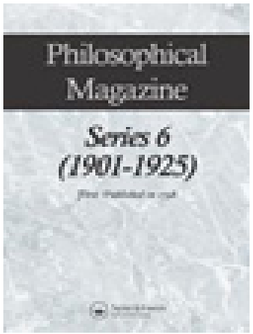

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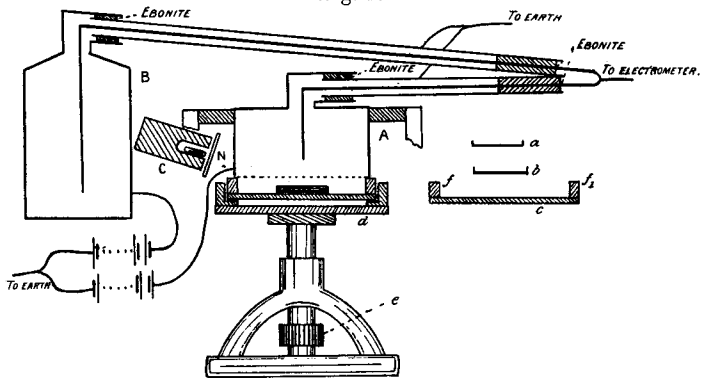
LXII. *On the Secondary Cathode Rays emitted by Substances when exposed to the γ Rays.* *By* R. D. KLEEMAN, *B.A., B.Sc.*, 1851 *Exhibition Research Scholar of the University of Adelaide*; *Emmanuel College, Cambridge* *.

§ I.

IT was discovered by Eve † that a substance exposed to the γ rays emits secondary cathode besides secondary γ rays. The object of this paper is to describe some experiments on the amount of secondary cathode radiation from different substances, as measured by the ionization these secondary rays produce in air.

Fig. 1 is a diagram of the apparatus used. The chamber

Fig. 1.



A is an ionization-chamber supported by means of a frame arrangement, so that its distance from the table on which the experiments were performed was about 18 cm. It consisted of an aluminium box 10 cm. high, 12·5 cm. long, and 7 cm. deep, with a wire gauze for its lower side. The chamber B is another ionization-chamber whose electrode was connected with that of the chamber A. It consisted of a cylindrical-shaped can 18 cm. in diameter and about 16 cm. high. The source of γ rays was 30 mgrm. of radium bromide contained in a closed glass tube which was placed into the tubular cavity of the lead cylinder C; a plate of lead 3 mm. thick placed over the opening of the cavity served to cut off the β rays. The position of the lead cylinder with respect to the chamber A was as shown in the figure. The chamber A was connected to a positive potential of 200 volts, and the chamber B to a negative potential of 200 volts; and the

* Communicated by Prof. J. J. Thomson, F.R.S.

† Phil. Mag. Dec. 1904.

distance of the chamber B from the radium so arranged that the leak in B partially compensated for that in A.

The substance under investigation, if in the form of powder, was tightly packed into the little dish *a*, the upper surface of the powder being made flush with the rim. The dish was of a circular form and made of thin sheet zinc, its diameter was 5·6 cm. and its depth 4 mm. This dish was then placed into another dish *b*, into which it fitted closely. The dish *b* was then placed in the centre of the aluminium plate *c*, and this placed on the table *d*, three strips of ebonite fixed to the table serving to keep the aluminium plate in a fixed position. By means of the screw *e* the table was then raised till the ebonite blocks f, f_1, attached to the aluminium plate, touched the gauze, the distance of the aluminium plate from the gauze in this position being 11 mm. The leak was then taken.

The aluminium plate *c*, when placed on the table *d*, made contact with an earthed wire; an electric field therefore existed between the gauze and plate, which prevented the diffusion of ions through the gauze into the chamber.

By partially compensating for the leak in the chamber A by means of the leak in the chamber B, the observed leak was under control, and the radium could be placed quite near to the chamber A. The secondary radiation from the substance in the dish *a* was thereby rendered intense, and the change in the leak when a different substance was substituted for the one in the dish was therefore much greater in comparison with the observed leak than would have been the case with one chamber only. In fact, with one chamber only, the change in the leak with change of substance would be, in many cases, so small that it would be difficult to measure.

The leak was allowed to run into the electrometer till the deflexion was approximately equal to some fixed deflexion of convenient magnitude, and the current then broken, and the first and second swings of the needle read. The position of rest of the needle was obtained by means of a formula given by the writer *, and knowing the time of leak, the leak for any given time could be calculated. The disturbing effect of the change of capacity of the electrometer with deflexion was avoided in this manner.

Since the leak due to the secondary radiation from a given substance depended on the position of the radium, the sensitiveness of the electrometer, &c., it became necessary to devise a method of comparison of the secondary radiation

* Phil. Mag. Oct. 1906, p. 276.

from the various substances, which would be independent of the magnitude of these external quantities. It was also necessary to elimininate the γ secondary radiation. This was obtained by the following process. After a reading had been taken when the dish a contained the substance under investigation, the dish with its contents was taken out of the dish b and placed in the centre of the aluminium plate and the dish b inverted and placed over it. A reading was then taken with the bottom of the dish b as source of secondary radiation. The bottom of the dish b consisted of sheet lead 3 mm. thick. A disk of aluminium of the same size as the dish a was then placed into the dish b, and a reading taken with this aluminium disk as source of secondary radiation. A reading with the bottom of the dish b was then taken in the same manner as before. The whole process was repeated several times. It will now be shown that the difference between the first and second readings is a measure of the difference between the amounts of secondary cathode radiation from the substance under investigation and from lead, and the difference between the third and fourth readings a measure of the difference between the amounts of secondary radiation from lead and aluminium.

Let nc, mc, uc, denote the secondary cathode radiations, and $n\gamma$, $m\gamma$, $u\gamma$, the secondary γ radiations, from the substance under investigation and from lead and aluminium respectively, as measured by their ionizing power. Let K denote the leak that would be obtained if the substance in the dish a and the lead bottom of the dish b did not emit either secondary γ or secondary cathode radiation. Then, when the substance n is in the dish a, the leak obtained is $(K+nc+n\gamma+m\gamma)$. It is supposed that the γ radiation from the lead is not appreciably diminished by passing through the substance in the dish. When the dish a is covered by the dish b the leak obtained is $(K+mc+m\gamma+n\gamma)$. The difference between these two leaks is $(mc-nc)$, which is a measure of the difference between the amount of cathode radiation from lead and the substance n. In the same way it can be shown that the difference between the leaks obtained with the substances m and u, that is lead and aluminium, is $(mc-uc)$.

The mean values of $(mc-nc)$ and $(mc-uc)$, found by the above process, were multiplied by a number which made $(mc-uc)$ equal to 800. The values of $(mc-nc)$ for the various substances were thus rendered comparable with one another, being relatively independent of all external quantities.

To give an idea of the magnitude of the ionizing effect

produced by the secondary cathode rays in these experiments, it may be stated that in one experiment, when the radiating substance was aluminium, a leak of 2319 divisions in 40 seconds was obtained; and when the radiating substance was lead, a leak of 2295 divisions in 30 seconds was obtained. The value of $(mc-uc)$ corresponded, therefore, to a leak of 741 divisions in 40 seconds. The capacity of the whole system was about 200 E.S.U., and the electrometer gave a deflexion of 4010 divisions for one volt*.

The secondary γ radiation, which was approximately eliminated in these experiments, was, with the thickness of the layers of substances used, in most cases so small as to be comparable with the experimental error, that is, equal to two or three per cent. of the total leak obtained.

The amount of secondary cathode radiation from a plate of a substance increases with the thickness of the plate up to a certain thickness, beyond which there is no increase of secondary radiation, the plate producing then the maximum amount of secondary radiation. It is therefore necessary to consider whether the thickness of substances used in these experiments gave the maximum amount of secondary radiation.

The secondary cathode rays from a substance exposed to γ rays are nearly, though not quite, so penetrating in character as those obtained with the β rays, according to S. J. Allen (Phys. Review, vol. xxiii. p. 82, August 1906). Therefore the thickness of a radiating plate of a given substance producing the maximum amount of secondary cathode radiation must be about the same as is necessary with β rays, that is a thickness of about 2 mm. in the case of lead. The layers of substances in these experiments were ·4 cm. thick, and therefore gave approximately the maximum amount of secondary radiation.

An experiment by Mackenzie† ought to be mentioned in this connexion. Mackenzie found that the maximum amount of secondary cathode and γ radiation from a lead plate exposed to the β and γ rays of a quantity of radium, was obtained with a thickness of about 2 mm. of lead, while the thickness of the plate which produced the maximum amount of secondary radiation, when it was exposed to the γ rays alone, was about 7 mm. The explanation of this seems to be that the secondary γ radiation, when the plate is exposed to the γ rays alone, is larger in comparison with the total radiation (which consists of secondary γ and secondary

* 10 divisions correspond to 1 mm. on scale.

† Phil. Mag. July 1907, p. 184.

cathode radiation), than when the plate is exposed to both the β and γ rays; and there would, therefore, be a greater comparative increase in the radiation beyond a certain thickness of substance with the γ rays, than with both the β and γ rays. It may be mentioned that according to the experiments of Eve the γ rays of radium produce about one-fifth of the total radiation from a plate exposed to both the β and γ rays. It follows, therefore, that the ratio of the total radiation to the γ radiation, when a substance is exposed to the γ rays, is about five times greater than when the substance is exposed to both the β and γ rays.

An unexpected difficulty encountered in these experiments will now be described. It was found that a number of leaks taken in succession with a single substance were subject to gradual fluctuations in magnitude: in the course of an hour a change of 5 or 10 per cent. in the value of the leaks might take place. When one of the chambers was disconnected from the electrometer, and the radium placed at such a distance from the other chamber that a convenient leak was obtained, these fluctuations were very small but still detectable. It thus appears that the leak in a single chamber was liable to fluctuations which were small in comparison with the whole leak, and therefore when the difference between two leaks was taken, both of which were large, the fluctuation in the observed leak necessarily became much larger in comparison with the whole leak. The fluctuations might have been due to changes in the centre of the γ radiation, caused by some emanation coming off in gusts from the radium, and the radium A thereby getting deposited on the inside of the walls of the glass tube instead of in the radium itself. By taking a large number of readings, alternately with the two standard substances, and one of the standard substances and the substance under investigation, and taking in each case the mean of the differences obtained, the disturbing effect of these fluctuations was rendered very small. About sixty-four observations were, as a rule, taken in all during the investigation of a single substance. It required about one hour and a half to make such a set of observations.

The differences between the amounts of secondary cathode radiation from a number of substances and the radiation from aluminium, corresponding to a difference of 800 of the standard pair of metals lead and aluminium, are given in Table I. They were not determined in any definite order, but as they came to hand; some of them are the mean of two or three separate determinations made at different times. In the case of those substances which were obtainable in the

TABLE I.

Differences of substances.	Difference in secondary radiation.	Difference in atomic weight.	Differences of substances.	Difference in secondary radiation.	Difference in atomic weight.
B−Al.....	+12	−16	Se−Al	238	52·1
C−Al.....	−155	−15	Zr−Al	205	63·7
Na−Al	−52	−4	Mo−Al	207	68·9
Mg−Al.....	+13	−2·6	Ru−Al	245	74·7
Si−Al	−27	+1·4	Ag−Al	348	81
P−Al	−1	4	Cd−Al	373	85
S−Al.....	+11	5	Sn−Al	401	91
Ca−Al	99	13	Sb−Al	405	93
Mn−Al.....	151	28	I−Al.....	441	100
Fe−Al	166	29	W−Al	552	157
Ni−Al	176	31·7	Pt−Al	743	168
Co−Al	181	31	Hg−Al	794	173
Cu−Al	206	36·3	Pb−Al	800	180
Zn−Al	215	38·5	Bi−Al	1018	181
As−Al	225	48			

An approximate value of the radiation from aluminium, corresponding to (Pb−Al)=800, is 330.

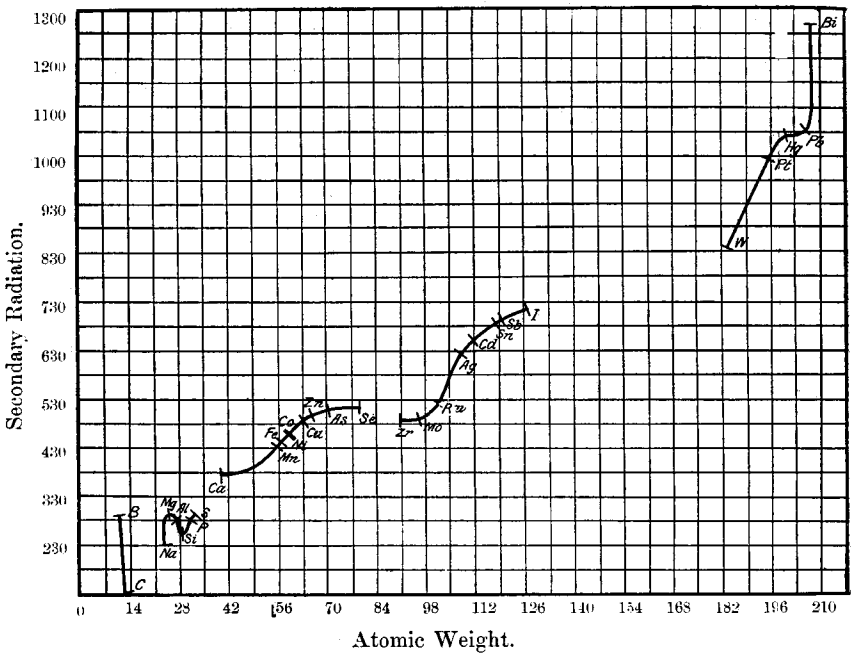
form of plates, little disks were turned by means of a lathe, equal in dimensions to the little dish *a*. The substances used in the form of filings or powder were: B, C (pure graphite), Mg, Si, P (red), S, Mn, Se, As, Co, Zr, Mo, Ru, Sb, I, W, Pt (black), Bi.

The radiating powers of the various elements, obtained from the table by making aluminium equal to 330, are plotted against their atomic weights in fig. 2; and the elements belonging to the same chemical period joined, in each case, by a smooth curve. The method by means of which the radiating power of aluminium was determined will be described later. For our present purpose it does not matter what value is assigned to aluminium, since the general form of the curves will thereby not be altered.

It will be seen afterwards that the γ rays from radium are heterogeneous, and that the constituent rays possess different powers of producing secondary radiation from a given substance. A partial separation of the rays can be effected, since they are selectively absorbed, by means of metal screens. Since the γ rays in this experiment passed through a lead screen only 3 mm. thick, the curves represent, at any rate approximately, the general nature of the curves showing the relation between the atomic weight of a substance and the secondary cathode radiation with the heterogeneous γ rays of radium.

The curves obtained are quite distinct from one another and resemble one another in some respects. They show that the elements fall into groups corresponding to the periodic classification.

Fig. 2.



The first sample of cobalt used in these experiments gave 98 for the value of (Co—Al), a value which did not make cobalt fit in with the other elements. The explanation was found to be that, since the cobalt was in the form of very fine powder, it had become more or less oxydized, which decreased the amount of radiation owing to the presence of matter of much smaller atomic weight than that of the cobalt. A determination with a fresh sample of cobalt of a coarser nature gave 181 for the value of (Co—Al), and this made cobalt fit in with the other elements.

The third and fourth curves in the figure, corresponding to the first and second long periods of the elements, resemble each the letter S in shape; while the second and fifth curves, corresponding to the second short period and the fourth long period, resemble each the letter S inverted.

It will be seen that the curves representing the first and second long periods are steepest in the middle; they resemble in this respect the curves obtained by Prof. J. J. Thomson* with X rays.

There is a comparatively great difference in the radiating powers of carbon and boron, and of lead and bismuth, although in both cases the atomic weights differ little from one another. Thus the addition of a few electrons to a boron or lead atom seems to produce a considerable change in the grouping of the electrons, whereby either the absorption of the primary γ rays, or the absorption of the secondary cathode rays, or both, are affected to a considerable extent. It is interesting that in the case of boron and carbon, the radiating power decreases with increase of atomic weight, while it increases with the atomic weight in the case of lead and bismuth.

Prof. Thomson† found that with X rays the radiating powers of bismuth and lead did not differ much from one another, and the same was found to be the case with boron and carbon. It ought to be mentioned that the radiation that Prof. Thomson measured consisted of secondary X rays and secondary cathode rays of small penetrating power.

It will be observed that the radiating powers of silicon and carbon are respectively smaller than those of aluminium and boron. According to the periodic classification of the elements, boron and carbon of the first short period correspond to aluminium and silicon of the second short period, boron and aluminium belonging to Group III. and silicon and carbon to Group IV. Thus we might expect the behaviour of aluminium and silicon to be similar to that of boron and carbon.

The curves show, as a whole, that the increase of secondary radiation with atomic weight is, on the average, greater the higher the atomic weight; in other words, the average steepness of the curves increases with the atomic weight.

McClelland‡ has investigated the amount of secondary radiation from various substances on which β and γ rays of radium were allowed to fall. The secondary radiation in his experiments consisted principally of the secondary cathode radiation due to the β rays, and a stream of reflected β rays (these constituents amounting to about 80 per cent. of the total radiation, according to the experiments of Eve). The remainder consisted of secondary γ radiation, and secondary cathode radiation due to the γ rays. His results, therefore,

* Proc. Camb. Phil. Soc. vol. xiv. pt. 1 (1906).

† *Loc. cit.*

‡ Trans. Roy. Soc. Dublin, vol. ix. p. 1 (1905), and p. 9 (1906).

give approximately the secondary cathode radiation from substances exposed only to β rays.

The curves which he obtains by plotting the secondary radiation against the atomic weight, and joining the elements of the same period by a smooth curve, differ in shape from those obtained by the writer with γ rays; but still there are points of resemblance. Both of his curves, representing the first and second long periods of the elements, are concave towards the atomic weight axis, at the extremities of the curves corresponding to higher atomic weight, a result obtained also by the writer in the case of γ rays. But his curves show that, on the whole, the change of secondary radiation with atomic weight decreases with increase of atomic weight; the opposite, we have seen, is the case with γ rays. Moreover, his curves approximate to a series of straight lines.

Also, he obtained with the β rays no such comparatively large difference in the radiating powers of lead and bismuth as the writer obtained with γ rays.

A stream of β rays falling on a plate diminishes very rapidly in intensity as it penetrates into the plate, and the amount of secondary radiation must therefore depend to a certain extent on the rate of absorption of the rays. In the case of γ rays the decrease in the intensity of the rays is small when they are passed through a thickness of matter producing the maximum amount of secondary cathode radiation. Therefore the difference in the rate of absorption of the β and γ rays by a substance, is one of the factors which tend to make the relative radiating powers of the various substances different with β and γ rays. We will now express the secondary radiation from a thick layer of a substance in terms of other quantities.

Let us suppose that the γ rays are not diminished in intensity when passing through a layer of a substance of the thickness necessary to produce the maximum amount of radiation, and let K denote the number of electrons ejected in each c.c. of the substance due to the action of the γ rays. The moving electrons in the substance may be resolved into two streams parallel to one another, but moving in opposite directions and at right angles to the parallel surfaces of the layer. Let r denote the intensity of the stream at a distance x from one of the radiating surfaces, moving away from the surface, and R the intensity of the stream approaching the surface. Let μ denote the coefficient of absorption of the electrons if there were no secondary radiation, and κ the ratio of the secondary to the absorbed radiation. Then we

have

$$-\frac{dR}{dx} = -\mu R + \frac{\mu R\kappa}{2} + \frac{\mu r\kappa}{2} + \frac{K_1}{2}, \quad . \quad . \quad . \quad (1)$$

and

$$\frac{dr}{dx} = -\mu r + \frac{\mu r\kappa}{2} + \frac{\mu R\kappa}{2} + \frac{K_1}{2}, \quad . \quad . \quad . \quad (2)$$

when a steady state is reached.

The first term of the right-hand side of equation (1) denotes the absorption of the stream R if there were no secondary radiation; the second and third terms denote the streams of secondary radiation moving in the same direction as the stream R, due to the streams R and r respectively; and the fourth term denotes the stream of radiation due to the action of the γ rays, moving in the same direction as the stream R. The terms on the right-hand side of equation (2) have similar meanings.

The equations may be written

$$\frac{dR}{dx} = aR - br - N, \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\frac{dr}{dx} = -ar + bR + N, \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where $a = \mu - \frac{\mu\kappa}{2}$, $b = \frac{\mu\kappa}{2}$, and $N = \frac{K_1}{2}$.

Eliminating r from these equations we get

$$\frac{d^2R}{dx^2} = (a^2 - b^2)R - (a+b)N. \quad . \quad . \quad . \quad . \quad (5)$$

The general solution of this equation is

$$R = A_1 e^{-x\sqrt{a^2-b^2}} + A_2 e^{x\sqrt{a^2-b^2}} + \frac{N}{a-b}. \quad . \quad . \quad (6)$$

The amount of radiation R_1 per cm.^{2} per second from the surface of the layer is obtained by putting $x=0$ in the last equation, this giving

$$R_1 = A_1 + A_2 + \frac{N}{a-b}. \quad . \quad . \quad . \quad . \quad . \quad (7)$$

It remains to determine the arbitrary constants A_1 and A_2.

Let n denote the thickness of the layer of substance. At the surface where $x=0$ we have $r=0$, and therefore from

equations (3) and (6) we have

$$\frac{dR}{dx}=aR-N=(A_2-A_1)\sqrt{a^2-b^2}$$

at that surface, that is

$$a\left(A_1+A_2+\frac{N}{a-b}\right)-N=(A_2-A_1)\sqrt{a^2-b^2}, \quad . \quad (8)$$

by equation (7). At the surface for which $x=n$ we have $R=0$, and thus

$$0=A_1 e^{-n\sqrt{a^2-b^2}}+A_2 e^{n\sqrt{a^2-b^2}}+\frac{N}{a-b}. \quad . \quad . \quad (9)$$

The values of A_1 and A_2 for a layer of thickness n are given by equations (8) and (9). In the case of a layer of thickness giving the maximum amount of radiation, we require the values of A_1 and A_2 obtained when n is made infinite.

It will be seen by inspection that if we substitute for A_2 in equation (8), and n is made infinite, the equation becomes

$$a\left(A_1+\frac{N}{a-b}\right)-N=-A_1\sqrt{a^2-b^2};$$

and therefore

$$A_1=\frac{-bN}{(a+\sqrt{a^2-b^2})(a-b)}.$$

From equation (9) it appears that when n becomes infinite, A_2 becomes infinitely small, but the product $A_2 e^{n\sqrt{a^2-b^2}}$ is always finite.

Substituting the above value for A_1 in equation (7) and putting $A_2=0$, we obtain

$$R_1=\frac{N}{a-b}\,\frac{a-b+\sqrt{a^2-b^2}}{a+\sqrt{a^2-b^2}},$$

that is

$$R_1=\frac{K_1}{\mu(1-\kappa)}\,\frac{1-\kappa+\sqrt{1-\kappa}}{2-\kappa+2\sqrt{1-\kappa}},$$

substituting for a, b, and N.

Since K_1 denotes the number of electrons ejected per c.c. we may put $K_1=\frac{M_1\rho}{w}$ in this equation, where ρ is the density of the substance, w the atomic weight, and M_1 the

ratio of the number of electrons ejected per second per atom.

The quantity M_1 is of theoretical interest and importance, and it will therefore be profitable to see whether we can obtain values of M_1 for some of the substances. It will be seen that to calculate M_1 for a particular substance, we must know the values of the quantities μ, κ, and K_1, relating to the substances. But the quantities μ and κ for the electrons ejected by γ rays in a substance have not yet been experimentally determined. It appears very probable, however, from the experiments of Allen mentioned, that these quantities have approximately the same values as found by McClelland and Hacket* for the secondary rays of the β rays from radium. Table II. contains the values of K_1

TABLE II.

Substance.	μ.	κ.	K_1.	M_1.	K_2.	M_2.
Aluminium	23	·625	10·0	10·0	10·0	10·0
Nickel	127	·755	62·5	40·0	66·2	42·8
Copper	107	·780	52·4	37·2	57·7	39·1
Zinc	103	·785	50·4	43·7	55·9	49·7
Silver.....	203	·825	108·0	107	116·0	115
Cadmium	160	·830	86·2	107	91·8	115
Tin.....	133	·835	73·3	113	76·7	119
Platinum	479	·870	333	288	289	235
Lead	268	·885	182	315	164	286

and M_1 for a number of substances calculated by means of the last two equations, using the values of μ and κ found by McClelland and Hacket, and the values of K_1 obtained from Table I. by making aluminium equal to 330. The values of M_1 and K_1 for aluminium have both been put equal to 10 in the table.

It will be seen that the values K_1 and M_1 fall into groups corresponding to the periodic classification of the elements. The values of K_1 for the substances belonging to the same group differ considerably from one another, and increase with decrease of atomic weight. The values of M_1 for the same group differ little from one another, but there is a considerable change in the values from group to group. It would be interesting to calculate the values of K_1 and M_1 for all the elements, if the necessary data were known.

* Trans. Roy. Soc. Dublin, vol. ix. p. 27 (1906), and p. 37 (1907).

Let us now find values of the quantities for the β rays corresponding to K_1 and M_1 for the γ rays. Let these quantities be denoted by K_2 and M_2 respectively; they represent respectively the number of electrons ejected per c.c. per second, and the number of electrons ejected per atom per second, in a substance exposed to the β rays.

The value of K_2 is given by $K_2=\mu\kappa$, and the value of M_2, since $\frac{\rho M_2}{w}=K_2$, by $M_2=\frac{\mu w\kappa}{\rho}$.

The values of M_2 and K_2 for the substances in Table II., calculated by means of these two equations, are given in the sixth and seventh columns of the table. The values of K_2 and M_2 for aluminium have been put, as before, equal to 10.

It will be seen that the values of K_2 and M_2 are approximately the same as those of K_1 and M_1. The values of M_2 and M_1 measure the relative probabilities of the atoms of the various substances being ionized when subjected to β or γ rays. It is interesting that the relative chances in both cases should be approximately the same when the nature of the rays seems to be so entirely different. It will be seen in the next section that the relative chances of ionization in the case of the γ rays depend to some extent on the nature of the ionizing rays.

The quantities M_1 and M_2 must be related to the ionization in a gas. If the above substances were in the form of, say, monatomic gases at the same pressure, we should expect, since these quantities represent the relative number of primary electrons ejected per second, that the ionization per c.c. in these gases would be the same with both β and γ rays. Now, the writer* has investigated the relative ionizations per c.c. with β and γ rays of a large number of complex gases, and found the ionization very approximately the same for both kind of rays. The results obtained are given in Table III. The values of the ionization per c.c. with the α particle for these gases have been placed in the table for comparison, being taken from a table compiled by the writer in the paper referred to. The larger number of the values for the α particle are due to Prof. Bragg, whose experimental results† were incorporated in the table mentioned.

It was also found that the ionization in a gas is approximately an additive property of the atoms of the molecule. The atomic ionizations for the γ, β, and α rays are given in

* Proc. Roy. Soc. A. vol. lxxix. p. 220 (1907).
† Phil. Mag. March 1907, p. 333.

the sixth, seventh, and eighth columns of the table respectively. Hydrogen is the only gas showing a serious deviation from the additive law. If the elements given in the fifth column could exist as monatomic gases, the atomic ionizations would give their ionization per c.c. It will be seen that the *atomic ionizations* for the β and γ rays are also approximately the same.

But if we compare the atomic ionizations with the values of M_1 and M_2, we see that the values of M_1 and M_2 increase more rapidly with increase of atomic weight than the atomic ionizations. Let us examine these quantities more closely, beginning with the ionization in a gas. The ionization in a gas consists of the primarily ejected electrons, and the ions that these electrons produce by collision. Since the primary electrons are ejected with a considerable velocity, the former quantity is probably small in comparison with the latter. The ionization per c.c. in a gas may therefore be expressed in terms of two factors, which are respectively proportional to the primary and secondary or collision ionization. This product for any particular gas expressed in terms of that of air must be the same for the β and γ rays, according to the experiments of the writer in Table III. The velocity of the

TABLE III.

Gas.	Ionization per c.c. γ rays.	Ionization per c.c. β rays.	Ionization per c.c. α rays.	Atom.	Ionization per atom. γ rays.	Ionization per atom. β rays.	Ionization per atom. α rays.
Air	1·00	1·00	1·00	H	·18	·18	·175
O_2	1·16	1·17	1·15	C	·46	·46	·51
CO_2	1·58	1·60	1·59	N	·45	·475	·47
CH_4O ...	1·75	1·69	1·74	O	·58	·58	·55
$C_4H_{10}O$ ...	4·29	4·39	4·40	S	1·60	1·60	1·24
C_6H_6	3·94	3·95	4·30	Cl	1·44	1·44	1·16
C_5H_{12} ...	4·53	4·55	4·85	Br	2·81	2·67	1·72
C_2H_4O ...	2·17	2·12	2·14	I	4·50	4·10	2·26
N_2O	1·55	1·55	1·53				
C_2N_2	1·71	1·86	1·94				
CH_3I	5·37	5·11	3·43				
C_2H_5I ...	6·47	5·90	4·00				
CH_3Cl ...	4·93	4·94	4·08				
C_2H_5Cl ...	3·19	3·24	3·12				
CCl_4	6·33	6·28	5·28				
CS_2	3·66	3·62	2·99				
CH_3Br ...	3·81	3·73	2·75				
C_2H_5Br ...	4·58	4·41	—				
SO_2	2·27	2·25	2·01				
NH_3	·898	·888	·99				
H_2	·160	·165	·24				

primary electrons is probably in any particular gas approximately the same for the β and γ rays, since the velocities of the secondary rays from a substance are approximately the same; and the amount of secondary ionization produced by the same number of primary electrons is therefore the same for the β and γ rays. From this it follows that the ratio of the secondary ionization per c.c. with the β rays to the secondary ionization in the same gas with the γ rays, is the same for all gases at the same pressure; and since the total ionization per c.c. is the same for the β and γ rays, this must also be true for the ratio of the primary ionizations. If the primary and secondary ionizations in a gas are each expressed in terms of these quantities in air, these ratios are both equal to unity. Thus the ionization by β or γ rays in a gas a in terms of that in air, may in each case be denoted by n_a m_a, and in the case of a gas b by n_b m_b, and so on, where n_a, n_b, &c. denote the primary ionizations, and m_a, m_b, &c. the secondary ionizations.

Now, if the primary ionizations are given by the values of M_1, or M_2 it follows that $m_a > m_b >$ &c., since the atomic ionizations increase less rapidly with the atomic weight than the values of M_1 and M_2. This means that the ionizing power of an electron from an atom in a gas composed of the same kind of atoms, decreases with increase of atomic weight of the atoms. This result is very improbable: and it follows therefore that the values found for M_1 and M_2 probably do not represent the primary ionizations. This point will now be considered.

If the secondary cathode rays from the various substances have not the same ionizing power in air, the values found for M_1 and M_2 will not represent exactly the quantities M_1 and M_2 according to the definition. If the ionizing power of the secondary cathode rays increases with increase of atomic weight, this would have the tendency to give values for M_1 and M_2 which increase too rapidly with the atomic weight. Now, although the ionizing power of the secondary cathode rays may vary to some extent with the nature of the substance by which they are emitted, it is very improbable that it varies to such an extent as to account for the above discrepancy. It is more likely that, besides the penetrating rays generated in a substance, more easily absorbable rays are generated which do not get free of the layer, and are therefore not taken into account in the measurements of secondary radiation. If this is the correct explanation it would follow, since the ionization in a gas does not increase so rapidly with increase of atomic weight as the values of M_1 and M_2, that the amount of more easily absorbable radiation produced decreases with increase of atomic weight.

We have seen that if the average velocity of ejection of an electron from a gaseous molecule ionized by β or γ rays is the same, the ratio of the primary ionization in any particular gas ionized by β rays to the primary ionization when the gas is ionized by γ rays is constant, and this constant is equal to unity if the primary ionization in any gas is expressed in terms of that in air at the same pressure. If the average velocity of ejection of an electron from a molecule in a substance ionized by β or γ rays is the same, the ratio of the values found for the quantities M_1 and M_2 for any particular substance gives, whatever these values may represent, the correct ratio of the quantities M_1 and M_2 according to the definition. For, since the radiation from a substance is measured by the ionization it produces in air, and the ionizing power of the radiation is the same for both ionizing agents, the ratio of the number of electrons radiated from the substance to the ionization they produce, is the same with both ionizing agents for any particular substance, and the ratio of the quantities M_1 and M_2 therefore in this case independent of the ionizing power of the electrons. Also, the number of electrons that do not get free from the layer of the substance must be in both cases approximately the same fraction of the number of electrons that do get free from the substance, and therefore the ratio of M_1 and M_2 for any particular substance also independent of the absorbable radiation produced. Now, the ratios of the values found for M_1 and M_2 are approximately equal to unity; and we therefore conclude that the average velocity of the electrons from molecules ionized by β or γ rays is approximately the same, and is not influenced by the state of aggregation of the molecules.

It will be useful to collect the formulæ expressing the relation between the various quantities involved in the secondary radiation from a layer of a substance exposed to β or γ rays.

McClelland has shown that the relative value p of the radiation from a layer of a substance exposed to the β rays of radium is given by

$$p = \frac{1 - \frac{\kappa}{2} - \sqrt{1-\kappa}}{\frac{\kappa}{2}}$$

It has been shown in this paper that the relative value R_1 of the radiation with γ rays is given by

$$R_1 = \frac{K_1}{\mu(1-\kappa)} \frac{1-\kappa+\sqrt{1-\kappa}}{2-\kappa+2\sqrt{1-\kappa}}.$$

The relative amount of radiation emitted per second per c.c. of a substance when exposed to the γ rays is independent of μ and κ, and therefore given by K_1 simply. The radiation emitted per c.c. when the substance is exposed to the β rays is given by $K_2=\mu\kappa$. The number of electrons ejected per atom is given by

$$M_1=\frac{R_1\mu w(1-\kappa)(2-\kappa+2\sqrt{1-\kappa})}{\rho(1-\kappa+\sqrt{1-\kappa})}$$

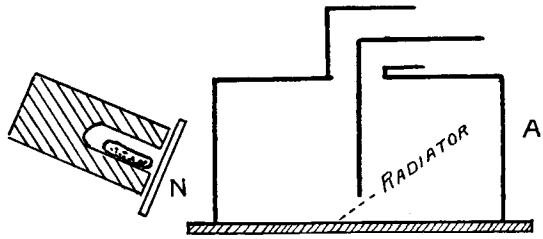
in the case of γ rays, and by $M_2=\frac{w\mu\kappa}{\rho}$ in the case of β rays. The ratio of M_1 to M_2 is given by

$$\frac{M_1}{M_2}=\frac{R_1(1-\kappa)(2-\kappa+2\sqrt{1-\kappa})}{\kappa(1-\kappa+\sqrt{1-\kappa})},$$

an equation which does not contain μ.

It remains to describe the method by means of which the radiating power of aluminium was determined corresponding to a difference of 800 in the radiating powers of lead and aluminium. The adjustable table was removed and also the wire gauze from the bottom of the aluminium chamber. The lead and aluminium plates used as radiators were each of the same dimensions as the plate c. The radiating plate was kept in contact with the edges of the opening of the aluminium box. Fig. 3 shows the modified part of the apparatus.

Fig. 3.



Leaks were taken with the aluminium and the lead plate, and a sheet of thin tissue-paper, used successively as radiators, the tissue-paper being stretched tightly over a metal frame enclosing an area somewhat greater than that enclosed by the edges of the aluminium box. All objects near the opening of the aluminium box were removed, in order to reduce to a minimum (when the tissue-paper was used as radiator), the amount of ionization caused by the secondary radiation from surrounding objects penetrating the tissue-paper and

entering the chamber. In this manner the value 330 was obtained for (Al–tissue paper), corresponding to the value 800 for (Pb–Al). The radiation from the tissue-paper must be small in comparison with that from the aluminium plate, and therefore the radiation from aluminium is approximately equal to 330, when the difference in radiation between lead and aluminium is put equal to 800.

But some of the radiation from the air and surrounding objects penetrates the tissue-paper and enters the chamber, and therefore the true value for the radiating power of aluminium is larger than the above value. Since the secondary cathode rays possess considerable penetrating power (their velocity being about half that of light), some of the rays that penetrate the tissue-paper have passed over a considerable distance in air, and the amount of radiation received from neighbouring objects is therefore probably of such a magnitude that the ionization produced cannot be neglected. The value obtained for the radiating power of aluminium is therefore only approximate, it may be said to be an inferior limit of the radiating power.

Eve has determined the secondary radiation from a number of substances when exposed to γ rays. The values that he obtained are given in Table IV. The γ rays were passed through a lead screen 6·3 mm. thick. Since the ionizing power of the secondary γ rays is small in comparison with the secondary cathode radiation, the values express the amounts of secondary cathode radiation from the given substances.

TABLE IV.

Radiator.	Secondary Radiation.
Lead	100
Copper	61
Brass	59
Aluminium	30
Glass	35
Paraffin	20

The relative values that he obtained for the metals copper, lead, and aluminium, agree with those of the writer as well

as can be expected, when it is remembered that the amount of secondary radiation from a substance depends on the nature of the screen placed in the path of the γ rays (see next section), and that the relative values of the radiating powers are liable to greater uncertainty than the relative differences.

§ II.

It was found, as has already been mentioned, that the γ rays from radium are heterogeneous, and that the different constituent rays give rise to different relative values for the secondary radiation of a set of substances.

The constituent rays are selectively absorbed, and a partial separation of different sets of rays from the original bundle could therefore be effected by means of metal screens.

Some slight alterations were made in the apparatus to make it more suitable for the investigation of this phenomenon. The gauze was removed, and the plate *c* and the dishes *a* and *b* were discarded. The substances which were used as secondary radiators were in the form of plates equal in dimensions to the plate *c*. The plate under investigation and the plate with which it was compared were placed one on top of the other on the table *d*, which was then raised by means of the screw *e* till the top plate or radiator made contact with the edges of the aluminium box forming one of its sides (see fig. 3, § I.). The difference in the amount of secondary radiation from a substance and a standard substance was, as in the foregoing experiments, compared with that of two standard substances.

The above modification of the apparatus increased its sensitiveness, by reason of the larger radiating surface employed, but it restricted the number of substances that could be used as radiators.

The substances used as radiators were: carbon (black lead contained in a shallow dish), aluminium, sulphur (a plate of sulphur, the surface of which was made a conductor of electricity by covering it with a thin layer of black lead), iron, copper, nickel, zinc, tin, and lead.

Screens of various substances were placed in the path of the γ rays. A screen was placed at N, and the differences between the radiating powers of the above substances and aluminium determined, the radiation from the substances being produced by the γ rays not absorbed by the screen. A screen of some other substance was then placed at N, and the process repeated, and so on. The screens used were of the following substances: iron, copper, zinc, tin, mercury

lead, and bismuth. The mercury screen consisted of a little box of thin sheet zinc filled with mercury, the inside surface of the box being covered with paraffin-wax to prevent the mercury coming into contact with the zinc. The dimensions of the box were: 4·8 cm. long, 1·3 cm. broad, and 5·5 cm. high.

That the amount of secondary cathode radiation from a substance depends on the nature of the γ rays to which it is exposed, can be conveniently demonstrated as follows:—The difference in the amount of radiation from iron and aluminium, and lead and aluminium, is determined with a screen of copper, and the former difference divided by the latter. A value of this ratio is then found, using a screen of lead. The whole process may be repeated several times and the means taken. Each ratio can be obtained with ease correct to five per cent. In this way, using screens of copper and lead respectively, 1·8 and 2·4 cm. thick, the writer obtained the corresponding ratios 6·4 and 4·2.

It will be well, before stating the principal experimental results obtained, to give some numbers from which an idea of the relative magnitude of the quantities measured, and the probable accuracy of the determinations, can be obtained. When a copper screen 1·8 cm. thick was used (see Table V.), and the radiating substance was aluminium, a leak of 1792 divisions in 40 seconds was obtained, and with lead as the radiating substance a leak of 1850 divisions in 10 seconds

TABLE V.

	Lead screen 2 mm. thick.	Bismuth screen 1·4 cm. thick.	Lead screen 1·3 cm. thick.	Mercury screen 1·4 cm. thick.	Tin screen 1·3 cm. thick.	Zinc screen 2·0 cm. thick.	Copper screen 1·8 cm. thick.	Iron screen 2·5 cm. thick.
C—Al ...	−155	−138	−126	−135	− 83	− 64	− 62	− 83
S—Al ...	+18	+ 26	+ 45	+ 34	+ 27	+ 28	+ 16	+ 26
Fe—Al ...	158	189	181	188	160	127	125	122
Ni—Al ...	176	225	227	218	185	156	156	160
Cu—Al ...	198	239	263	230	191	158	156	167
Zn—Al ...	216	271	272	270	222	189	185	202
Sn—Al ...	408	465	442	456	389	365	374	408
Pb—Al ...	**800**	**800**	**800**	**800**	**800**	**800**	**800**	**800**

was obtained. The difference in the leaks is 5608 divisions in 40 seconds, which is a measure of the difference of the ionization produced by the secondary cathode rays from aluminium and lead. And since an observation could be repeated any desired number of times and the mean taken, a considerable accuracy could be reached in the determination of the difference in the amount of secondary radiation from any two substances. As a rule, about 64 observations were made in determining the difference in the radiating powers of a given substance and aluminium, in comparison with that of the two standard substances lead and aluminium.

The principal results obtained in these experiments are given in Table V. The nature and thickness of the screen used in a set of determinations are given at the top of the column containing these determinations. The difference between the radiating powers of lead and aluminium has in each case been reduced to 800. The results will now be discussed and an endeavour made to draw some conclusions from them.

Since the difference in the amount of secondary radiation from any two substances is independent of the intensity of the primary γ rays, if the difference of the two standard substances is always reduced to the same figure, the secondary radiation from a given substance with the different screens in the above table should be, obviously, the same if the screens produced a change in intensity only of the γ rays. But the figures distinctly show that the γ rays that penetrated the various screens differed in their power of producing secondary radiation from a given substance. Therefore the relative differences in each column of the table depend on the nature and thickness of the screen used in their determination.

A beam of γ rays will probably not change much in nature when sifted through a screen of lead 2 mm. thick only, and therefore the second column of the table gives approximately the differences in the radiating powers of the substances under the influence of the full γ radiation emitted by radium in radioactive equilibrium. The screen of lead placed in the path of the γ rays served to cut off the β rays.

In order to be able to draw any conclusions from the effect of the various screens on the relative differences of the radiating powers of the various substances, it is necessary to compare these differences with those in the second column of the table.

Thus, it will be seen that the difference (C − Al) is decreased with a screen of lead, mercury, or bismuth, while the

differences (S—Al), (Fe—Al), (Ni—Al), (Cu—Al), (Zn—Al), (Sn—Al), are increased with these screens. With a screen of iron, copper, zinc, or tin, the difference (C—Al) is very much decreased, while the other differences are also nearly always more or less decreased. Thus it seems that the γ rays from radium consist principally of two groups of rays, the rays of one of the groups being much better absorbed by a screen of lead, mercury, or bismuth than by a screen of iron, copper, zinc, or tin, the opposite being the case with the rays of the other group.

Let us examine more closely the values given in the table. It will be convenient to express the radiation from a substance in terms of that from aluminium, so that for (Pb—Al) we may write (k_1-1)Al, and in the case of any substance D write (k_d-1)Al for (D—Al). It will also be convenient to denote the group of substances sulphur, iron, nickel, copper, zinc, and tin, by the symbol N_m, so that (N_m—Al) stands for (S—Al), (Fe—Al), &c.

Now, when the thin lead screen is replaced by the thick screen of lead, we should expect, if we assume that the γ rays are heterogeneous, that the radiation from lead would decrease in a greater proportion than that from aluminium, and the value of (k_1-1) therefore decrease. Further, if we assume that the radiation from each of the substances N_m is decreased in the same proportion as that from aluminium each of the values of (k_a-1) of the differences (N_m—Al) will remain unchanged. Therefore, if we multiply (k_1-1)Al and the values of (k_a-1)Al by a factor which brings (k_1-1)Al to its previous value, each of the values of (k_a-1)Al will become greater than its previous value. This result agrees with that obtained by experiment with the differences (N_m—Al), when the thin lead screen was replaced by the thick screen of lead (see table). The greater decrease of the radiation from lead than that from aluminium and the substances N_m, with increase of thickness of lead screen, shows that the rays that are most efficient in producing secondary radiation from lead are more easily absorbed by lead, than the rays that are respectively most efficient in producing secondary radiation from aluminium and the substances N_m. It appears also that the rays that are respectively most efficient in producing secondary radiation from aluminium and the substances N_m are absorbed to an approximately equal though small extent by lead.

It will be seen in Table V. that the value of the difference (C—Al) is decreased instead of increased, as the other differences, when the thin lead screen is replaced by the

thick screen of lead. This is explained if the radiation from aluminium is decreased in a greater proportion than that from carbon, an element of smaller atomic weight, when the thin screen is replaced by the thick screen (a similar assumption we have seen fits the facts for Pb and Al). For, the numerical value of (k_a-1) of (C—Al) is then decreased, since it is negative; and this decrease may be of such a magnitude that the value of (k_a-1)Al becomes less than its previous value when multiplied by a factor which brings (k_1-1)Al to its previous value. It will be observed that it follows from the investigation in the preceding paragraph that this factor tends to increase the value of (C—Al). Thus the greater decrease of the radiation from aluminium than that from carbon, with increase of thickness of lead screen, shows that the rays that are most efficient in producing secondary radiation from carbon are less absorbed by a screen of lead than the rays that are most efficient in producing secondary radiation from aluminium.

Since the results obtained with a screen of mercury or bismuth resemble those obtained with the lead screen, the foregoing conclusions hold good for these screens also.

Next, let us investigate the results obtained with the screens of iron, copper, zinc, and tin. We should expect from the foregoing results, and the fact that the differences of the radiating powers obtained with these screens resemble one another, that each of these screens would absorb approximately to the same extent the rays that are respectively most efficient in producing secondary radiation from aluminium and the substances N_m or (S, Fe, Ni, Cu, Zn, Sn). Also, we should expect these rays to be more easily absorbed by these screens than the rays that are most efficient in producing secondary radiation from lead. In this case the radiation from aluminium should decrease in a greater proportion than that from lead, when the thin lead screen is replaced by one of the above-mentioned screens, and the radiation from each of the substances N_m and aluminium decrease in the same proportion. Therefore the value of (k_1-1) will be increased, while each value of (k_a-1) of the differences (N_m-Al) will remain approximately the same. Therefore, when (k_1-1)Al or (Pb—Al) and the values of (k_a-1)Al or (N_m-Al) are each multiplied by a factor which reduces (Pb—Al) to its previous value, the values of (N_m-Al) will become less than their previous value. Now, this result is approximately obtained by experiment with the differences (N_m-Al), when the thin lead screen is replaced by a screen of iron, copper,

zinc, or tin, and the supposition made at the beginning of this paragraph therefore true.

It will be seen that the differences ($N_m - Al$) are least affected when the thin screen of lead is replaced by a screen of tin. This is probably due to the fact that the atomic weight of tin lies between that of lead and zinc, and therefore partakes to a greater extent of the properties of lead than the substances zinc, copper, and iron. The effect of a screen of lead, it will be remembered, is to increase these differences.

It will also be seen that the difference in the radiating power of aluminium and a substance, when the thin screen of lead is replaced by a screen of this substance, is in nearly all cases decreased to a greater extent than any of the other differences. The magnitude of the decrease of the differences becomes smaller as we pass progressively from this difference to the neighbouring differences. Now, if the radiation from a substance A is decreased in a greater proportion than that from any one of a number of other substances B_m, when the thin lead screen is replaced by a screen of the substance A, the value of $(k_a - 1)$ of (A—Al) will decrease more than its value for any of the differences ($B_m - Al$). Therefore we conclude that the rays that are most efficient in producing secondary radiation from a substance are most easily absorbed by a screen of the same substance.

A further examination of the differences obtained with the screens of copper, iron, zinc, and tin, shows that with these screens the differences (Ni—Al) and (Cu—Al) become approximately equal to one another. Now, if the radiation from copper decreased in a greater proportion than that from nickel, when the thin lead screen is replaced by one of these screens, this would decrease the value of $(k_a - 1)$ for the difference (Cu—Al) more than its value for the difference (Ni—Al). And since the value of (Cu—Al) is larger than that of (Ni—Al) with the thin lead screen, this would have the tendency of making the values of $(k_a - 1)$ of these differences more nearly equal. Thus a screen of iron, copper, zinc, or tin, absorbs to a slightly greater extent the rays that are most efficient in producing secondary radiation from copper, than the rays that are most efficient in producing secondary radiation from nickel.

The large change in the value of the difference (C—Al), when the thin lead screen is replaced by a screen of iron, copper, zinc, or tin, remains to be examined. We have seen that the decrease of the differences ($N_m - Al$), when the thin lead screen is replaced by one of these screens, can be explained

by assuming that the radiation from aluminium decreases in a greater proportion than that from lead, and the radiation from each of the substances N_m decreases in the same proportion as that from aluminium. For in this case these differences decrease when they are multiplied by a factor which makes (Pb—Al) equal to its previous value. But it will be seen that the decrease of the difference (C—Al) is much greater than that of any of the other differences, and cannot therefore be explained altogether in this manner. It is evident that the radiation from carbon does not decrease in the same proportion as that from aluminium, when the thin lead screen is replaced by one of the above-mentioned screens. If we assume that the radiation from carbon decreases in a less proportion than that from aluminium, the value of (k_a-1) of the difference (C—Al) is numerically decreased, since it is negative. In this case the value of (C—Al) or (k_a-1)Al would be much more decreased than that of any of the other differences when they are multiplied by a factor which brings (Pb—Al) or (k_1-1)Al equal to its previous value. Thus the rays that are most efficient in producing secondary radiation from carbon are less absorbed by a screen of iron, copper, zinc, or tin, than the rays that are most efficient in producing secondary radiation from aluminium and the substances N_m.

We have seen that the rays that are most efficient in producing secondary radiation from carbon are also less absorbed by a screen of lead, mercury, or bismuth than the rays that are most efficient in producing secondary radiation from lead.

It will be profitable to place some of the foregoing conclusions side by side for comparison. We have seen that the decrease of (C—Al), when the thin lead screen is replaced by a screen of iron, copper, zinc, or tin, is due, firstly, to the radiation from carbon decreasing in a less proportion than that from aluminium, and secondly, to the multiplying of (C—Al) and (Pb—Al) by a factor which brings (Pb—Al) to its previous value. This factor gives rise to the decrease of the other differences, since the radiation from lead is decreased with any one of the above changes of screen, in a *less* proportion than that from aluminium and the other substances.

The decrease of the difference (C—Al), when the thin lead screen is replaced by a screen of lead, mercury, or bismuth, is due to the decrease of (C—Al), produced by the radiation from carbon decreasing in a less proportion than that from aluminium, being greater than the increase produced by multiplying (C—Al) and (Pb—Al) by a factor

which increases (Pb—Al) to its previous value. This factor gives rise to the increase of the other differences, since the radiation from lead is decreased in a *greater* proportion than that from aluminium and the other substances.

From the foregoing we see why the difference (C—Al), when the thin screen of lead is replaced by a screen of iron, copper, zinc, or tin, is more decreased than in the case when the thin screen of lead is replaced by a screen of lead, mercury, or bismuth.

To sum up, the experiments as far as they have gone indicate that the rays from radium consist principally of two groups of rays, the constituent rays of each group differing not much from one another in their properties. The rays of one of the groups are more efficient in producing secondary cathode radiation from aluminium, sulphur, iron, nickel, zinc, and tin, than from lead, and are all more or less easily absorbed by each of these substances excepting lead, the absorption by lead being much less. The rays of the other group are more efficient in producing secondary cathode radiation from lead than from the other substances, and are more easily absorbed by lead, mercury, and bismuth, than by any of the other substances.

There is also a third—apparently weak group of rays which is most efficient in producing secondary radiation from carbon. This group of rays is less easily absorbed by the above-mentioned substances than either of the other groups.

It may be pointed out in passing that according to the foregoing, when it is required to shield a piece of apparatus from the γ rays of radium, it is better to use a combined screen of lead and one of the metals iron, zinc, or copper, than a screen composed of one of these metals only.

The γ rays of radium thus resemble X rays in the absorption by a substance depending on the nature of the rays and that of the absorbing substance. Further, the amount of secondary radiation from a substance exposed to γ rays depends on the nature of the rays, and this has been shown to be also the case with X rays. These facts are additional evidence that the general nature of the γ and X rays is the same. Both the γ and X rays probably consist of electromagnetic pulses produced by the acceleration of electric charges. Since the β ray activity due to radium E is small in comparison with that due to radium C, in the case of radium only a few years old, the γ rays from radium are principally produced by the acceleration of the electrons ejected by radium C.

Paschen * has found that the electrons ejected by radium bromide (that is to say, by radium C) possess different velocities, but may be divided into two groups, the average velocity of the electrons of one of the groups being greater than that of the other group. These two groups of electrons might possibly correspond to the above two principal groups of rays.

It gives me much pleasure to thank Prof. Thomson for his inspiring interest and advice during these experiments.

Cavendish Laboratory, Aug. 14, 1907.

LXIII. *A Form of Cosine Flicker Photometer.* *By* J. S. Dow, *A.C.G.I., B.Sc.* †

[Plate XVI.]

THE illumination of the white surface employed in any photometer is equal to $\frac{I \cos \theta}{d^2}$, [where I equals the intensity of the source illuminating the surface, d the distance of this source from the surface, and θ the angle between the rays of light striking the surface and a normal to the surface].

Hence, when measuring the intensity of a source of light, we may either vary "d," in which case we utilize the inverse square law, or θ, in which case the cosine law is utilized.

While the inverse square law is almost invariably utilized in photometric measurements, this method is inconvenient in one respect. In order to vary "d" the photometer is usually moved to and fro between the two sources of light to be compared. The observer is therefore obliged to be continually moving his head in order to follow the motion of the photometer, and this is particularly distracting when the eye is applied to a telescope. In order to avoid this necessity, many workers prefer to keep the photometer stationary and to move one of the sources of light. But in the case of gas-lamps and many other sources of light, this method is obviously unsatisfactory, and, even in the case of glow-lamps, is sometimes inconvenient.

The utilization of the cosine law is advantageous in this respect, for the photometer may then be kept stationary and the illumination of the photometrical surfaces adjusted in the photometer itself. The type of instrument about to be described by the author, and shown in fig. 1 (Pl. XVI.), has this advantage. Indeed, while it is desirable that such a photometer

* Paschen, *Ann. der Phys.* xiv. p. 389 (1904).

† Communicated by the Physical Society: read June 28, 1907.