On a Want of Symmetry shown by Secondary X-Rays

1907 Proc. Phys. Soc. London 21 735

(http://iopscience.iop.org/1478-7814/21/1/350)

L. *On a Want of Symmetry shown by Secondary X-Rays. By* W. H. Bragg, *M.A., F.R.S., Elder Professor of Mathematics and Physics in the University of Adelaide, and* J. L. Glasson *.

[From "Transactions of the Royal Society of South Australia," vol. xxxii., 1908.]

On the assumption that the Röntgen rays consist of æther pulses it has been shown by J. J. Thomson ('Conduct. of Electr. through Gases," p. 323) that it is possible to account for the existence of secondary Röntgen rays by assuming that the primary pulses set in motion electrons over which they pass, and cause them to become new centres of radiation. If the electron easily follows the guiding force of the primary pulse, then the secondary radiation resembles the primary in quality. But if the electron is hampered by attachments to other portions of the atom to which it belongs, then the new pulse has not the same quality as the old; the time of motion of the electron is dragged out, and the pulse produced is softer.

Now, if an electron becomes in this way a centre of radiation the intensity of the secondary effect must be symmetrical about the line of motion of the electron. In particular, the intensity of the secondary radiation must be symmetrical about a plane passing through the electron perpendicular to the primary ray, since this ray contains the line of motion referred to. This deduction forms an integral part of Thomson's theory of secondary Röntgen radiation, and its truth has been assumed in calculations intended to show that experimental results are in agreement with theory. Barkla proves the same deduction in a paper published in the Philosophical Magazine of February 1908.

Now it has recently been shown (Bragg and Madsen, Trans. Roy. Soc. S.A., May 1908) that the cathode radiations excited by γ rays show a very marked want of symmetry about the plane normal to the exciting ray; and again (Madsen, Trans. Roy. Soc. S.A., July 1908) that

* Read April 23, 1909.

there is a similar want of symmetry in respect to the secondary γ rays. The γ rays and X-rays resemble one another so closely in all their known properties, that it is fairly safe to assume any effect found to be true of the one kind to be true also of the other kind, though perhaps to a different degree. In this case, indeed, Cooksey ('Nature,' April 2, 1908) has already shown that the secondary cathode radiations excited by X-rays are not at all symmetrical about the normal plane, the emergence rays being greater than the incidence, as in the case of the γ rays.

It remained, therefore, to examine the secondary X-rays excited by primary X-rays; and the experiments described in this paper were made with that object. We find that in general want of symmetry does exist, that it is sometimes very pronounced, and that is in keeping with expectation based on Madsen's study of the secondary γ rays. Hard γ rays show a very large difference between the quantities of emergence and incidence radiation; for soft γ rays the difference is smaller. Since X-rays are to be looked on as a very soft form of γ rays, the difference should be smaller still; and this is what we have found to be the case.

The general form of the apparatus which we have used is shown in fig. 1. Variations of the upper portion of it are shown in figs. 2 and 3. A small pencil of X-rays passed upwards through apertures in lead plates at A and B, and then along the axis of the ionization-chamber and out into the open. In our first experiments the upper part of the apparatus was arranged as in fig. 3. The primary rays did not pass through the effective part of the ionization-chamber, being separated therefrom by the cylindrical screen SS, which could be made of various thicknesses and various materials. But if a thin sheet of any substance was laid over the hole at B, secondary X-rays spread out therefrom, and some passed through the screen SS, and caused a deflexion in the electrometer. The difference between the deflexions (*a*) without and (*b*) with the sheet at B was taken as a measure of the emergence secondary X-ray radiation. When the sheet was removed from B, and the same or a similar sheet placed in the plane of the top of the screen so as to be struck from below by the primary rays, then the measure of the incidence secondary radiation was obtained as the difference between the deflexions (a) without and (c) with the sheet so placed.

In this way it was easy to show that the expected want of symmetry actually existed, particularly with aluminium,

Fig. 1.

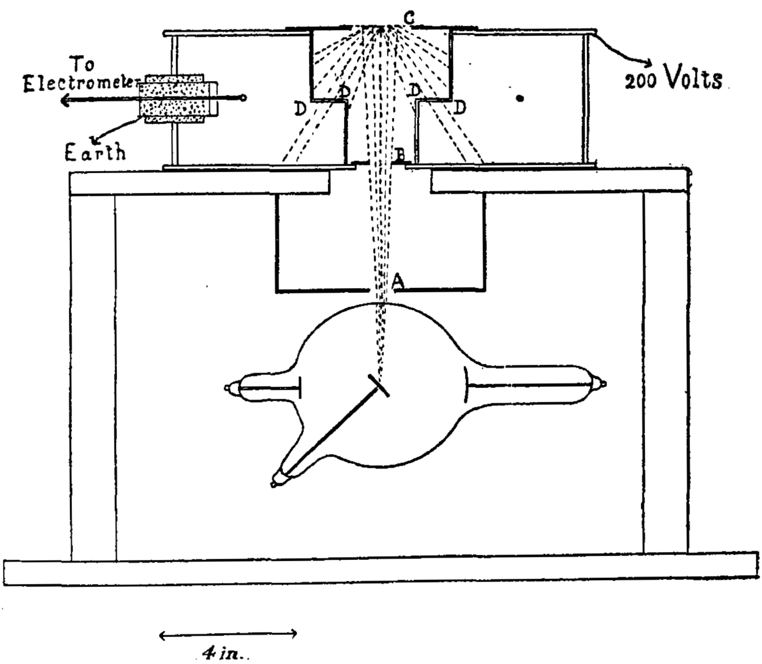


Fig. 2.

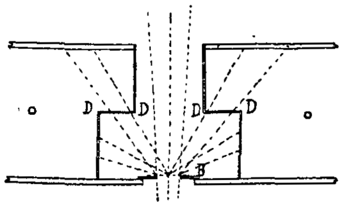
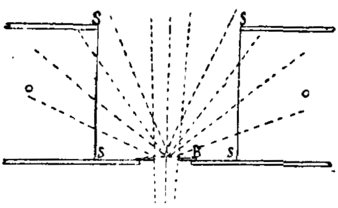


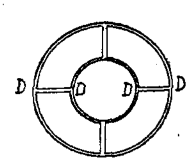
Fig. 3.



celluloid, or paper as the radiators, substances of small atomic weight. But the experiments were open to some extent to the objection that a was too large compared with $b-c$, and that possibly the excess of emergence over incidence was an apparent effect due to actual variations of a under different circumstances. The current a was, in fact, due to several causes. There was a small natural ionization leak even when the X-rays were not acting; there was an effect due to primary X-rays which had penetrated the walls of the chamber, though they were made of zinc one-eighth of an inch thick. But the greatest part of a was due to a diffusion of soft rays about the primary beam, much of which came through the hole at B at such an angle as to penetrate the screen SS; it could be largely cut out by thickening the screen. Again, part of a was due to radiation returned from the open air above the ionization-chamber. Some of these radiations might be appreciably interfered with by placing the radiating sheet at B or at the top of the chamber. We were, however, able to satisfy ourselves by special experiments that the want of symmetry was quite real, and that as a matter of fact no valid objection could be made. But we abandoned the first arrangement for a second which, as we expected, would show the want of symmetry more clearly, and which proved better than the first in every way. The first method was exactly the same as that used by Madsen in examining the secondary γ rays; but it was clear that the enormous difference which these rays showed was not going to be repeated in the case of the X-rays.

Our new arrangement was, as shown in fig. 1, or, inverted, in fig. 2. Two cylinders of brass, each 2 in. long, but of different diameters—4 in. and 2 in.—were fixed to a connecting piece DD, shown in plan in fig. 4. The latter resembled a light brass wheel with four spokes, and various thin screens cut in the form of flat rings could be attached to it, filling up all the spaces between the spokes. In fig. 1 the double cylinder is shown as arranged for the measurement of incidence secondary radiations; the radiating sheet was placed at C, supported by a sheet of celluloid lying flat on the top of the cylinder. A hole was cut in the centre of the celluloid sheet big enough to allow the primary beam to pass through without touching the edges; and a fluorescent screen was used to make sure

Fig. 4.



that this was the case. The radiating sheets were of thin metal, about $1\frac{1}{2}$ in. square. In fig. 2 the cylinder is shown as arranged for the measurement of emergence secondary radiations : it hardly requires further explanation.

We expected that this arrangement would show up the want of symmetry better than the former, because the portions of the emergence and incidence beams under comparison would be more nearly normal to the plate. Looking upon the radiations as material, we should naturally expect the intensity of the secondary radiation to decrease gradually as its direction increased in inclination to the forward direction of the primary ray. The emergence rays lie, in inclination, between 0° and 90° ; the incidence between 90° and 180°. In our first arrangement we compared the emergence rays between about 40° and 90°, with the incidence rays between about 90° and 140°. There should be a larger ratio of emergence to incidence with the newer arrangement, since the emergence rays between about 30° and 50° would be compared with the incidence between about 130° and 150°. This proved to be the case ; the improvement was considerable. Again, with the new arrangement, the current with no radiator in position became relatively far smaller. For example, when the radiator was Al, ·4 mm. thick, and the absorbing screen DD of tinfoil (two thin sheets), the currents with and without the radiator at B in fig. 1 caused deflexions of 86 and 26 mm. in ten seconds respectively ; the currents with and without the radiator at B in fig. 2 were 220 and 35 respectively. There could be very little error, therefore, in taking the incidence and emergence radiations as 60 and 185 respectively ; and the want of symmetry is beyond doubt.

It should be observed that the emergence radiation can never be shown to an unfair advantage in these experiments, and is often at a disadvantage, for the radiator, when placed as in fig. 2, cuts down the very primary rays to which the secondary radiation is due. It is not difficult to show that if the thickness of the radiator is so adjusted as to give the maximum emergence current (it can of course be too thick or too thin), then the ratio of this maximum to the maximum incidence current (which can be obtained simply by making the radiator thick enough) is only $2/e$ of the true ratio of emergence to incidence; provided that the secondary rays are as penetrating as the primary, and that we are considering homogeneous radiations. But if, other conditions being the same, the secondary rays are less penetrating than the primary, then the ratio, as found, is more nearly correct, and is very nearly so when the secondary rays are much less penetrating than the primary, as, for example, when we are considering secondary cathode rays due to X- or γ rays.

We have made a large number of measurements by the method described above, using the following metal sheets as radiators :—Pt, weight per square cm., ·0150 gr. : Sn, ·0096 gr. ; Cu, ·0083 gr. ; Fe, ·0077 gr. ; Al, ·105 gr. ; celluloid, ·20 gr. As screens we have used various thicknesses of Sn, Cu, and Al.

The proportion of emergence to incidence radiation differs considerably for the different radiators, but is much the same for different screens or different thicknesses of screen, except that the proportion tends to increase slightly as the screen is made thicker; and the tendency is most pronounced in the case of those metals which give out a quantity of soft secondary radiation. For example, Fe and Cu show little difference between incidence and emergence radiations until the screen is so thick that only a small fraction of either of the radiations can pass through. The results vary somewhat with the state of the bulb; and since these variations are comparable with those which are met with on changing the nature of the screens, we are not now in a position to discuss smaller variations in detail. We must content ourselves with quoting a few results in order to show the want of symmetry, which is a persistent effect. When, for example, two tinfoils were used as screen (weight per square cm. of each, ·0056), we obtained the following figures, which represent movements of the scale in mm. during 10 secs. :—

Radiator	Sn.	Cu.	Fe.	Al.
Emergence Current	176	140	39	185
Incidence Current	122	119	15	60

With four tinfoils the figures were :—

Radiator	Sn.	Cu.	Fe.	Al.
Emergence Current	143	24	23	116
Incidence Current	87	1	0	34

Again, using a copper screen ·002 cm. thick, we found :—

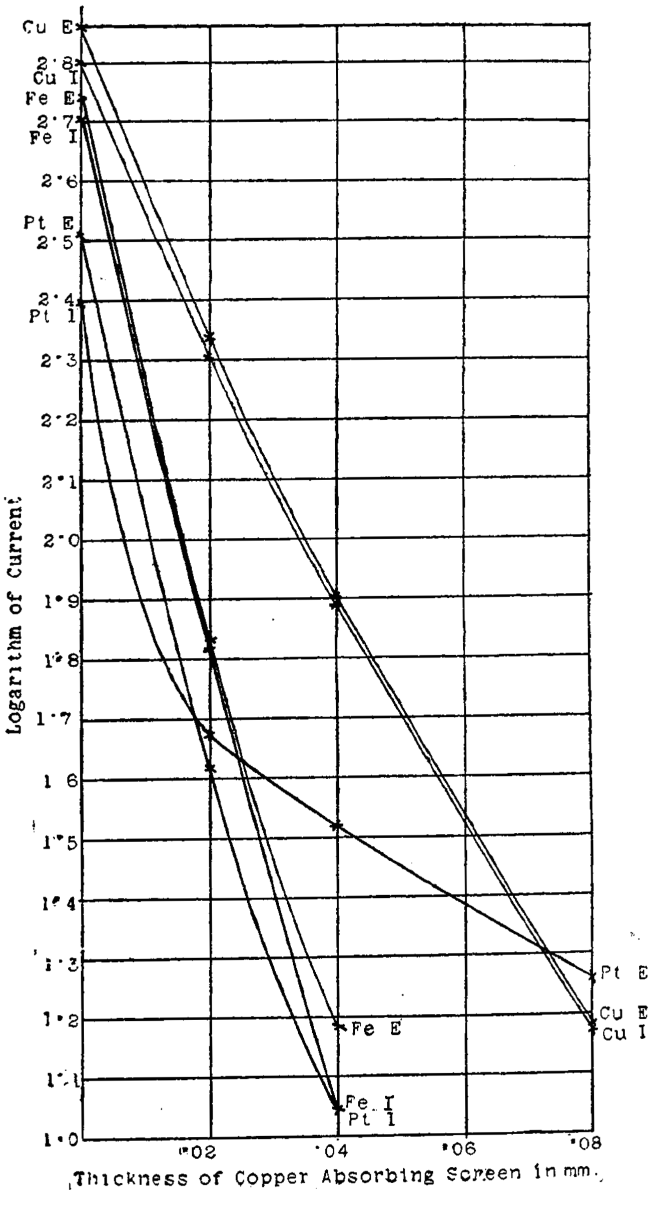
Radiator	Pt.	Sn.	Cu.	Fe.	Al.	Celluloid.
Emergence Current	86	140	361	118	80	138
Incidence Current	65	104	364	118	32	93

Putting together a number of results for Cu screens of different thicknesses we obtain the logarithmic curves of absorption shown in the accompanying figures (figs. 5 and 6). It should be observed that some of the results thus shown were obtained at different times, so that too much must not be built upon a comparison between them ; only the relative positions of the emergence and incidence curves of each substance are sufficiently correct, and the form of each curve as showing the homogeneity or otherwise of the various radiations. One figure shows the emergence (E) and incidence (I) curves for Pt, Cu, and Fe; the other the corresponding curves for Sn, Al, and celluloid.

The experiments described in this paper show that a very marked want of symmetry occurs in the case of secondary X-rays, the emergence rays being generally greater than the incidence. This is another instance of the close parallelism between X- and γ rays. On a material theory of X- and γ rays the effect is easily explained, and is to be classed with the scattering to which β, and also, as lately shown clearly by Geiger, α rays are subject. But if the X- and γ rays consist of energy bundles of very small volume, as suggested by J. J. Thomson, then these bundles must be capable of deflexions in going through atoms—that is to say, swung out of their paths by the electrical forces to be found within the atoms, just as neutral pairs would be in virtue of their electrical fields. It seems hard to understand the distinction between such bundles and entities generally classed as material.

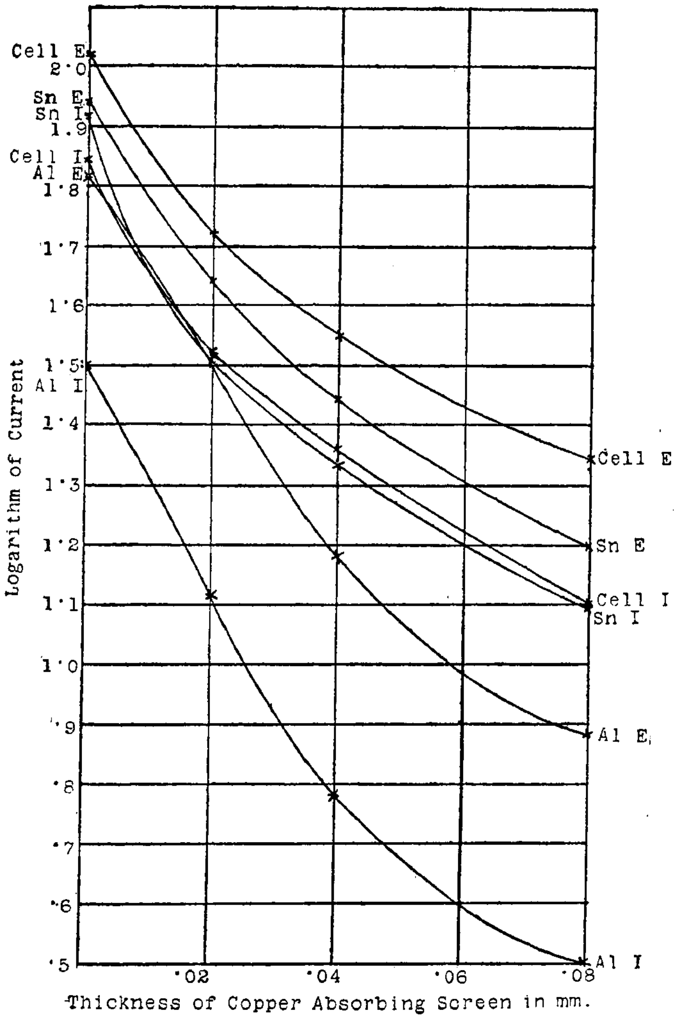
In the course of this investigation we have made a number

Fig. 5.


Cu E
2·8
Cu I
Fe E
2·7
Fe I
2·6
Pt E
2·5
2·4
Pt I
2·3
2·2
2·1
2·0
1·9
1·8
1·7
1·6
1·5
1·4
1·3
1·2
1·1
1·0
Logarithm of Current
·02
·04
·06
·08
Thickness of Copper Absorbing Screen in mm.
Pt E
Cu E
Cu I
Fe E
Fe I
Pt I

of experiments on the quantities and qualities of the secondary radiations. This subject has been fully treated by Barkla, some of whose recent papers have not yet reached us, and

Fig. 6.



any discussion we gave might be merely a duplication of part of his inquiry. There is, however, one point to which we should like to refer.

Very hard γ rays follow a density law of absorption, treating all atoms alike, except in respect to weight. Soft γ rays are not independent of atomic groupings of matter, and are far more strongly absorbed by heavy atoms than by light, after allowance has been made for weight. The same is generally true of X-rays; but in the case of very soft X-rays there is a tendency to revert to the density law again. For instance, X-rays that have passed through the glass of the bulb are soft to copper, silver, tin, and so on, but hard to aluminium, carbon, and low atomic weight generally. No doubt those rays which are soft to such light atoms have already been absorbed by the glass. But secondary X-rays from most substances are softer than anything emerging from the bulb and contained in the primary ray. The difference is not very great when the absorption is measured with the aid of screens made of substances of the higher atomic weights, because to these the primary rays are soft already. But if the screens are made of aluminium, still more of filter-paper, the difference now seems to be very great, for the secondary rays are soft even to low atomic weights. For example, in one experiment, a sheet of copper weighing ·018 gr. per square cm. caused a drop of ·401 in the logarithm (to base 10) of the primary rays, and only of ·447 in the case of the emergence secondary rays from copper, of ·645 in the case of platinum rays, and ·805 of iron rays. But when four filter-papers weighing ·02 gr. per square cm. were used as screen, the drop in the case of the primary rays was ·010—only one-fortieth of the drop caused by a copper screen of nearly equal weight. In the case of the secondary rays, however, the same screen caused a drop in the case of copper rays of ·100, platinum rays ·053, and iron rays of ·188—that is to say, for these soft rays the filter-papers are much more nearly on an equality with copper, weight for weight, than they were for hard rays. It is interesting to bear this in mind when considering the very large quantities of secondary ionization which some substances seem to give. The ionization is always measured in air, which of course consists of atoms not very different in weight from those contained in filter-papers. Consequently primary rays, and secondary rays which differ very little from the primary, are very penetrating to air, and cause relatively small ionizations therein. But secondary rays from Cu and Fe are softened so much as to bring them within reach, so to speak, of air, which rapidly converts them into cathode rays, so that there is a very large ionization. For the cathode rays produced from these secondary rays have probably but little less energy than those produced from the primary ; the speed of the cathode ray does not differ very greatly with the penetration of the primary X-ray, so far as experiments have shown. The very large secondary radiations, which some substances appear to give, therefore, owe their magnitude largely to the fact that the air in which they are measured is sometimes ten to twenty times as favourable to them as to the primary rays which produced them. In this way we may account to some extent for the startling results obtained by Crowther in the case of arsenic and bromine (Phil. Mag. Nov. 1907).

Discussion.

Prof. C. H. Lees said that Prof. Bragg had given a lucid account of his theories of γ and X rays. His researches would make physicists more careful in accepting the æther-pulse theory. He asked if it was likely that better means would be devised to discriminate between various forms of γ and X rays than dividing them into "hard" and "soft" radiations. He thought many discrepancies could be attributed to this want of discrimination.

Mr. C. A. Sadler pointed out that whatever lack of symmetry might exist in the emergence and incidence secondary X radiations from a plate of a substance which was a source of scattered primary radiation, Professor Bragg's own results conclusively proved that such lack of symmetry did *not* exist when the plate was a source of homogeneous radiation. If then it was a necessary condition of Professor Bragg's theory that such lack of symmetry should exist with secondary X radiations, we must either conclude that the theory here breaks down or that these homogeneous radiations are not X radiations as usually understood. It was to be noted also that the measured lack of symmetry (ignoring the lack of symmetry in the case of homogeneous beams, which can be shown to be only apparent) in the most pronounced cases was small compared with those obtained with γ rays.

Prof. Bragg, referring to the remarks of Prof. Lees, said that for precision the actual speed of all electrons ought to be measured. Instead of measuring the speed the penetrating power might be determined.