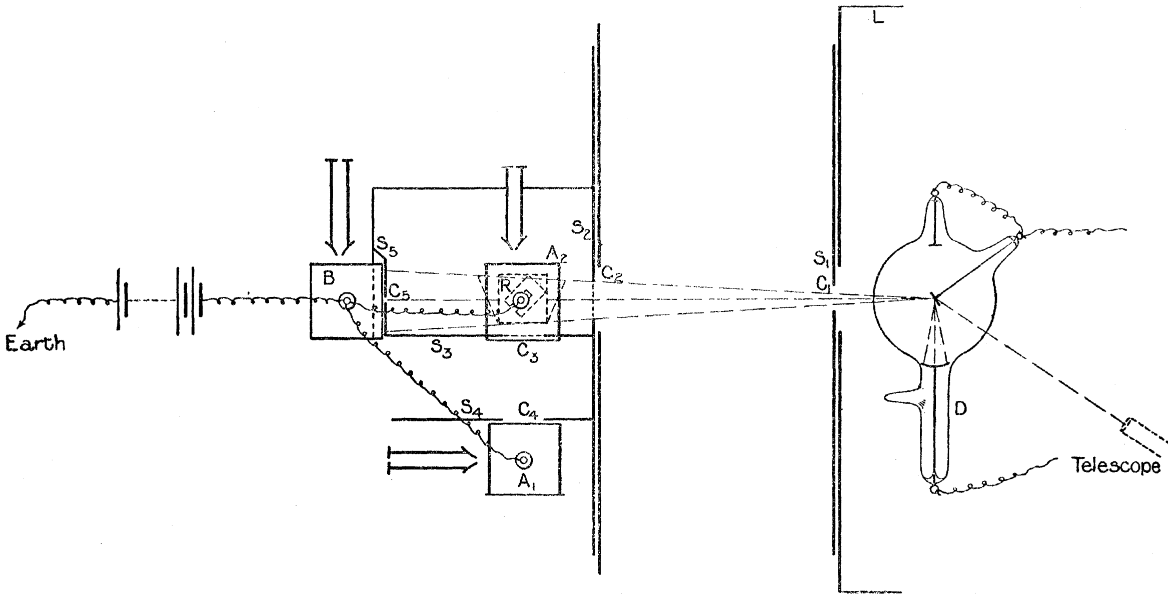

Fig. 1. Showing position of bulb giving a maximum deflexion of electroscope A_2 and a minimum of electroscope A_1.

through the apertures and entered an electroscope, A_2, through a thin paper and aluminium face. In the primary beam, at a distance of about 14 centims. beyond the secondary radiator and 21 centims. from screens S_2, was placed another thick lead screen, S_5. In this was a small circular aperture through which a narrow pencil of primary radiation passed into an electroscope B beyond.

Electroscopes A_1 and B were similar, each consisting of a case (as shown in fig. 2), with four sides of stout metal—one brass, the other zinc. One end, G, was of glass, and the opposite end consisted of a thin sheet of paper covered with aluminium leaf. The gold-leaf and copper-wire to which it was attached were suspended in this case by a bead of sulphur, S, which was fixed to the lower end of a vertical brass rod, K. This passed axially through a cylindrical brass neck, N, the whole of the suspension being like that used by C. T. R. WILSON in his 'Experiments on Spontaneous Ionization of Air.'* Connexion between the rod and the insulated wire and gold-leaf could be made by means of a light spring which was attached to the rod at its upper end and which, when set in vibration, made momentary contact with the insulated portion of the electroscope, the capacity of which was very small. The deflexion of the gold-leaf was observed through a microscope with graduated eye-piece, which was fixed just outside a small glass window, M, in one side of the case.

* 'Roy. Soc. Proc.,' vol. 68, pp. 151–161, 1901.

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Electroscope A_2 differed from these in having its lower face of paper and aluminium instead of one of the side faces, so that it could be used to measure the intensity of a vertical beam of X-rays.

The rod of each electroscope was connected to one terminal of a battery of Leclanché cells, whose other terminal was earthed so that the insulated wire and gold-leaf of each electroscope could be charged by means of the contact maker, which momentarily connected the rod and wire, afterwards leaving the wire and gold-leaf charged and insulated.

There was a small leak in each electroscope, due to the normal ionization of the air within the case containing the gold-leaf. The support leak through the sulphur, which must have been excessively small, was from the rod kept at constant potential to the wire and gold-leaf. In the steady normal state, when the potential was high enough to produce a saturation current, the leak measured the normal ionization of the air within the case. The cases and screens were all earth-connected during the experiments.

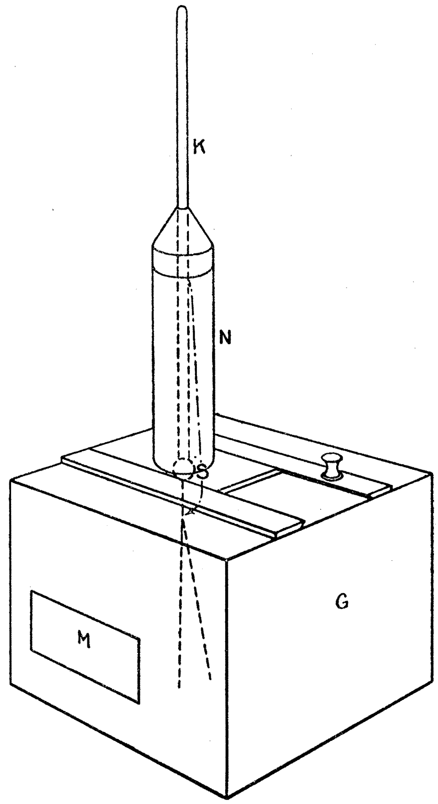

Fig. 2.

The radiator first experimented upon consisted of sheets of paper approximately square in shape, but slightly modified so that a pencil of the primary radiation passed through an opening almost at the centre of the square, then through the aperture C_5 in the lead screen S_5 into electroscope B. The radiator was held in position by a fine support of wood, cardboard, or aluminium. Paper was first chosen because experiments had led to the conclusion that the secondary radiation from such a light substance was very similar to that from gases, and, according to the theory given, should vary in intensity in any direction at right angles to that of propagation of the primary beam with a change in the position of the plane of polarisation of that beam.

The position of the radiator was such that the whole of one side was exposed to the primary radiation, the angle of incidence of which varied in different experiments, and electroscopes A_1 and A_2 were exposed to secondary radiation proceeding from the same face, also in oblique directions.

When a beam of Röntgen radiation was sent through the two apertures, C_1 and C_2, the rates of deflexion of the three electroscopes were considerably increased. By placing lead screens at the different apertures and again determining the rates of deflexion when the discharge was sent through the X-ray tube, it was seen that the gold-leaves in electroscopes A_1 and A_2 were deflected by secondary radiation proceeding from the radiator placed in the primary beam opposite apertures C_3 and C'_3, and that the deflexion of B was due to the narrow beam of primary radiation passing through C_5.

It was found that when the bulb was in a given position, there was a constant relation between the three rates of deflexion when the character of the primary radiation was constant. As the radiation emitted by the bulb gradually changed, there was found to be with some radiators a change in the ratio of the deflexions of the secondary and primary electroscopes. This change, however, was a slow one, and the primary electroscope deflexion could always be used to standardize the intensity of primary radiation.

The method of experiment was then as follows :—

The X-ray bulb was placed with the axis of the conical beam of kathode rays (proceeding from the kathode to the antikathode) in a vertical position, and consequently perpendicular to the line joining the antikathode to the middle of the secondary radiator. The primary beam thus studied proceeded from the antikathode in a direction perpendicular to that of propagation of the kathode rays which produced it. The relation between the rates of deflexion of the electroscopes was obtained when a discharge was sent through the bulb by an induction coil. A number of successive observations showed this to be constant.

The bulb was then turned round the axis of the primary beam into some other position. Care was taken to keep the source of X-rays in as nearly the same position as possible. To do this the centre of the antikathode was viewed through a telescope when the door of box L was open, and was focussed on the cross-wires of the eye-piece. The telescope was fixed, and when the position of the bulb was changed the adjustment was made so that the centre of the antikathode was again focussed on the cross-wires. It was also kept in a plane parallel to the side of the containing box by viewing it along such a fixed plane, so that the source of X-radiation in the experiments was not displaced more than a few millimetres.

The axis of the kathode stream was kept perpendicular to the direction of propagation of the primary beam studied, by simply observing that the axis of the tube D was always in a plane approximately perpendicular to what might be called the axis of the primary beam. As neither the kathode rays in the bulb nor different portions of the primary X-beam were parallel, perfect adjustment of the bulb in this manner was not essential. It was also experimentally found that much larger angular displacements of the bulb than might possibly occur in the adjustment did not produce an appreciable change in the ratio of the rates of deflexion of the electroscopes.

As the bulb was rotated round the axis of the primary beam there was, of course, no change in the intensity of primary radiation in that direction. There was, however, a considerable change in the intensity of secondary radiation in both the horizontal and vertical directions, one reaching a maximum when the other attained a minimum.

By turning the bulb through a right angle the electroscope which had previously indicated a maximum of intensity indicated a minimum, and *vice versâ*. The position of the bulb when the vertical secondary beam attained a maximum of intensity and the horizontal secondary beam a minimum was that in which the kathode stream was horizontal (see fig. 1), the maximum and minimum being reversed when the kathode stream was vertical. By turning the bulb through another right angle, so that the kathode stream was again horizontal but in the opposite direction to that in the other horizontal position, the maximum and minimum were attained as before.

These are the results that were expected from a consideration of the theory of the production of X-rays.

Many experiments were made in order, if possible, to account for these results in any other way than on the theory of partial polarisation of the primary beam.

By placing lead screens in front of apertures C_3 and C'_3 it was found that the resulting deflexions of the electroscopes A_1 and A_2 were negligible in any position of the bulb. They were therefore due to the radiations proceeding through these apertures. No direct radiation passed through them, hence there were variations in the intensity of secondary radiation with changes of position of the bulb.

Placing radiators of the same material but of very different mass in the position shown in the diagram showed that, though the absolute intensity of secondary radiation was considerably altered, the relative changes produced by turning the bulb were, within the limits of experimental error, unchanged.

When different substances, which emitted a secondary radiation differing little from the primary, were used as secondary radiators, variation in intensity was exhibited to approximately the same extent.

When all solid radiators were removed and only the secondary radiation from air could affect the electroscopes, relative changes of the same order of magnitude were observed.

It was thus conclusively proved that the total intensity of secondary radiation in a given direction depended on the position of a plane passing through the axis of the primary beam and fixed in the beam.

As the secondary radiators were not very small in area, we have to consider the possibility of the primary radiation incident on the secondary radiator not being uniform in intensity over the whole of the radiator and the effect of this.

The angle subtended by extreme points of the radiator at the antikathode was very small, being about 6°, so that the variation in intensity through this angle could only be small. But admitting the possibility of a distribution of the primary radiation which was not uniform, there would be a corresponding distribution of the intensity of secondary radiation, and the two secondary electroscopes not being equidistant from all points of the radiator would be affected to a greater extent by the nearer portions. I, however, find it impossible to conceive of any distribution of intensity which would account for the results obtained. It was experimentally found

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that a change of position of the bulb by any such angle did not appreciably affect the result, so that by using an entirely different portion of the primary radiation no sensible difference in the results was detected. But, perhaps, the most conclusive proof of all was given when lead, copper, iron and such heavy metals were used as radiators. The shape and size of these were exactly those of the paper and aluminium radiators, yet when they were used no variation in intensity was detected.

This result must be connected with the fact that from these metals the radiation differs considerably from the primary which produces it, while from paper and aluminium the radiation bears a much closer resemblance to the primary.

In addition to these experiments many changes were made in the apparatus without affecting the results described. Three or four different X-ray tubes were used to produce the radiation, though all were of the same type,* the sizes of apertures were varied considerably, the whole apparatus was taken down and reconstructed, and the distances between screens were varied.

Having given the experimental evidence that the variation in intensity was due simply to the fact that from certain light radiators placed in such a primary beam the intensity of secondary radiation depended on the position of a plane passing through the axis of the beam and fixed relative to the bulb, the maxima and minima being in directions at right angles, that is, that the primary beam is partially polarised, we will consider some of the results a little more in detail.

Many experiments were made with paper or cardboard as the radiator, and not one failed to give evidence of polarisation in the manner described.

Table I. gives an example of readings obtained.

As will be seen from these results, there was a small variation in the ratio of the deflexions of the electroscopes when all controllable conditions were kept the same, but this was small and irregular compared with the variation depending on the position of the bulb.

When the kathode stream was vertical, the deflexions representing the vertical and horizontal intensities were 16·85 and 13·6; when the kathode stream was horizontal they became 18·6 and 12·15 respectively.

The numbers taken absolutely have no special significance, as they depended on the construction of the electroscopes, but the changes due to change of position of the bulb show the change in intensity of secondary radiation due to rotation of the primary beam.

When aluminium was used as the secondary radiator similar results were obtained, the polarisation being well marked. Some of the readings are given in Table II.

The secondary radiation proceeding from air was also studied, but for various reasons the results were more inconstant. The ionization produced in each of the secondary electroscopes in a given time was very much smaller than that produced by the radiation from a solid, consequently the possible error due to irregularities in the

* Cox's "Record Tubes" were used in these experiments.

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TABLE I.

Secondary radiator.	Position of kathode stream.	Deflexion of primary electroscope.	Deflexion of electroscope A_2 receiving vertical secondary beam.	Deflexion of electroscope A_1 receiving horizontal secondary beam.
Cardboard	Vertical	33	16·9	14
	Horizontal	33·3	18·4	12·3
	"	34	19·6	12·3
	Vertical	32·4	16·5	13
	Correcting for variation in intensity of primary radiation these were—			
	Vertical	33	16·9	14
	Horizontal	33	18·2	12·2
	"	33	19·0	11·9
	Vertical	33	16·8	13·2
	Taking the mean of the two values we get—			
	Vertical	33	16·85	13·6
	Horizontal	33	18·6	12·05
	Duration of each experiment = $2\frac{1}{2}$ minutes.			

TABLE II.

After Correction for Variation in Intensity of the Primary Radiation.

Secondary radiator.	Position of kathode stream.	Deflexion of primary electroscope.	Deflexion of electroscope A_2 receiving vertical secondary beam.	Deflexion of electroscope A_1 receiving horizontal secondary beam.
Aluminium	Horizontal	41·2	18·8	12·5
	Vertical	41·2	17	13·6
	Horizontal	41·2	18·9	12·7
	Duration of each experiment = $3\frac{1}{2}$ minutes.			

movement of the gold-leaves was considerably increased. A consideration of the air, the radiation from which entered electroscopes A_1 and A_2, shows that the masses of air were not identical. Again, much of the radiation entering these electroscopes made a considerable angle with the plane perpendicular to the direction of propagation in the primary beam.

The results, however, indicate a partial polarisation of the same order of magnitude as that obtained by experiments with paper or aluminium. Some of these are shown in Table III.

Table III.

After Correction for Variation in Intensity of the Primary Radiation.

Secondary radiator.	Position of kathode stream.	Deflexion of primary electroscope.	Deflexion of electroscope A_2 receiving vertical secondary beam.	Deflexion of electroscope A_1 receiving horizontal secondary beam.
Air	Vertical	5·6	7	3·6
	Horizontal	5·6	7·7	3·05
	Vertical	—	5·6	2·7
	”	—	5·6	3
	Horizontal	—	5·6	2·15
	Duration of each experiment = 4 minutes.			

Table IV.

Secondary radiator.	Position of kathode stream.	Deflexion of primary electroscope.	Deflexion of electroscope A_2 receiving vertical secondary beam.	Deflexion of electroscope A_1 receiving horizontal secondary beam.
Copper	Horizontal	9·1	18·1	16·2
	Vertical	8·8	17·8	15·9
	Duration of each experiment = 30 seconds.			

Table V.

Secondary radiator.	Position of kathode stream.	Deflexion of primary electroscope.	Deflexion of electroscope A_2 receiving vertical secondary beam.	Deflexion of electroscope A_1 receiving horizontal secondary beam.
Tin (with ·04 centim. aluminium before secondary electroscopes)	Vertical	30·7	19·2	14·9
	Horizontal	30·3 or 4	19	14·3
	”	29·3	18·9	14·7
	Vertical	29·2	18·4	14·1
	Taking the means we get—			
	Vertical	29·95	18·8	14·5
	Horizontal	29·8	18·95	14·5
	Duration of each experiment = $2\frac{1}{2}$ minutes.			

When, however, the secondary radiator was a substance which emitted a radiation differing considerably in character from the primary which produced it, the variation in intensity of the secondary radiation by rotating the bulb was very much smaller than in the cases previously considered. In fact, with the metals experimented upon it could not be detected.

Using copper as the radiator, the almost perfect agreement between the relative deflexions of the secondary electroscopes in the two positions of the bulb is shown in Table IV.

Tin and iron also gave results similar to those obtained with copper. They are shown in Tables V. and VI.

TABLE VI.

Secondary radiator.	Position of kathode stream.	Deflexion of primary electroscope.	Deflexion of electroscope A_2 receiving vertical secondary beam.	Deflexion of electroscope A_1 receiving horizontal secondary beam.
Iron (with ·01 centim. aluminium before secondary electroscopes)	Vertical	39·6	20·9	13
	Horizontal	38·4	19·9	11·9
	,,	37·2	19·2	11·2
	Vertical	34·6	18	10·5
	Writing the ratios of deflexions of the two secondary electroscopes we get—			
	Vertical	—	20·9	13
	Horizontal	—	20·9	12·6
	,,	—	20·9	12·3
	Vertical	—	20·9	12·45
	Duration of each experiment = 3½ minutes.			

These results considered in connection with the fact that the secondary radiation from heavy metals differs considerably in character from the primary producing it are significant. In light substances, on the electronic theory, the distances between the electrons are greater than in the heavier substances. It seems possible that this is the immediate cause of the difference, for when the distance apart becomes so small as to be comparable with a pulse thickness the theory is not such a simple one as that given, as there are mutual actions between the electrons. Other possibilities might be discussed, as that of the vibration frequency in the heavier atoms being such as to cause a radiation having ionizing power not possessed by that proceeding from the electrons of lighter atoms, or of a temporary radioactivity being set up in the heavier atoms by the transmission of X-rays. Experiments are being made on the subject, and will be treated in a later paper on Secondary Radiation from Metals.

With copper as secondary radiator, no evidence of a change in intensity of secondary radiation, when the position of the X-ray bulb was changed in the manner described, was given. It was thought possible that by using more penetrating radiation for the primary beam—that is, on the generally accepted theory, a radiation consisting of thinner pulses—the action in copper might more nearly approximate to that taking place in light substances during the passage of thicker pulses. The more easily absorbed portion of the secondary radiation was therefore cut off from the secondary electroscopes by plates of aluminium ·04 centim. thick, and in many experiments there appeared to be a slight variation as with lighter substances. This, however, was within the limits of possible error of experiment. Also it must be remembered that there was a radiation from air superposed on that from copper, and though it was negligible in comparison when the radiation was unintercepted by any absorbing plates, yet when the aluminium plates were used the radiation from copper was absorbed to a much greater extent than that from air and the resultant effect from air became appreciable ; hence the slight variation may be accounted for.

Similar experiments were made with other heavy metals, but no evidence of variation in intensity of secondary radiation was obtained when the bulb was turned about the axis of the primary beam.

Regarding the amount of variation of intensity of the secondary beam as the bulb was turned, it will be seen that from the light substances it was 11 or 12 per cent. of the total intensity. This is not a true measure of the amount of polarisation, for beams of considerable cross section were studied, consequently secondary rays making a considerable angle with the normal to the direction of propagation of the primary rays were admitted into the electroscopes.

Different experiments with a given bulb and given radiator in a fixed position appeared to indicate polarisation to a slightly different extent as the bulb was worked. It is possible that the amount of polarisation depends to a certain extent on the method of discharge through the X-ray bulb, but the variation was not sufficient to absolutely prove this.

The variation between the amount of polarisation shown by using air, cardboard, and aluminium as radiators was not outside the limits of experimental error.

The conclusions from these experiments may be briefly stated thus :—

Partial polarisation exists in a beam of Röntgen radiation proceeding from an X-ray focus tube.

The intensity of secondary radiation from air and light solids in a direction perpendicular to that of propagation of the primary radiation depends on the position of the plane of polarisation of that primary radiation.

The intensity of secondary radiation from the heavier metals is independent of the position of the plane of polarisation of the primary radiation.

[Variation in the penetrating power of the primary radiation has not been observed to affect this result.]

[NOTE, *April* 15, 1905.—Since writing the above paper I have obtained a primary X-radiation which gives rise to secondary radiation differing in intensity in the two principal directions by about 20 per cent. ; consequently the possible error has been reduced. It will be seen from Table III. that in the earlier experiments in which the radiator was air alone the possible error was a considerable fraction of the total variation.

I give the result of later observations which show the polarisation effect much more clearly :—

Secondary radiator.	Position of kathode stream.	Deflexion of electroscope A_2 receiving vertical secondary beam.	Deflexion of electroscope A_1 receiving horizontal secondary beam.
Air	Horizontal	22·5	8·7
	Vertical	22·6	11
	"	22·6	11·3
	Horizontal	22·4	8·1

The duration of each experiment was regulated to give an approximately constant deflexion of electroscope A_2 so that, as in the second part of Table III., the numbers give merely the ratios of deflexions.

I have also studied the radiation from a large number of substances and have found that with an increase in atomic weight of the radiator the disappearance of the variation in intensity does not take place abruptly, but that there are elements having atomic weights between those of the two classes of substances spoken of in this paper which exhibit an intermediate variation.

Calcium, for instance, when subject to a certain radiation, was the source of a secondary radiation, the variation in intensity of which was about half that exhibited by substances of low atomic weight.

The change with atomic weight may, however, take place in well-defined steps. Also, I have found that there is a considerable change in the amount of variation with a change in the hardness of a given X-ray tube.

A full discussion of these results, along with others outside this subject, will be published later in a paper on Secondary Radiation.]