

In the case of a cylinder ($r=c$) whose surface has been at 0 up to $t=0$ and afterwards at $t=1$, we have from (83) with $n=0$

$$v = \frac{1}{2} + \frac{c^{\frac{1}{2}}}{i\pi r^{\frac{1}{2}}} \int_0^{\infty} e^{ipt+(c-r)\sqrt{(ip)}} \frac{J_{-\frac{1}{2}}(i^{\frac{1}{2}} p^{\frac{1}{2}} r)}{J_{-\frac{1}{2}}(i^{\frac{1}{2}} p^{\frac{1}{2}} c)} \frac{dp}{p}, \quad (90)$$

of which only the real part is to be retained. This applies to the region outside the cylinder.

It may be observed that when t is negative (87) must vanish for positive z and (90) for $r > c$.

July 19, Terling Place, Witham, Essex.

XXXIX. *The Spectra of the Fluorescent Röntgen Radiations.*

By CHARLES G. BARKLA, M.A., D.Sc., *Wheatstone Professor of Physics, University of London, King's College* *.

THOUGH the properties of the fluorescent X-radiations, emitted by various substances during exposure to X-rays, have been dealt with in a number of papers and notes by the writer †, the accounts have been neither complete nor connected. The purpose of the present paper is to present the subject as it stands at the time of writing, without entering into details of experiments. This seems almost a necessity in indicating lines of future research, and in showing the true simplicity of what appear at first sight to be very complex phenomena.

When substances are exposed to Röntgen radiation they emit X-radiations of two distinct types. One of these radiations, like the primary in penetrating power and general properties, has been termed the scattered radiation, being analogous to light scattered from small particles. The other, a completely transformed X-radiation has been termed the characteristic secondary X-radiation, the homogeneous secondary X-radiation, and latterly the fluorescent X-radiation, on account of its similarity to fluorescent light.

The scattered radiation has been fully dealt with by the writer ‡, but it is necessary here to note its characteristics in

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† Barkla, *Phil. Mag.* June 1906, Feb. 1908, Oct. 1910; *Proc. Camb. Phil. Soc.* May 1909; *Jahrbuch der Radioaktivität*, iii. pp. 246-324. Barkla and Sadler, *Phil. Mag.* Sept. 1907, Oct. 1908, May 1909. Barkla and Ayres, *Phil. Mag.* Feb. 1911.

‡ *Phil. Mag.* June 1903, May 1904, Feb. 1908, Feb. 1911; *Phil. Trans. A.* vol. cciv. 1905, pp. 467-479; *Proc. Roy. Soc. A.* vol. lxxvii. 1906, pp. 247-255.

order to distinguish it from the fluorescent radiation. Observation of radiation of this type has been possible owing to the fact that the lightest elements—from hydrogen to sulphur—when subject to a beam of X-rays of ordinary penetrating power, emit X-radiation which at a distance of several centimetres in air is almost entirely, if not entirely, a scattered radiation. If these elements emit fluorescent X-radiations under such conditions, they are either absorbed in a very thin layer of air and do not reach the electroscopes, or are so penetrating as to produce no appreciable ionization in the electroscopes. The former appears probable, the latter highly improbable, as will subsequently be seen.

The scattered radiation is indistinguishable in most of its properties from the primary radiation producing it. It has the same penetrating power as the primary. When slight differences are observed these differences are most marked when the experimental conditions are such as to introduce a quantity of the fluorescent radiation, that is when more penetrating primary beams are used. In experiments with only moderately penetrating rays, the primary and secondary beams are indistinguishable as regards penetrating power. It has yet to be proved that a secondary X-radiation which does not contain some fluorescent X-radiation differs in penetrating power from the primary radiation producing it.

As the ordinary primary beam is extremely heterogeneous, as shown by successive absorptions by similar plates of any material, the similarity in character of the scattered radiation is evidence of the equality of scattering of the various constituents, that is the various constituents appear in the secondary beam in the same proportion as in the primary. It is also seen by direct experiment that X-rays varying considerably in penetrating power are scattered to the same extent in passing through a given quantity of matter. A limit to this law has not been found, though the range of penetrating power might be considerably extended.

The scattered radiation proceeding in a direction perpendicular to that of propagation of the original primary radiation is very fully polarized, and in the same manner as light scattered from small particles.

The scattered radiation is not equally intense in all directions around the primary beam, but exhibits a slight polarity of the primary such as would be expected on the electromagnetic theory of the production of X-rays.

The writer found the polarization to diminish with an increase in the penetrating power of the radiation from the bulb, whereas with the bulb in a given state the more

penetrating portion of the primary beam exhibited greater polarization than the more absorbable portion. These results may be explained from a consideration of the origin of primary and secondary rays in the anticathode of an X-ray tube. Sufficient experiments have, however, not been made to permit one to say whether these results are perfectly general or not.

The distribution of the scattered radiation in a plane containing the direction of propagation of the primary beam agrees remarkably well with the theoretical distribution within wide limits. The intensity I_θ in any direction making an angle θ with the direction of propagation of the primary beam is given by $I_\theta = I_r \left(1 + \cos^2 \theta\right)$. There is, however, a large discrepancy between the theoretical and experimental values when θ is less than 30° . From the accuracy of the agreement for all other values of θ , it may be concluded that this discrepancy is due to some special conditions in directions near to that of propagation of the primary beam. Further experiments are at present being made to determine these. It is unnecessary at this stage to consider various hypotheses in explanation of the experimental result.

The total fraction of the energy of primary radiation which is scattered depends on both the penetrating power of the primary radiation and on the particular substance traversed by the primary beam. The elements from hydrogen to sulphur scatter the same amount mass for mass; that is when a given beam passes through sulphur and oxygen say, the scattering is twice as great per atom of sulphur as per atom of oxygen. From heavier elements it appears that the scattering is greater mass for mass than from light elements. From copper, for instance, after the fluorescent radiation had been absorbed there remained twice as much radiation, presumably scattered radiation, as from an equal mass of the light elements. From silver, too, a radiation showing practically full polarization effects, and therefore a scattered radiation, was of the order of six times the intensity of that from the light elements. These results may only be taken as giving the order of magnitude of the relative intensities. Further work on other elements under exposure to various primary beams is needed.

The fluorescent X-radiations emitted by elements exposed to an ordinary beam of X-rays have been described in early papers by the writer and Dr. Sadler as homogeneous secondary X-radiations, or as characteristic secondary X-radiations.

The term fluorescent radiation seems, however, preferable to either of the others. Radiation of this type may very readily be observed from elements of higher atomic weight than sulphur, when the observing electroscope is at a distance of several centimetres from the substance exposed to the primary rays. In most cases, unless special precautions are taken, the ionizing effect of these radiations from any particular element is very much greater than that of the scattered X-rays—indeed it completely swamps the effect of the latter. But, as will be seen later, the scattered radiation may be isolated by using a primary beam which is incapable of exciting this fluorescent X-radiation.

In many cases the radiation which reaches an electroscope situated several centimetres from the radiating element is an almost perfectly homogeneous radiation. It is important to point out that though very careful experiments have been made to test this, both directly and indirectly, there is no evidence of the slightest deviation from homogeneity of the fluorescent radiations. There is not only no evidence of lack of homogeneity, but striking evidence of homogeneity. Perfect homogeneity is, of course, not to be expected in these radiations any more than in light, for instance, but for all practical purposes we may assume the radiations accurately homogeneous. The reasons for regarding the radiations as homogeneous will, however, be given.

The direct experiment of successively placing thin sheets of aluminium or other absorbing substance in the path of the radiation and observing the absorptions produced, shows that whereas the fractional diminution in the ionization produced by an ordinary primary beam becomes less and less as plate after plate of absorbing substance is placed in its path—owing to the more absorbable constituents being absorbed by the earlier plates—the fractional diminution of the ionization produced by a secondary beam does not vary after partial absorption. This was shown by Barkla and Sadler (*Phil. Mag.* Oct. 1908) and need not be repeated here. The very slight deviation from homogeneity which is observed after a considerable portion of the radiation has been absorbed is such as would be produced by the superposition of a small amount of scattered radiation. This scattered radiation in some cases produced no more than half of one per cent. of the ionization produced by the homogeneous radiation. The proportion of scattered to fluorescent radiation depends, however, upon the particular primary beam used. The radiations from elements of atomic weights in the neighbourhood of iron, copper, zinc, &c., when subject to a radiation

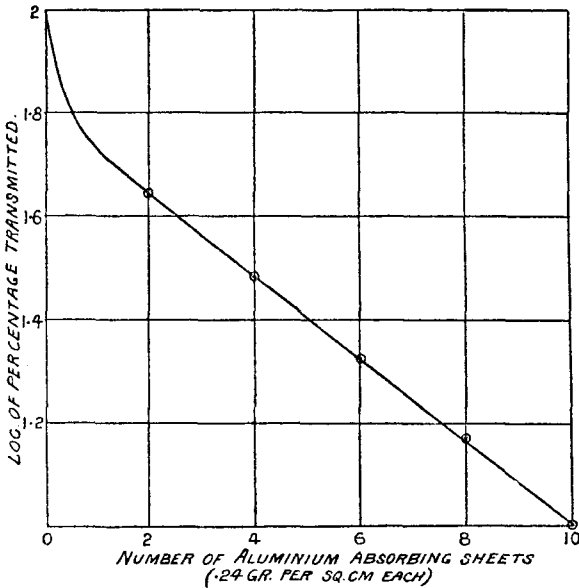
of ordinary penetrating power, are the most homogeneous, that is contain the smallest proportion of scattered radiation. It was found that the amount of scattered radiation necessary to produce the heterogeneity observed in the radiation from copper was twice that which would be given by an equal mass of the light elements H to S. Even with this admixture of scattered radiation the total radiation was strikingly homogeneous, as shown by fig. 1 in the paper referred to above. It is necessary to absorb an amount somewhere about 95 per cent. of the fluorescent radiation before the effect of the scattered radiation becomes evident.

In the radiation emitted under exposure to an ordinary primary beam by elements of atomic weight in the neighbourhood of Ag, Sn, Sb, ... Ce, there are two homogeneous radiations superposed in addition to the scattered radiation—which is more intense than from an equal mass of the light elements. Special precautions have thus to be taken to obtain homogeneous beams from these. Owing to the wide difference in penetrating power between these two principal constituents and to variations in their proportion when excited by a variable primary, the secondary radiation appears heterogeneous, and much more variable in penetrating power than the primary. A small change in the penetrating power of the primary frequently produces very much greater changes in the character of the secondary radiation. This is easily understood from the relation given later between the penetrating power of the primary radiation and the intensity of the secondary radiation which it excites. The homogeneity of the more penetrating fluorescent radiation from barium is shown in fig. 1, in which the logarithm of the fraction transmitted through various sheets of aluminium is plotted against the number of those sheets. The initial drop is due to the easily absorbed constituent; the linear portion exhibits the homogeneity of the more penetrating fluorescent radiation. The homogeneity of the more absorbable constituent was observed by Barkla and Nicol by using a very soft primary beam. This method will be understood from what follows.

The radiations which have been observed from the elements W, Pt, Au, Pb, Bi when these are exposed to primary radiations of ordinary penetrating power are not so homogeneous as the radiations from Fe, Cu, Zn, &c. Slight variations in penetrating power may also be observed when much more considerable variations take place in the primary. Whether there is appreciable heterogeneity in the true fluorescent radiations from these elements or not has not been very

accurately tested. It appears probable that the radiation from these elements contains a greater proportion of scattered radiation. There is also the possibility of the superposition of a small quantity of a second more penetrating fluorescent

Fig. 1.



radiation. The full analysis of these radiations when excited by homogeneous primary radiations would lead to more accurate conclusions. Experiments on the resultant secondary radiation show, however, that these radiations are very homogeneous in comparison with any ordinary primary beam. The fluorescent radiations are thus at any rate approximately homogeneous, and in the absence of more exact evidence will be considered homogeneous, like those radiations upon which more accurate experiments have hitherto been possible.

Indirect evidence that the fluorescent radiations are approximately homogeneous has also been obtained by Barkla and Collier in studying the relation between the absorption of homogeneous X-rays in platinum and gold and the absorption of these rays in aluminium. The curves showing the relation exhibit similar characteristics to those obtained from

experiments on absorption by elements Fe, Cu, &c., which do emit homogeneous fluorescent radiations. (See fig. 2.)

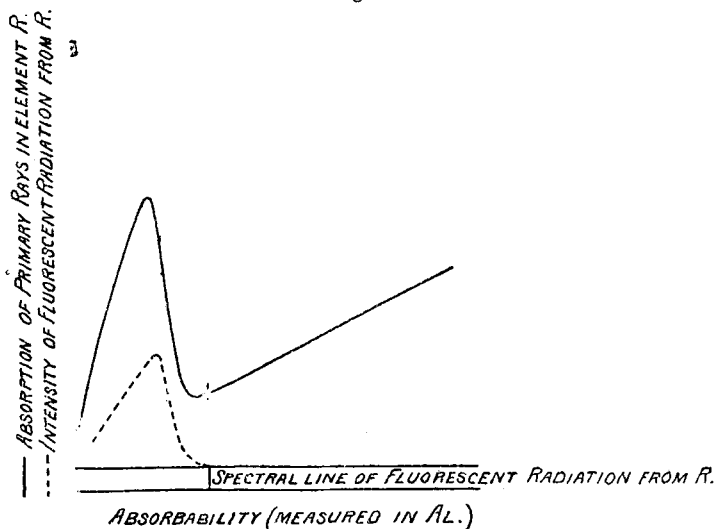
One of the most interesting facts concerning each of these homogeneous fluorescent X-radiations is that it is not excited by radiation of lower penetrating power. [The penetrating power must be measured in some substance whose characteristic radiations are not within the range of penetrating power experimented upon, and not near to this range on its more absorbable side.] This was first shown by Barkla and Sadler in the case of the secondary radiation from silver. When a heterogeneous primary beam was used it was frequently found that the homogeneous fluorescent radiation from silver was more penetrating than the primary as a whole; but however absorbable the primary beam was, a plate of aluminium placed in that primary beam diminished the intensity of fluorescent radiation less than the same plate placed so as to intercept the secondary radiation itself, showing that the secondary beam was more absorbable than the portion of the primary beam producing it. Again, in transmitting the homogeneous radiation from copper through iron, it was found that a certain transformation had taken place in the transmitted radiation, due to the excitation in iron of its slightly softer characteristic radiation and the superposition of this on the truly transmitted radiation; whereas when iron radiation was transmitted through copper, that is a very soft radiation through a substance whose characteristic fluorescent X-radiation is of slightly more penetrating type, the radiation emerging was purely iron radiation without the admixture of radiation characteristic of copper. Similar experiments were performed with copper and zinc. The radiation from zinc being slightly more penetrating than that from copper excited in copper its fluorescent radiation, but the process could not be reversed. Dr. Sadler later verified the law with considerable accuracy for a number of radiators, by using homogeneous radiations to excite the fluorescent radiation. All experiments have only further shown the generality and the accuracy of this law, which is analogous to Stokes's law of light fluorescence.

Not only is there this direct evidence, but a considerable amount of indirect evidence obtained from observation of the relation between the absorption in a given substance of X-rays, and their absorption in aluminium, say; also from the relation between ionization produced in different gases by rays of varying penetrating power.

To take the phenomenon of absorption first, it has been shown by the writer and Dr. Sadler that the general variation

in the absorption of X-rays with variation of penetrating power is determined solely by the fluorescent or characteristic radiation of the absorbing substance. Thus as the general absorbability of a radiation decreases—that is as its penetrating power increases—it becomes less and less absorbed in a substance R, say, its absorption being approximately proportional to its absorption in any other substance when the radiations used are not near on the more penetrating side of the radiation characteristic of this second substance. This approximate proportionality holds until the radiation absorbed becomes just more penetrating than the fluorescent radiation characteristic of R. Then as the radiation becomes more penetrating it is absorbed more in R than would be given by this law, the additional absorption being accompanied by the emission of fluorescent radiation from R, by an increased corpuscular radiation from R, and if R is in a gaseous state by an additional ionization in R. The relation between the absorption in R and in any other substance whose characteristic radiations are not near on the more absorbable side to the radiations experimented upon is shown in fig. 2.

Fig 2.



The special point to be observed is the accuracy of this relation in all cases experimented upon. The simple law of approximate proportionality is obeyed until the absorbability of the primary radiation is *just* that of the radiation characteristic of the absorbing substance ; the slightest increase in

penetrating power of the primary is accompanied by a special absorption connected with the emission of fluorescent radiation. The emission of fluorescent radiation implies the special absorption of the primary radiation, and *vice versa*. The absorption curves published by Barkla and Sadler*, drawn from the results of experiments on absorption by metal sheets, thus indirectly exhibit the accuracy of this law of fluorescence. Similar curves have been got by Barkla and Collier from experiments on absorption by gases and vapours, and with fewer observations near the critical point in the case of absorption by gold and platinum, so that the generality of the law has been well tested.

Similar relations hold between the ionization in R when in the gaseous state and the ionization in another gas or vapour whose fluorescent radiation is not near the range of penetrating power experimented upon on its more absorbable side. The writer showed this in a paper on "Phenomena of X-ray Transmission" †, and later published the relation in detail in the case of ionization in ethyl bromide. A similar relation holds in the case of every gas upon which experiments have been made.

Now the definiteness of the turning point in these absorption and ionization curves, and the coincidence of this penetrating power with that of the fluorescent radiation characteristic of the absorbing and ionized substance is further evidence not only of the homogeneity of the fluorescent radiations, but of the accuracy of the law of X-ray fluorescence analogous to Stokes's law.

Unlike the scattered radiation the fluorescent radiation is uniformly distributed around a polarized beam of X-rays ‡. It is also uniformly distributed in a plane containing the direction of propagation of the primary radiation §. Thus the intensity is entirely independent of the direction of electric force or of propagation of the exciting primary beam.

The total energy of the secondary fluorescent radiation is in some cases certainly very great. The variation of intensity with the penetrating power of the primary is shown by the curve in fig. 2 ||, and at its maximum the copper radiation carries away—if we measure energy by total ionizing power

* Phil. Mag. May 1909.

† Proc. Camb. Phil. Soc. May 1909.

‡ Phil. Trans. A. vol. cciv. 1905, pp. 467-479; Proc. Roy. Soc. A. vol. lxxvii. 1906, pp. 247-255.

§ Phil. Mag. Feb. 1911.

|| Fig. 2 was given by Barkla and Sadler in a paper on "Absorption of Röntgen Rays" (Phil. Mag. May 1909).

—about $\frac{1}{3}$ of the energy of the primary beam absorbed, and quite 100 times the energy of the scattered radiation.

The isolation of any particular fluorescent radiation may usually be effected very simply. If it is a fairly penetrating radiation such as that from tin which it is wished to study, then a primary beam should be used with a fair proportion of constituents of more penetrating type. This, as shown, excites the desired radiation and all softer radiations characteristic of the particular substance. But as all the characteristic radiations of a particular element appear to be widely different in penetrating power, the softer constituents may be absorbed by a sheet of aluminium without diminishing to any considerable extent the intensity of the particular radiation studied. Thus, as shown by the absorption curve fig. 1, after the first absorbing plate the remaining radiation was homo-

geneous and of absorbability given by $\frac{\lambda}{\rho} = \cdot 8$. The preliminary filtering out of the easily absorbed constituents is frequently effected by the surface layers of the radiator itself, and by the air separating it from the detecting electroscope.

In order to obtain a very soft fluorescent radiation, such as that from tin, antimony, &c., a very soft X-ray tube should be used to give the primary radiation. This is then not sufficiently penetrating to excite the more penetrating fluorescent radiation, and provided the testing electroscope is placed near to the radiator the more absorbable fluorescent radiation may be readily studied. This radiation is, however, usually mixed with a large quantity of more penetrating scattered radiation. The quantity of this may be estimated by finding how much is transmitted through sheets of aluminium of sufficient thickness to completely absorb the soft fluorescent radiation. By comparison of this with the intensity of radiation transmitted through similar plates of aluminium from a substance such as carbon giving only scattered radiation, the intensity of scattered radiation superposed on the soft fluorescent radiation, and passing through any number of absorbing plates, may be got by proportion from the corresponding intensity from carbon.

After subtraction of the ionization due to the scattered radiation, it is found that the successive sheets by absorption diminish the effect of the radiation transmitted by the same fraction, showing the homogeneity of the soft characteristic radiation (Barkla and Nicol, 'Nature,' Aug. 4, 1910).

Phil. Mag. S. 6. Vol. 22. No. 129. *Sept.* 1911. 2 E

Dealing with the various elements in this way, a large number of fluorescent radiations have been identified. As we have no method of determining the wave-length of the radiation with which we deal, it is necessary to classify the various X-radiations by their absorption in some standard substance. This is not always a complete definition of an X-radiation, for, as has been shown, radiations of three different penetrating powers are absorbed to the same extent in copper, or in iron, or in zinc, &c. This is analogous to saying that refrangibility of light in one substance does not always completely define the light. But just as the refrangibility of light in a substance whose absorption bands are far removed from the radiation used is a sufficient measure of the character of the radiation, so the absorption in aluminium is sufficient to define the Röntgen radiation used, for aluminium does not emit a characteristic fluorescent radiation within the range of penetrating power here dealt with, nor near to it on its more absorbable side. In the following table, column 3 gives the absorbability of the fluorescent radiations as measured in aluminium. The quantity tabulated is λ/ρ , where λ is defined by the equation $I=I_0 e^{-\lambda x}$ representing the intensity of radiation transmitted through aluminium sheets of density ρ .

In a number of cases the characteristic radiations from elements were obtained by using compounds containing the elements in combination with light atoms. The only effect of these light atoms was then to add a little scattered radiation to the fluorescent radiation which it was desired to study. The effect of this was, however, negligible. The radiations from Br, Sr, Rb, I, Ba, and Ce were obtained from the compounds bromal hydrate, strontium hydroxide, rubidium carbonate, iodoform, barium hydroxide, and cerium oxide.

It is seen that the radiations fall into two distinct series, here denoted by the letters K and L*. Though only these two have so far been found, it seems highly improbable that these, consisting of radiations of penetrating power most easily experimented upon, include all fluorescent radiations actually emitted by elements. In support of this we will look first at the phenomena of absorption. As shown in fig. 2, the absorption in a substance R of rays softer than

* Previously denoted by letters B and A (Proc. Camb. Phil. Soc. May 1909). The letters K and L are, however, preferable, as it is highly probable that series of radiations both more absorbable and more penetrating exist.

TABLE.

Element	Atomic Weight.	Absorbability of Fluorescent Radiation ($\frac{\lambda}{\rho}$ in Al).		Remarks.
		Series K.	Series L.	
...	1·008—24·32	No radiation observed: probably very absorbable. } Effects of fluorescent radiation observed: measurements not made.
.....	27·1	
.....	32·07	
.....	40·09	435	...	Not so accurate as values below.
.....	52	136	...	Easily observed and homogeneity proved with considerable accuracy.
.....	55·85	88·5	...	
.....	58·97	71·6	...	
.....	58·68 (61·3)	59·1	...	
.....	63·57	47·7	...	
.....	65·37	39·4	...	For atomic weight of Ni see paper by Barkla & Sadler (Phil. Mag. Sept. 1907). } Not accurately determined for Rb.
.....	74·96	22·5	...	
.....	79·2	18·9	...	
.....	79·92	16·4	...	
.....	85·45	13·7	...	
.....	87·62	9·4	...	
.....	96·0	4·7	...	
.....	102·9	3·1	...	
.....	107·88	2·5	700	
.....	119·0	1·57	...	
.....	120·2	1·21	435	Owing to two fluorescent radiations total radiation appears very variable in experiments with primary radiation of ordinary penetrating power. Series L not obtained with accuracy of series K.
.....	126·92	·92	306	
.....	137·37	·8	224	
.....	140·25	·6	...	
.....	184·0	...	33	Homogeneity not shown with accuracy, consequently values of absorbability only approximate, } —possibly rather high.
.....	195·0	...	27·5	
.....	197·2	...	25	
.....	207·1	...	20	
.....	208	...	19	

Note.—Radiations from Cr, Fe, Co, Ni, Cu, Zn, As, Se, Ag were obtained by Barkla and Sadler (Phil. Mag. May 1909); from Mo and Rh by Sadler (Phil. Mag. March 1910); from Ca, Sb, I, Ba AgL by Barkla and Nicol ('Nature,' Aug. 4, 1910); from Br by Chapman.

the softest known fluorescent radiation characteristic of R is approximately proportional to the absorption in aluminium. With rays of higher penetrating power than that of the fluorescent radiation of R, there is a regular deviation from this proportionality, and when the penetrating power is far removed from that of the fluorescent radiation there is again approximation to proportionality to the absorption in aluminium.

This recurrence of the proportionality suggests the possibility, indeed the probability, of similar relations with rays of penetrating power in the neighbourhood of that of a softer fluorescent radiation not yet discovered. This argument might have been applied to indicate the probability of a radiation belonging to series L, when only that of series K was known. It is equally applicable in indicating the probability of a radiation belonging to an undiscovered series M, consisting of still softer radiations, for the same features as those described are shown by the absorption curves for gold and platinum over a range of penetrating power including that of the fluorescent radiation of series L. These absorption curves thus suggest the existence of a more absorbable fluorescent radiation from gold and platinum than that of series L. From the similarity of the behaviour of all the elements we must then admit the probability of the existence of a series M, and the possibility of further series M, N, &c.

Again, the writer has shown the connexion which exists between absorption, secondary radiation, and ionization. The emission of fluorescent radiation from a substance traversed by a primary beam of X-rays is invariably accompanied by a special absorption of the primary rays, and when the substance is in the gaseous state by a special ionization of that substance. It is natural to connect the absorption of *soft* primary beams and the ionization produced by these in passing through matter with the emission of an undetected softer fluorescent X-radiation of series M.

The extreme variation in the penetrating power of the fluorescent radiations thus far observed is enormous, the K radiation from cerium being more than a thousand times as penetrating as the L radiation from silver. The determination of more penetrating radiation than that from cerium and of more absorbable radiation than that from silver has, however, been limited solely by the unsuitability of the methods hitherto employed. It will probably be an easy matter by modification of these methods to considerably extend the number of radiations in these two series.

It is important to notice that there is no evidence of any abrupt change in the character of the radiation with a change in the atomic weight of the radiating substance. It would, for instance, not be surprising to find groupings of the elements similar to those based on chemical properties. No indication of anything of the sort has been obtained.

In early papers the elements were for convenience divided into groups according to the characteristics of the radiation they emitted when exposed to primary beams of ordinary penetrating power. The elements of different groups appeared at first sight to be fundamentally different in their behaviour, but it was later shown by the writer that the behaviour of one element is typical of all. The observed differences were due simply to wide differences in the relation between the penetrating power of the primary radiation and the fluorescent radiations.

An increase in the atomic weight of an element is invariably accompanied by an increase in the penetrating power of the fluorescent radiation of the same series. This is not always apparent without analysis of the radiations owing to differences in the relative proportions of the fluorescent radiations from various elements under exposure to the same primary radiation. The relation between the atomic weight of an element and the absorbability (as measured by the absorption in aluminium) of its fluorescent X-radiations is shown in fig. 3 (p. 410). The range of absorbability is, however, too great to admit of accurate representation of the relative absorptions of the most penetrating radiations. A more convenient method of exhibiting the relation throughout the entire range is that of plotting the logarithm of the absorbability against atomic weight of the radiator, absorbability being λ/ρ , where λ is given by the equation $I=I_0 e^{-\lambda x}$, representing transmission through aluminium of density ρ (fig. 4, p. 411).

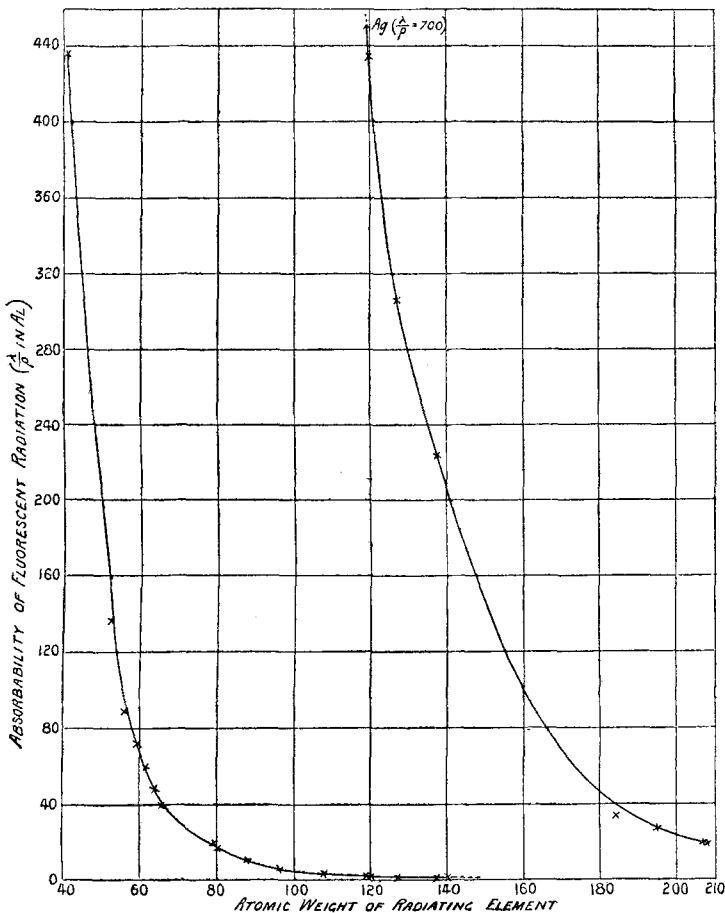
It will be observed that for each series the value of $\log \lambda/\rho$ is approximately a linear function of the atomic weight of the radiating element. It is remarkable that this should hold closely over such a range in penetrating power.

As all the principal phenomena connected with the transmission of X-rays through matter—absorption, ionization, secondary radiation—are determined by the character of the fluorescent radiations characteristic of the elements constituting the matter traversed*, it is essential to a complete

* Proc. Camb. Phil. Soc. May 1909.

understanding of these phenomena to be acquainted with the penetrating powers of these fluorescent radiations.

Fig. 3.



It has been shown that each element has its own characteristic fluorescent line spectrum in X-rays. This is very conveniently represented as is a spectrum of ordinary light, except that without a knowledge of the wave-length we are

obliged to define the radiations by their absorption in some standard substance. Thus we may represent the known

Fig. 4.

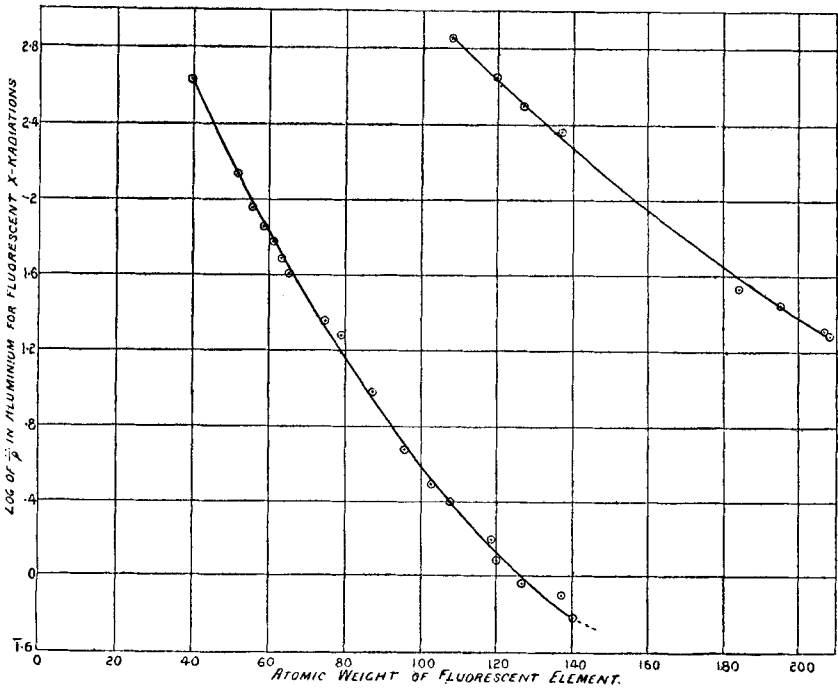
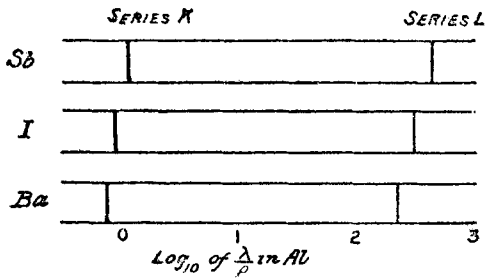


Fig. 5.



portion of the spectra of elements Sb, I, and Ba as in fig. 5. The lines move towards the more penetrating end of the spectrum with an increase in the atomic weight of the element.

It is scarcely too much to say that all the phenomena connected with the transmission of X-rays through matter may be readily explained in terms of a few simple laws expressed with reference to these spectra.

[I wish to express my indebtedness to Mr. G. H. Martyn for his assistance in some of these experiments.—C. G. B.]

XL. The Intensity of the Ultra-Violet Light emitted by an Electrical Discharge at Low Pressures. By E. W. B. GILL, M.A., B.Sc., Fellow of Merton College, Oxford.*

THE phenomena accompanying the discharge of electricity through gases at low pressures have been examined in great detail by many observers, and accurate measurements have been made of the distribution of electric force along the discharge, the number of ions at various points, the temperature and other properties.

The experiments here described are a set of measurements of a different nature relating to the distribution of intensity of the light emitted, or more strictly of the intensity of a certain portion of the spectrum of the light emitted from various parts of the discharge. The results obtained, though not throwing much light upon the actual mechanism of the discharge, are of some interest as showing a systematic variation with change of pressure of rather a curious kind.

When ultra-violet light falls upon a metal plate, zinc being usually used, negative ions are set free at its surface; and Griffiths has shown that, other things being equal, the number of ions set free is nearly proportional to the intensity of the light.

An estimate of the number of ions set free by the light coming from different portions of the tube will therefore give at once the relative intensities. A previous research † has shown that the rays chiefly instrumental in setting free the ions vary from about $250 \mu\mu$ to $180 \mu\mu$, and it must be understood that the results of these experiments refer to the intensity of this particular range of wave-lengths.

Description of Apparatus.

The discharge-tube was constructed of quartz, and was joined to a large glass reservoir containing mercury in its

* Communicated by Prof. J. S. Townsend.

† *Phil. Mag.* Feb. 1910, p. 290.