higher value) the room (positive or negative) which 1 gram of matter takes up in the æther is certainly not more than 1/45 that of the total bulk of electrons, and is probably very much less.

The cost of the experimental work above referred to was partly defrayed by a Government grant received from the Royal Society.

Boars Hill, Oxford,
Feb. 1914.

XCIV. *The Wave-Length of the Soft γ Rays from Radium B.*

By Sir ERNEST RUTHERFORD, *F.R.S.*, *and* E. N. DA C. ANDRADE, *B.Sc.*, *Ph.D.*, *John Harling Fellow, University of Manchester* *.

[Plate XII.]

DURING the last few years, a large amount of attention has been directed to the absorption of the γ rays emitted by radioactive bodies. At first, the nature of the absorption by matter of the very penetrating γ rays emitted by the products radium C, mesothorium 2, thorium D, and uranium X, was carefully examined, and it was found that all these types of radiation were absorbed by light elements very nearly according to an exponential law over a large range of thickness, but with different constants of absorption for each radiation. In order to explain the emission of homogeneous groups of β rays from a number of products, Rutherford suggested that the γ rays emitted by the radioactive products must be regarded as the "characteristic" radiations excited in the radioelements by the escape of β particles from them. These "characteristic" radiations were supposed to be analogous to one or more of the groups of characteristic radiations observed by Barkla to be excited in different elements by X rays. It was suggested that the emission of homogeneous groups of β rays was directly connected with the emission of different types of characteristic γ rays from each element, and that the energy of the escaping β particle was diminished by multiples of definite units depending on the energy required to set the electronic system of the atom in a definite form of vibration.

In order to test this point of view, Rutherford and Richardson † analysed in detail the γ rays emitted by a

* Communicated by the Authors.

† Rutherford and Richardson, Phil. Mag. May 1913, p. 722; August 1913, p. 325; Feb. 1914, p. 252.

number of radioactive substances, using the absorption method to distinguish broadly between the different types of γ rays emitted. It was found that the γ radiation from the B products, viz., radium B, thorium B, and actinium B, could all be conveniently divided into three types of widely different penetrating power. For example, the absorption coefficients in aluminium for the groups of γ rays from radium B were found to be 230, 40, and 0·5. In the case of the C products, viz., radium C, thorium C, and actinium C, the γ radiation was found to be mainly of one very penetrating type exponentially absorbed in aluminium. The radiations from the various radioactive substances can be conveniently divided into three distinct classes, viz.:—(1) a soft radiation, varying in different elements from $\mu=24$ to $\mu=45$, probably corresponding to characteristic radiations of the "L" type excited in the radioatoms; (2) a very penetrating radiation with a value of μ in aluminium of about 0·1, probably corresponding to the "K" characteristic radiation of these heavy atoms; (3) radiations of penetrating power intermediate between (1) and (2) corresponding to one or more types of characteristic radiations not so far observed with X rays.

In the meantime, the experiments of W. H. and W. L. Bragg * and Moseley and Darwin † had shown that the reflexion of X rays from crystals afforded a definite and reliable method of studying the wave-length of X rays. It was found that the radiations from a platinum anticathode consisted in part of a series of strong lines, no doubt corresponding to the "L" characteristic radiation of this element. By using a number of anticathodes of different metals, the X-ray spectra of a number of elements were determined by W. H. and W. L. Bragg ‡ and by Moseley §. The latter has made a comparative study of the strong lines of the spectra emitted by the great majority of the elements. For most of the lighter elements from aluminium to silver, the spectra obtained corresponded to the "K" characteristic radiations, while for the heavier elements the "L" series has been determined. The simple relations which Moseley finds to hold between the spectra of successive elements has been discussed by him in his recent paper.

* W. H. Bragg and W. L. Bragg, Proc. Roy. Soc. A. lxxxviii. 1913, p. 428.

† H. G. J. Moseley and C. G. Darwin, Phil. Mag. July 1913, p. 210.

‡ W. H. Bragg and W. L. Bragg, Proc. Roy. Soc. A. lxxxix. 1913, p. 277, and *loc. cit.*

§ H. G. J. Moseley, Phil. Mag. Dec. 1913, p. 1024; April 1914, p. 703.

From the analysis of the types of γ rays, it appeared probable that each corresponded to one of the characteristic types of radiation of the element in question. It was consequently to be anticipated that each of these radiations would give definite line spectra when reflected from the surface of crystals.

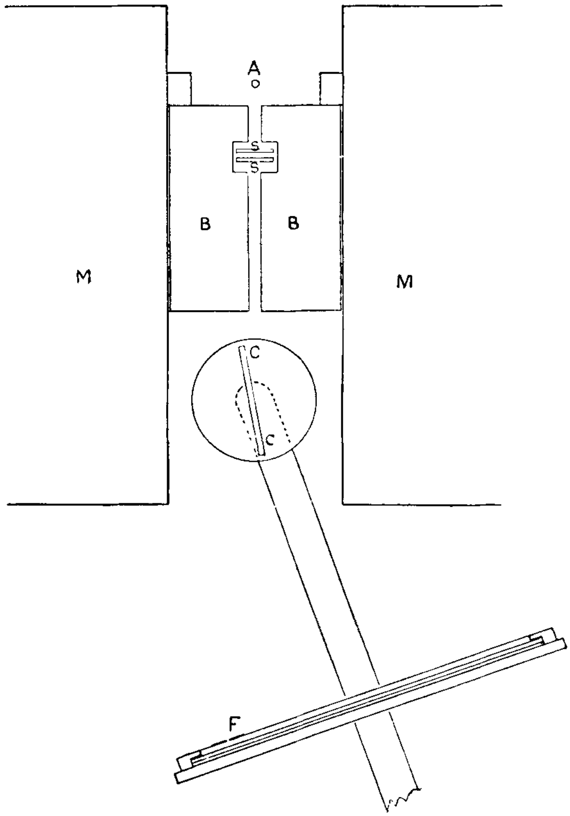
In order to examine this question, experiments were begun to determine the wave-lengths of the γ radiations from the products radium B and radium C. For this purpose, a thin walled α-ray tube, filled with a large quantity of emanation, served as a source of γ rays. The rays were allowed to fall at a definite angle on a crystal, generally rocksalt, and the intensities of the "reflected," or rather diffracted, rays were examined by a photographic method.

The determination of the γ-ray spectra is in some respects far more difficult than similar measurements for X rays. In the first place, the photographic effect of the γ rays, even from the strongest source of emanation available, is very feeble compared with that due to the X rays from an ordinary focus tube. For example, using a source of 100 millicuries of radium emanation, an exposure of 24 hours is necessary to obtain a marked photographic effect due to the reflected γ rays. Under similar conditions, 10 minutes exposure suffices to obtain a well-marked X-ray spectrum. In the second place, special precautions have to be taken to screen the photographic plate from the effects of the very penetrating γ radiation from radium C. The greatest difficulty of all, however, is to get rid of the disturbing effect of the very swift primary β particles emitted from the source and the swift β particles emitted from all material through which the γ rays pass. This can only be accomplished by placing the source of radiation, absorbing screens, and crystal in a strong magnetic field, so that practically all the β rays, both the primary ones and those excited by the γ rays in matter, are bent away from the photographic plate.

Method of Experiment.

The straight emanation tube, A, about 0·5 mm. in diameter and 1 cm. in length (fig. 1), was fixed behind a massive block of lead BB, so that the rays from it passed through a horizontal slit in the block; a square vertical hole in the lead allowed screens SS to be interposed in the path of the rays when desired. The length of the block from back to front was 6 cm., the width of the slit 3 mm. The emergent pencil of rays fell on the crystal CC, which was mounted on a small turn-table so that the axis of revolution of the table passed accurately through the reflecting face; the angle of the crystal was measured on a metal scale by means of a glass pointer attached to the table. The emanation tube, lead block, and crystal were all placed between

Fig. 1.



the rectangular pole-pieces of a powerful electromagnet MM, as indicated in the diagram; the magnetic field usually employed was 2500 gauss.

The photographic plate was held with its film towards the source of the rays in a special carrier mounted on a rotating arm, the axis of rotation of which coincided with the axis of the crystal turn-table; in front of the film there was a single thickness of black paper to protect the plate from stray light. As it was possible that the position of the plate in the holder might vary in successive experiments, it was necessary for purposes of measurement to mark its position relative to the holder. To enable this to be done, a narrow strip was removed from this black paper, and the hole thus formed covered with a slip of metal in which was a fine slit F; by means of a fixed lamp a fiducial line could then be marked on the plate, the plate-holder being always put in the same position for this purpose.

The distance of the source from the centre of the crystal was arranged so as to be exactly equal to the distance of this centre from the photographic plate (about 9 cm.). It is well known that under these conditions no correction for the length of the crystal is necessary in determining the angle of reflexion of the spectral lines, for reflexion of the same wave-length from any point of the crystal always falls at the same point on the plate. The crystal was arranged with the centre of its reflecting face as near as possible opposite the centre of the slit; the plate-holder was adjusted perpendicular to the slit for the zero reading. In making an experiment the crystal was set at a given angle with the central incident ray and the plate-holder rotated through double the angle from the zero position; the plate was inserted, the fiducial line marked on it, and an exposure of some hours (usually 24) was made, the magnetic field remaining on throughout. The crystals used were rocksalt and heavy spar. The whole apparatus was in a dark room.

Owing to the finite angle of the beam of γ rays, and to the length of the crystal, for any given setting of the crystal there are rays striking it at all angles within a certain small range. To enlarge the range and thus obtain more lines on the plate for a single exposure, the crystal was in some cases slowly rotated during the experiment, as in the experiments of M. de Broglie *. The rotation was effected by the following device. Supported by the water in a tall cylindrical vessel was a float, which subsided slowly, owing to the escape of the water, drop by drop, through a capillary tube of suitable size attached to an opening in the bottom of the vessel. The float as it sank rotated the crystal by means of a light horizontal arm, to one end of which it was fastened by means of a thread passing over a pulley; the other end was attached to the turn-table carrying the crystal. The moving end of the arm was carried without friction by means of wheels on a glass plate, and the motion attained was very uniform and could be adjusted by changing the length of the capillary tube. A rotation of one degree occupied from four to eight hours.

* M. de Broglie, *Journal de Physique*, Feb. 1914, p. 101.

Measurement of the Plates.

The positions of the lines were measured as distances from the fiducial line, which fixes the position of the plate relative to the plate-holder. From this was calculated the angle which the ray corresponding to any line made with the normal to the plate; the angle which the plate-holder made with the zero position being known, the angle of reflexion of the given ray followed at once. To correct for possible errors in the fixing of the zero, the same line was photographed twice, the crystal being rotated between the two photographs to a symmetrical position on the other side of the zero, so as to throw the line in the one case to the right, in the other case to the left, of the undeflected beam. This enables the angle of reflexion to be fixed with considerable accuracy if the zero positions are only roughly determined.

Experimental Results.

In this paper an analysis will be given of the soft type of γ radiation from radium B. Evidence of lines corresponding to the more penetrating rays from radium B and the penetrating rays from radium C has been obtained on the photographs, and the spectra have been separated by the interposition of absorbing screens; lines have been found, due to radium C, with 6 mm. of lead between the radium tube and the crystal. The spectra due to the penetrating rays from radium B and radium C are faint compared with that of the soft radiation from radium B, and have not yet been fully investigated; an account of them is withheld for a future paper.

The stronger lines due to radium B appeared with great distinctness on the photographic plate, as will be seen from fig. 2 (Pl. XII.), which is reproduced from an actual photograph; they permit of accurate measurement. In the photograph B is the band made by the direct rays coming through the slit, β and α are the two strong lines formed by the reflected rays, and F is the fiducial line. The fainter lines do not appear on all the plates; however, no line is given in the table which has not been measured on at least two plates. The main feature of the spectra of the radiation reflected from rocksalt is two strong lines at almost exactly 10° and 12° respectively; they are accompanied by a number of fainter lines at angles of from 8° to 14°. There is also a large group of faint lines between 18° and 22°, which do not permit of accurate measurement, and so are omitted in the table; some of these, at least, are probably repetitions of the measured lines in the second order.

Most of the photographs were taken with crystals of rocksalt, the crystal in some cases being a slip less than a millimetre thick, in others a specimen about a centimetre thick; the results did not differ noticeably for the soft rays. To check the measurements of the angles of reflexion made with the rocksalt, photographs were also taken by reflexion from the cleavage (001) face of a crystal of heavy spar (barium sulphate). Since the scattering by an atom is proportional to its atomic weight, it was thought that the heavy spar might give spectral lines of more intensity than the rocksalt for the more penetrating rays. In order to compare the constants, or "grating space," of the two crystals, special experiments were made with them both with X rays by the photographic method developed by Moseley, who kindly designed for us an X-ray tube with a nickel anticathode. This was provided with a side tube and slit, and the rays escaped through a thin aluminium window; the tube emitted an intense beam of soft X rays consisting mainly of the characteristic radiation of nickel. The angle of reflexion for the two strong lines in the nickel rays was directly determined for both rocksalt and heavy spar; for the (100) plane of rocksalt the angles obtained agreed closely with those determined by Moseley. The angles of reflexion from the (001) plane of heavy spar were found to be 12° 5′ and 13° 23′ in the first order. The ratio for the corresponding angles for the two crystals was 1·278. This enables us to compare numerically the photographs taken with the two crystals by the γ rays.

The spectra obtained with heavy spar appeared to be less intense than with rocksalt for the soft rays, and did not show the harder rays with much greater clearness. The angle of reflexion for the two strong lines of the radium B radiation were found to be 7° 52′ and 9° 28′. Multiplying by the factor 1·278 to express them in terms of rocksalt, these become 10° 3′ and 12° 6′, agreeing closely with the values obtained directly with this crystal. This puts it beyond doubt that the lines given by rocksalt are true diffraction lines, and do not arise from irregularities in the crystal.

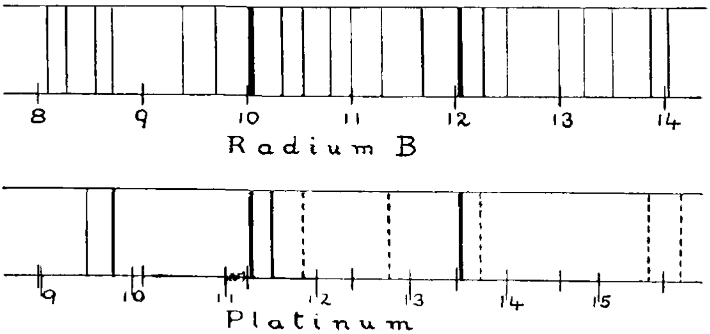
In the following table the angle of reflexion of the different homogeneous rays which make up the softer γ radiation from radium B are given for rocksalt. Their relative intensities are denoted by the letters "s." (strong), "m." (medium), and "f." (faint), but this indication is only very rough, as the circumstances conditioning the intensity vary from photograph to photograph. The wave-lengths (in centimetres) corresponding to the different angles of reflexion are calculated from the formula $\lambda = 2d \sin\theta$, the value

$d = 2{\cdot}814 \times 10^{-8}$ cm. being taken from Moseley's paper. The spectrum of the characteristic radiation from platinum, suitably reduced by division by a constant factor, is added for comparison: this will be referred to again later (p. 864).

TABLE I.

Radium B. Soft γ-ray spectrum.			Platinum. X-ray spectrum.
Angle of reflexion from rocksalt.	Wave-length (in cm.).	Intensity.	Angle of reflexion / 1·122
8° 6′	$\cdot 793 \times 10^{-8}$	m.	
8° 16′	·809	m.	
8° 34′	·838	m.	8° 27′
8° 43′	·853	m.	8° 43′
9° 23′	·917	f.	
9° 45′	·953	m.	
10° 3′	·982	s.	10° 2′
10° 18′	1·006	m.	10° 13′
10° 32′	1·029	m.	
10° 48′	1·055	f.	
11° 0′	1·074	f.	
11° 17′	1·100	f.	
11° 42′	1·141	m.	
12° 3′	1·175	s.	12° 3′
12° 16′	1·196	m.	
12° 31′	1·219	f.	
13° 0′	1·266	f.	
13° 14′	1·286	f.	
13° 31′	1·315	f.	
13° 52′	1·349	m.	
14° 2′	1·365	m.	

Fig. 3.



In fig. 3 the spectrum is shown diagrammatically, and below it that of platinum, the scale being adjusted so as to make the strong 10° line coincide with the corresponding platinum line. The dotted lines in the platinum spectrum are taken from a paper of de Broglie *; as his determination of the strong line differs somewhat from that of Moseley and Darwin, the whole spectrum given by him has been reduced by multiplying by a constant factor chosen so as to make the strong lines agree.

Structure of the Spectral Lines.

In the case of the stronger lines from rocksalt, viz. the 10° or 12° lines, the structure of the lines could be studied in some detail. They consisted of slightly curved bands about 0·5 mm. wide, the photographic intensity being greatest at the edge of the bands. A reproduction of part of one of these bands, magnified about five times, is shown in Pl. XII. fig. 4. With weak intensities only the outer edges of the band could be seen, and the band appeared as a close double. The spectral band appeared to be the exact mirror-image of the source, both as regards magnitude and distribution of intensity in radiation; the width of the image was the same as the diameter of the α-ray tube, viz. 0·50 mm. The sharp and well-marked edges of the band are due to the fact that the intensity of the radiation is least from the centre of the cylindrical α-ray tube, and increases to a maximum from the edges, owing to the active matter deposited on its inner surface. It is well known that a photograph taken of an α-ray tube by its own rays through a narrow slit parallel to the source always shows these variations of intensity. The fact that the spectral band on the photographic plate is the mirror-image of the source, indicates clearly that the scattered rays forming the band come from very near the surface of the crystal. Attention has been drawn to the completeness of the reflexion of X rays from a crystal at the proper angle by Darwin †, and shown by him to be a necessary consequence of the mathematical theory. The efficiency of the reflexion is also well shown by recent experiments of W. L. Bragg ‡.

Imperfection of Crystals.

In most of our experiments we have employed a crystal of rocksalt, since its structure has been worked out in detail by W. H. and W. L. Bragg, and since it gives fairly strong

* *Journal de Physique*, loc. cit.
† C. G. Darwin, Phil. Mag. Feb. 1914, p. 315.
‡ W. L. Bragg, 'Nature,' March 1914, p. 31.

reflexions for soft radiations. The crystals employed, however, showed many imperfections, and their behaviour was very different from that to be expected for an ideal crystal; for example, when the crystal was set at an angle of 12° to the incident beam, and with the width of the pencil such that only radiations between 11° and 13° should be strongly reflected, in addition to the lines in this region other outside lines are observed in varying positions on the photographic plate: for example, in a particular case at 2° 40′ and 13° 50′.

Special experiments showed that the position of these lines on the plate corresponded to a definite frequency of vibration in the incident beam. All our photographs showed similar peculiarities, but the outside lines which appear are very variable for different angles of the crystal. This behaviour of rocksalt led us to make many fruitless experiments to obtain a more perfect crystal, but all the crystals of rocksalt we have examined show similar imperfections, though in varying degrees. The crystal of heavy spar employed, for which the face appeared very plane and perfect, also behaved similarly. There appears to be no doubt that many crystals, and especially those of rocksalt, have a contorted or undulating surface, and that the orientation of the planes varies within certain limits from point to point of the crystal. At the same time, these irregularities may lead to the absence of a line in the photograph, although the crystal is set at the correct theoretical angle. To avoid this difficulty, it is desirable to keep the crystal in rotation during the experiment. Darwin has examined the consequences of such imperfections in a crystalline structure *, and considers that they offer an explanation of the fact that the intensity of the reflected beam is in general greater than the theoretical value to be expected for an ideal crystal.

Connexion of Radium B with Lead.

In recent papers †, Moseley has examined the X-ray spectra of a number of the ordinary elements. For this purpose, each element either in the state of metal or compound is exposed as anticathode in a focus tube, and the resulting X-ray spectra are obtained photographically by the crystal method. He has shown that the "K" characteristic radiation of all the elements between aluminium and silver shows a similar type of spectrum, and the frequency of the corresponding lines changes by definite steps in passing from one

* C. G. Darwin, Phil. Mag. April 1914, p. 975.

† Phil. Mag. *loc. cit.*

element to the next. The frequency of the strongest spectrum line has been shown to vary as $(N-a)^2$ where N is a whole number and a a constant (about unity) for all this group of elements. N changes by unity in passing from one element to the next, and is supposed to represent the number of fundamental units of positive charge carried by the atomic nucleus and may for convenience be called the "atomic number," since it represents the number of the element when arranged in order of increasing atomic weight supposing that no elements are missing.

It is well known from the work of Barkla that the heavier atoms emit a second type of characteristic radiation known as the "L" radiation. Moseley has examined the X-ray spectra of this type for elements of atomic weight from silver to gold, and finds that the spectra of all these elements are similar, but as in the case of the "K" type, the frequency increases by definite steps as we pass from one element to the next. He has shown that the frequency of the chief line of the spectra is nearly proportional to $(N-b)^2$, where N as before is the atomic number (or nucleus charge) and b a constant (about 7·4) for the whole groups of elements.

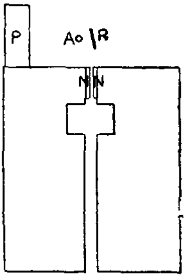
On the general theory of the nucleus atom, the nucleus charge determines the chemical and physical properties of the atom, and it is consequently of great importance to determine the value of this constant for the radioactive atoms. Before the publication of this paper, Mr. Moseley kindly informed us of his experimental results, and it became of great interest to determine the nucleus charge of radium B. As we have already seen, the soft radiation from radium B, whose absorption coefficient is $\mu=40$ in aluminium, was believed to be the "L" type of characteristic radiation of radium B, and this is completely borne out by the comparison of the γ-ray spectrum of the soft radiations of radium B with that of platinum (see page 861) Using Moseley's formula, and assuming for the atomic numbers the values to be given in a following paragraph, the factor by which the angle of the strong platinum line must be divided to give the angle of the corresponding line of radium B is 1·118: the value 1·122 used in Table I. was chosen so as to make the experimental lines agree exactly.

A determination of the nucleus charge of radium B is for another reason of the highest importance, for this radioactive element has been shown by Fleck to have the chemical properties of lead and to be chemically inseparable from it. As is well known, a very comprehensive and far reaching theory of the relation between the chemical and physical properties of the radioelements has been advanced by Fajans and Soddy. From the point of view of the nucleus theory of the atom, their conclusions may be expressed by the simple relation that the expulsion of an α particle (carrying two positive charges) from an atom lowers its nucleus charge by two units, and the expulsion of a β particle (carrying one negative charge) raises its nucleus charge by one unit. Soddy has pointed out that the products radium B, actinium B, thorium B, and radium D are the "isotopes" of lead, *i. e.* they show identical chemical properties with those of lead, from which they are inseparable by chemical methods. If this view is correct, the atoms of these elements should have the same nucleus charge, although they may differ slightly in atomic weight.

If radium B has the same nucleus charge as lead, it must give an X-ray spectra almost identical with that of lead. It should, however, be pointed out that a very small variation in the frequency of the vibrations may be possible if the nuclear masses are different. In his recent paper (*loc. cit.*) Moseley has not determined the X-ray spectra of lead, but he kindly pointed out to us that on his results its atomic number or nucleus charge should be 82. He found gold had the nucleus charge 79; the two intervening elements, mercury and thallium, should have a nucleus charge of 80 and 81 respectively. From the relations found by him, it followed by calculation that the strongest line of lead should be reflected at 12·07° from rocksalt. The strongest line from radium B found by us was 12·05°—a very close agreement.

As it was possible, however, that there might be a small error in comparing the reflexion angles of rocksalt with different crystals and with such different experimental arrangements, it was decided to test by a straightforward method whether the X-ray spectra of radium B and lead were identical within the limits of experimental error. For this purpose it was arranged that the γ-ray spectra of radium B and of lead should be compared, using the same apparatus and under as nearly as possible identical conditions. H. Richardson, working in this laboratory, has found that the β rays expelled from radium B and radium C excite strongly the characteristic "L" type of radiation when they fall on heavy elements. In order to take advantage of this result, the β rays from an emanation tube of the kind already described were used to excite the characteristic radiation in a strip of lead, 1 mm. thick and 5 mm. broad, which was then used as the source in place of the tube itself, the rest of the apparatus being disposed much as before. The arrangement was as shown in fig. 5; the slit was narrowed down to about 0·8 mm. by means of aluminium strips N, N, and the radiator R placed opposite it in the position indicated. The emanation tube A was fixed to one side, so that no direct rays

Fig. 5.



from it could strike the photographic plate. A second block of lead P was placed behind it, to increase the intensity by means of successive "reflexions" of the β rays between this block and R.

The spectrum of the radiation excited in the lead plate L was then determined under as nearly as possible the same conditions as for the γ rays from the emanation tube. For a given source, the photographic effect of the spectrum lines from lead only showed up faintly against the general blackening of the plate, but was sufficiently clear to admit of measurements of some of the angles of reflexion. Only a few lines of lead could be measured; two of these gave reflexion angles of $10^\circ\ 2'$ and $12^\circ\ 0'$ in good agreement with the strong lines of the radium B spectrum. Other faint lines were also observed but were difficult to measure. There was, however, a possibility of error in such an experiment. It was conceivable that the spectrum lines observed were not due to the characteristic radiations from the lead but were to be ascribed to some of the soft γ radiations from radium B scattered by the lead plate. To test this point, the lead plate was replaced by one of platinum of the same dimensions and the spectrum again measured. The positions of the lines were quite distinct from those observed with the lead radiator, and the measurements of the reflexion angles of two of the strongest lines were in fair agreement with those given by Moseley and Darwin for platinum.

According to Moseley's results, the frequency of a reference line for the X-ray spectra of successive elements changes by well-marked steps. For example, on the formula given by him, the reflexion angles from rocksalt of the strongest line of the spectrum from an element of nucleus charge 81 is 12·41°, for 82, 12·07°, for 83, 11·77°. In order to make a mistake of one unit in the nucleus charge, an error of 2 per cent. is necessary in measuring the angle of reflexion of the reference line, while the experimental determination of the reflexion angles of the γ rays from radium B is believed to be correct within 0·3 per cent.

It thus appears that the nucleus charge of radium B is the same as that of lead, for the atomic number of radium B, deduced by Moseley's formula from the γ-ray spectrum, is that to be expected for lead, and the strong lines of the γ-ray spectrum of radium B seem to be coincident with those of lead. According to radioactive calculation, the atomic weight of radium B is 214, while that of lead is 207. Provided the difference in atomic mass has not a large influence on the vibration frequencies of the outer distribution of electrons, it is to be anticipated that the ordinary light spectra of radium B and lead should be nearly identical, while we already know that these two elements have apparently identical chemical properties.

These results confirm in an unexpected way the correctness of this deduction of Soddy and Fajans, and also give a definite verification of the hypothesis that two elements of different atomic weights may have identical spectra and identical chemical properties. A similar result has been recorded by Sir J. J. Thomson and Aston in their work indicating that neon consists of a mixture of two gases of atomic weights about 20 and 22. The theory of the nucleus atom affords a simple explanation of such a result; for the chemical and physical properties are for the most part determined by the charge on the nucleus, and are practically independent of the mass of the nucleus. The properties of radioactivity and gravitation belong mainly to the nucleus. The fact that radium B is radioactive while lead is not, shows that the constitution of the nucleus is different in the two cases, and this is borne out by the known difference in atomic weights.

Taking the nucleus charge of radium B as 82, the nucleus charge of all the elements in the uranium-radium family can be deduced at once from the generalization already referred to. The numbers are given in the following table: an α radiation gives a decrease of 2 in the nucleus charge, a β radiation an increase of 1.

TABLE II.

Element.	Radiation.	Atomic Number.
Uranium I.	α	92
Uranium X_1	β	90
Uranium X_2	β	91
Uranium II............	α	92
Ionium	α	90
Radium	α	88
Emanation	α	86
Radium A	α	84
Radium B	β	82
Radium C	$\alpha+\beta$	83
Radium D	β	82
Radium E	β	83
Radium F	α	84
End product (Lead)...	...	82

If the general formula of Moseley holds throughout, the frequencies of vibration of the "L" type of radiation for each of these elements can be simply calculated.

Summary.

(1) The γ-ray spectrum of the soft radiations from radium B has been examined by reflexion from the cleavage faces of crystals, and found to consist of a number of well-marked lines.

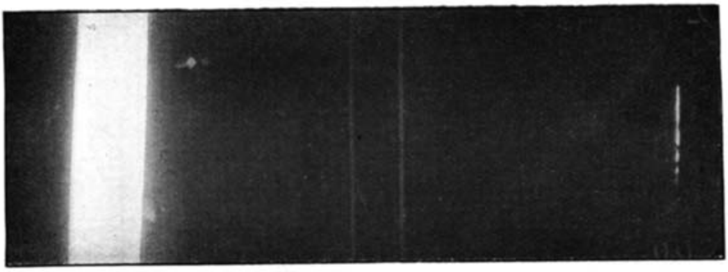
(2) The γ-ray spectrum of radium B is found to be of the same general type as that found for platinum and other heavy elements when bombarded by cathode rays.

(3) Attention is directed to the structure of the spectral lines using an emanation tube as source of radiation, and also to the imperfections of the crystals employed.

(4) Evidence is given indicating that the spectrum of the soft γ-rays spontaneously emitted from radium B, is identical within the limits of experimental error with the spectrum given by lead when the "L" characteristic radiation is excited by the bombardments of β rays.

(5) The bearing of these results on the structure of the atom is discussed.

FIG. 2.



B β α F

FIG. 4.