WAVE-LENGTH MEASUREMENTS OF GAMMA-RAYS FROM RADIUM AND ITS PRODUCTS*

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Abstract

Wave-length measurements.—The wave-lengths of the gamma-rays in the spectrum of Ra, RaB, RaC, and RaD were determined by the method of crystal diffraction. The rays which experienced diffraction on transmission through a crystal of calcite were received in a Geiger counting chamber which was provided with a slit system that could be turned about a pivot situated at the chamber. By turning the crystal a little so that the diffracted rays were not able to enter the chamber, a method was developed for obtaining the background of the intensity curve and the intensities of the γ-rays, and for investigating the intensity of a possible continuous γ-ray spectrum. Practically all the wave-lengths found by other investigators were obtained and good agreement among all the results was noted. In addition, several other short wave-length γ-rays were found, of which the shortest was 0.42 X.U. Four of them were again determined from measurements made with a diamond which also revealed a γ-ray of wave-length 0.17 X.U.

Intensities of the rays.—In general the changes in intensity from one wave-length to another throughout the spectrum corresponded to those given by other workers, but the intensities of the rays were not found to vary as much.

Continuous spectrum.—A determination of the background of the intensity curve showed that no continuous γ-radiation of any appreciable intensity was present. A more precise measurement made at a wave-length of 53.9 X.U. indicated that a continuous spectrum of γ-rays if existing at all raises the background intensity to less than one tenth the height of the least prominent peaks here found. It has already been concluded from indirect reasoning that the continuous γ-ray spectrum is unimportant.

Introduction

THERE are several methods by which a rough estimate of the hardness of the gamma-radiation from radioactive elements has been obtained. The quantity which characterizes the hardness has been termed the effective wave-length, and its magnitude is closely associated with the wave-length of some line or lines of strong intensity in the source of the radiation. Kohlrausch,[1] Compton,[2] and Ahmad,[3] have applied the x-ray absorption formula, $\mu = AZ + B\lambda^3 Z^4$, to their work on the absorption of γ-rays and have given $\lambda_{eff.}$, for the hard γ-rays from RaC to be from 14 to 20 X.U. Similar results were obtained from measurements on the intensity of scattered rays by Owen-Fleming-Fage.[4] The diffraction of γ-rays by a single atom depends

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[1] K. W. F. Kohlrausch, Wiener Ber. **126**, IIa, 441, 683, 887 (1917).

[2] A. H. Compton, "X-Rays and Electrons," p. 390.

[3] N. Ahmad, Proc. Roy. Soc. **A109**, 207 (1925).

upon the interference between the rays scattered by the electrons grouped close together in a heavy atom. Compton[2] has found $\lambda_{eff.} = 25$ X. U. by this method. He also obtaned a value for $\lambda_{eff.} = 16$ X. U. by calculating the wave-length of the scattered rays from their absorption coefficient.

A quantitative investigation of the various wave-lengths in the γ-ray spectrum of a radioactive element was first made by Rutherford-Andrade.[5] They used a crystal of rock salt to reflect the rays emitted by the disintegration products of radium contained in an emanation tube. The diffracted rays which emerged from the crystal at definite angles depending on their wave-lengths, were detected by their action on a photographic plate. However, the lines found by them belonged for the most part to the spectra of hard x-rays emitted by the atoms in the source after they had been excited by the nuclear γ-rays of high energy value.

The introduction of the counting method to the study of the high frequency γ-radiation from radium and its products by Kovarik[6] enabled him to find many of the true nuclear γ-rays. The rays, after reflection by a calcite crystal were detected by means of a Geiger counter.

The problem was also taken up by several investigators[7,8,9,10,11,12] who employed the β-ray spectrum method which makes use of the photoelectric effect of the γ-rays. Ellis-Skinner in particular give values for the wave-lengths of some twenty-two γ-rays of nuclear origin in RaB+RaC. In addition, relative intensities have been assigned to the lines. The theory in connection with this has been developed by Ellis-Wooster.[13] They have taken into account the observed intensities of the β-ray groups as indicated by the photographic plate and also the probability of conversion of the γ-rays into β-rays. However, their method for obtaining the wave-lengths and the intensities of the γ-rays is not considered to be as direct and straightforward as that of crystal diffraction.

Recently, Frilley[14] has made some experimental improvements in the method of Rutherford-Andrade and has been able to extend the measurements by means of photographic registration of the γ-rays. He has identified a large number of the wave-lengths obtained by the β-ray spectrum method. Great difficulty has always been experienced when trying to use the photographic plate to find rays of very short wave-length on account of the large quantity of primary radiation coming from the source. A general back-

[4] E. A. Owen, N. Fleming, W. E. Fage, Proc. Phys. Soc. London **36,** 355 (1924).

[5] E. Rutherford and E. N. daC. Andrade, Phil. Mag. [6] **27,** 854 (1914), [6] **28,** 263 (1914).

[6] A. F. Kovarik, Phys. Rev. [2] **19,** 433 (1922).

[7] E. Rutherford, H. Robinson and W. F. Rawlinson, Phil. Mag. [6] **28,** 281 (1914).

[8] C. D. Ellis and H. W. B. Skinner, Proc. Roy. Soc. **A105,** 60 (1924).

[9] C. D. Ellis and W. A. Wooster, Proc. Camb. Phil. Soc. **22,** 849 (1925).

[10] O. Hahn and L. Meitner, Zeits. f. Physik **26,** 161 (1924).

[11] J. Thibaud, C. R. **179,** 1322 (1924), Journal de Physique [6] **6,** 82 (1925).

[12] L. F. Curtiss, Phys. Rev. [2] **27,** 257 (1926).

[13] C. D. Ellis and W. A. Wooster, Proc. Camb. Phil. Soc. **22,** 595 (1925), Phil. Mag. [6] **50,** 521 (1925), Proc. Camb. Phil. Soc. **23,** 717 (1927).

[14] M. Frilley, C. R. **186,** 137 (1928), Ann. de Physique [10] **11,** 483 (1929).

ground of stray and scattered radiation also makes it hard to distinguish very weak lines.

The general consensus of opinion thus far has been that there is no continuous spectrum for the γ-rays. This view has been arrived at on consideration of the results of several experiments including the counting by Kovarik[15] of the number of γ-rays from RaB to RaC per atom disintegrating, the study of the intensities in the β-ray spectra by Gurney,[16] the measurements by Ellis-Wooster[13] on the heating effect of the γ-rays from RaB +RaC, and all the work mentioned above on the γ-ray wave-lengths and their intensities. It was concluded that the energy given off in the heating effect when the rays were absorbed in a suitable material could just about be accounted for by the total energy of all the monochromatic rays observed. There was no necessity for postulating a quantity of energy in the form of a continuous radiation. Because of the indirect method of measurement however it has usually been considered that there has been as yet no real proof either for or against the existence of a continuous spectrum.

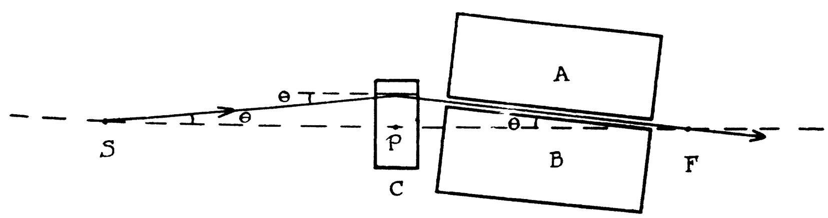

Fig. 1A. Crystal set.

In view of this fact and in particular because the lines determined by the β-ray spectrum method had not been completely checked by any crystal diffraction method, and in addition because some of the lines found by one observer had not been found by others, it was considered advisable to continue the investigation of these problems using the counting method. The experimental method used in the present measurements differed from that devised by Kovarik principally in the fact that diffraction of the rays was accomplished by transmission through a crystal instead of by reflection from the surface planes. The crystal was not rotated. Consequently there was one less experimental quantity to be determined and the range of the instrument in the direction of short wave-lengths was increased. The author was able to check nearly all the wave-lengths found before and to extend the measurements to several new γ-rays of very short wave-length. Additional direct evidence was obtained which supports the view of the non-existence of a continuous spectrum of any appreciable intensity. The intensity values found for the γ-rays are more or less in agreement with the results of other observers.

[15] A. F. Kovarik, Phys. Rev. [2] **23,** 559 (1924).
[16] R. W. Gurney, Proc. Roy. Soc. **A112,** 380 (1926).

Experimental Method

The diffraction of a single γ-ray is represented in Fig. 1A. S is a point source of the rays situated on the line SPF which may be considered as a line of reference. The crystal C is placed so that one set of its (1 0 0) planes is parallel to this line and perpendicular to the page. Then, a γ-ray of wave-length λ, coming from S and making an angle θ with the crystal planes, may undergo diffraction during transmission through the crystal, and if so the diffracted ray will pass over the point F. It can be shown from simple geometrical considerations that $FP = PS$ where P is a point at the center of the crystal. Such a ray must satisfy the Bragg formula for diffraction,

$$n\lambda = 2d\sin\theta$$

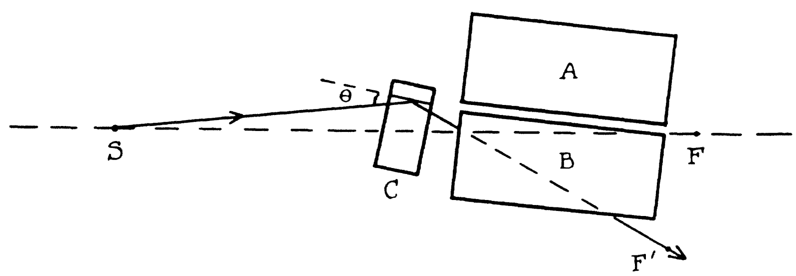

Fig. 1B. Crystal turned.

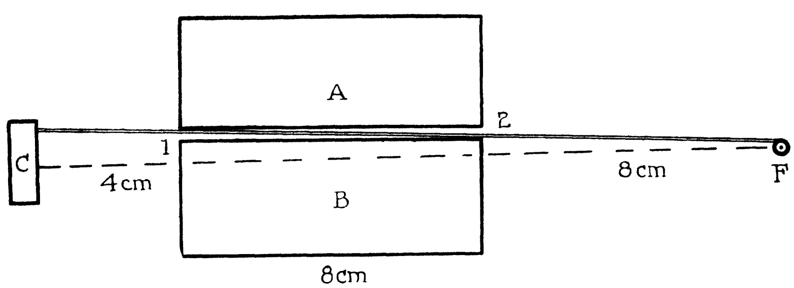

Fig. 1C. Diagram showing that the beam of monochromatic rays which passes into the counting chamber may have a width less than that of the slit.

where n is an integer, d the grating space, λ and θ the wave-length and angle of diffraction respectively. As the angles of diffraction concerned with here are all very small it is sufficient to use the formula $n\lambda = 2d\theta$. Furthermore, the cylindrical source that is used has a definite length and diameter and emits a great many rays in all directions; diffraction therefore will be possible for rays of all wave-lengths provided they are incident at the proper angle θ, and they will pass through the image of the source at F. The lead blocks A, B are shown in positions to form a deep slit or channel through which the rays may pass.

If a detector of γ-rays such as a Geiger counter is placed at F, the impulses which are counted will be due to several types of radiation. A considerable number of γ-rays may pass right through the lead blocks A, B and come either from the source S or from sources of penetrating radiation in the neighborhood. The rays which pass through the deep slit may be diffracted γ-rays satisfying the above expression, rays which are scattered by the crystal and other parts of the apparatus, and also high speed electrons. At very small angles there will be, in addition, a considerable amount of direct radiation coming through the slit system from the source. If the axis of the slit passes through F and makes the angle θ with FPS the γ-rays diffracted at an angle θ are transmitted without absorption. The slit system is pivoted at F.

In Fig. 1B the crystal is shown turned through an angle of a few degrees about an axis perpendicular to the page. The conditions relating to the absorption and scattering by the crystal remain essentially the same for the two cases. Thus it is readily seen that by taking a γ-ray count for both positions of the crystal, one can obtain the background of the spectrum and the intensities of the γ-rays.

Apparatus

The gamma-ray spectrometer was constructed as shown in Fig. 2. The base plate A, 24 in. by 8 in., was of cast iron and had strengthening ribs on the bottom. The lead blocks used to shield the source at S and to form

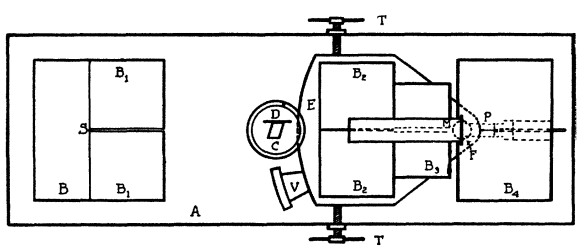

Fig. 2. Gamma-ray spectrometer.

the two slit systems were all 15 cm in height and about 8 cm thick, thickness being measured always in a direction along the axis of the instrument. The two blocks B_1, B_1 placed about 3 mm apart were used to limit the angular width of the incident beam. The spectrometer rested on a stone pier.

The source of γ-radiation was a preparation of radium salt containing 5.002 mg of radium together with its disintegration products. The glass container was 7 mm long and about 1.5 mm inside diameter and, protected by its thin silver casing, was supported so that its long dimension was in the vertical direction. The experiments were concerned mainly with nuclear rays. Since therefore it was desirable to have as few hard x-rays as possible, no other absorbing material was placed between the source and the crystal.

The crystal holder of a Bragg x-ray spectrometer was used to support the crystal and to orientate it in its proper position. The calcite crystal was 7 mm thick, 10 mm wide, and 25 mm high. It was placed with one of its faces in contact with the plate D. The vertical axis of the crystal holder together with the center of the source and the middle of the pivot determines the axis of the instrument. D was adjusted parallel to this by means of a straight edge. By turning the holder a little so that the horizontal peg in its edge was no longer in contact with the peg in the grooved disk beneath, the position illustrated in Fig. 1B was obtained. The distances between S and C and between C and F were each 20 cm.

A diamond crystal was also used to measure the shortest wave-lengths. Its dimensions were: height 9 mm, width 4 mm, and thickness 2.5 mm. The orientation of the (1 0 0) planes was determined by means of a goniometer. The grating space for the (1 0 0) planes in calcite is given as 3.0288 (10^{-8}) cm. In the case of the diamond the 4th order reflection was the one used as the (1 0 0) planes give no 1st, 2nd, or 3rd order. For diamond 1/4 of d_{100} is 0.885 (10^{-8}) cm.

The steel plate E carrying the slit system could be turned in either direction about the 0.5 inch pivot by means of two small pitch screws. Its zero position with respect to the axis of the spectrometer was determined by the scale and vernier. The angular positions of the slit system, however,

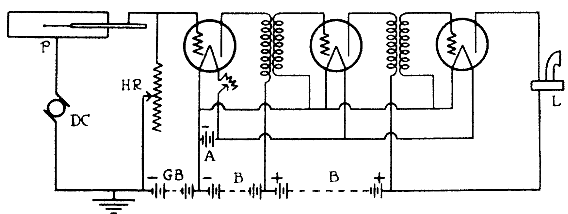

Fig. 3. Geiger counter and amplifier.

were measured by means of a lamp and transparent scale fastened to the wall at a distance of 286.48 cm from a lens and mirror M. The scale was accurately ruled in millimeters and one could estimate to 0.1 mm which corresponds to an angle of 3.600 sec. of arc. Since the angles to be measured were very small, the 0.2 mm distance corresponding to 7.200 sec of arc was taken as the unit of angular measurement. A lead plug 3 mm thick inside the slot cut through B_3 prevented high speed electrons from entering the counting chamber.

The counting chamber consisted of a brass cylinder 13 mm in diameter and 5 cm long with a 3 mm aluminum front, cast in the center of the lead block B_4 which was insulated from the base and to which the positive high potential connection was made. In especially damp weather dry dust free air was introduced into the chamber before counting. The potential necessary for operating the Geiger counter was supplied by a 3000 volt motor-generator set operating on 100 volts from a storage battery. The output was found to be very steady and constant to within 10 volts.

The electrical counting apparatus was essentially the same as that used by Kovarik.[17] Similar arrangements have been used by others for counting

[17] A. F. Kovarik, Phys. Rev. [2] 13, 273 (1919).

purposes. Fig. 3 is a schematic diagram of the electrical circuit. A loud speaker was used in the output circuit and the sharp clicks heard from it, one for each discharge in the chamber, were counted by a hand tally.

Platinum ball points about 0.003 inch in diameter were found to be very satisfactory. A point was made by melting one end of a half-inch piece of 0.001 inch hard drawn platinum wire in a very tiny gas-oxygen flame. As an indication of their practicability it may be said that throughout the experiments only about eight good points were used, and that with them somewhat more than two million γ-rays were counted.

Procedure

The adjustment of the slit system was accomplished by placing one of the blocks B_2 on the carriage before the other and bringing its slit face into line with the axis of the spectrometer by means of a straight edge. The width of the slit formed by the two blocks was changed by moving the second block and inserting various thicknesses of paper between them, after which the paper was removed.

In general, the experimental procedure was to count the number of γ-ray impulses in a period of 20 minutes for each successive angular position of the slit, in order to obtain a curve of intensity plotted against angular measurement for the while beam of diffracted rays. The slit system was always moved in the same direction in the course of a series of measurements. In each series a large portion of the spectrum was investigated.

In the preliminary work of measuring the wave-lengths the slit system was realigned several times and adjustments of the slit width and orientation of the crystal were made in order to obtain the best results. The positions D_1 and $-D_2$ of the peaks on either side of the zero were found for a number of wave-lengths. These positions were correlated in pairs and the mean zero of the spectrum determined from the average of $(D_1-D_2)/2$ for all wave-lengths and used as a basis for further measurements.

The results showed that two diffracted rays could be completely resolved if their angular separation was about 20 sec of arc, corresponding to a difference in their wave-lengths of about 0.6 X.U. Calculation showed however, that for the smallest slit width, 0.126 mm, all the diffracted rays in a beam of at least 5 minutes angular width could pass through the slit and enter the counting chamber. Accordingly, the reasonable assumption was made that the slit must not be in perfect alignment with the image of the source, and in Fig. 1C is shown the manner in which a narrow beam of monochromatic rays from the crystal was assumed to pass through the slit.

Several experiments were performed later which confirmed this view. With the diamond crystal, no peaks could be found when the width of the slit was decreased from 0.126 to 0.063 mm, and also when the width at end 1 was increased to 0.126 again, the width at end 2 remaining 0.063 mm. But when the width at end 2 was made 0.126 and that at end 1 was changed to 0.063 the peaks reappeared. Furthermore, with the calcite crystal and a width of 0.19 mm, the peak at 35 X.U. was found again when the width at end 1 was reduced to 0.126 mm, but the peak disappeared when end 2 of block B was moved the small distance 0.025 mm toward A. The position of A on the carriage was left unchanged throughout all the experiments. In order to calculate the resolving power, the position of the image of the source with respect to the pivot and the slit system must be known. Assuming their relative positions to be as shown in the figure, the two experiments indicated that two γ-rays could be resolved in the first case if their angular separation was about two minutes of arc and in the second case if the separation was less than one minute.

In the wave-length measurements it was found necessary to use three different slit widths, namely, 0.126, 0.19, and 0.38 mm. For angles of diffraction less than 40 units the first was used in order to have the rate of counting less than 55 per minute. The second was employed to decrease the slope of the background intensity curve for larger angles, and the third was found to be best for angles of diffraction greater than 195 units.

The portion of the background at large angles due to scattered rays was obtained from additional intensity measurements which were made with the slit closed. An intensity curve taken with the crystal removed did not show any peaks proving that they were due to diffracted rays only. A precise determination of the extent to which a possible continuous spectrum raises the background intensity was made by finding the intensities, for the two positions of the crystal, at a particular point on the curve where no peaks were to be expected either for first, second, or third order diffracted rays of any known wave-lengths.

The zero of the transparent scale was compared frequently with the zero of the steel scale and vernier. The deflections on the scale were noted at the beginning and at the end of each 20 minute period. In this way slight variations in the readings which occurred now and then due to the effect of temperature changes in the spectrometer were taken care of.

The operating potential on the Geiger counter was about 1800 volts, the exact value depending on the sensitive point in use. Its magnitude was always adjusted to the potential at which the impulses due to the γ-rays were slightly drawn out. The number of stray counts, or in other words, the number of impulses received when all sources of radiation were removed to a considerable distance, was about two or three per minute. A small test source placed in a definite position with respect to the counting chamber was used in standardizing the action of the points and in testing new ones. One person did the counting in all the experiments.

The expression for the probability of a number of counts n appearing in an interval of time for which x is the true average count was shown by Bateman[18] to be,

$$P = \frac{x^n e^{-x}}{n!} \cdot$$

[18] H. Bateman, Phil. Mag. [6] **20**, 704 (1910).

It has also been shown from this that the average deviation from the mean for a number of particles N counted in some interval of time t is $(nt)^{1/2}$, where n is the rate of emission. The probable deviation may therefore be taken as $0.67\ (x)^{1/2}$.

Since in the counting experiments there was always the possibility of getting a large deviation at some time or another because of the random nature of the counts, it was the practice immediately to repeat a count

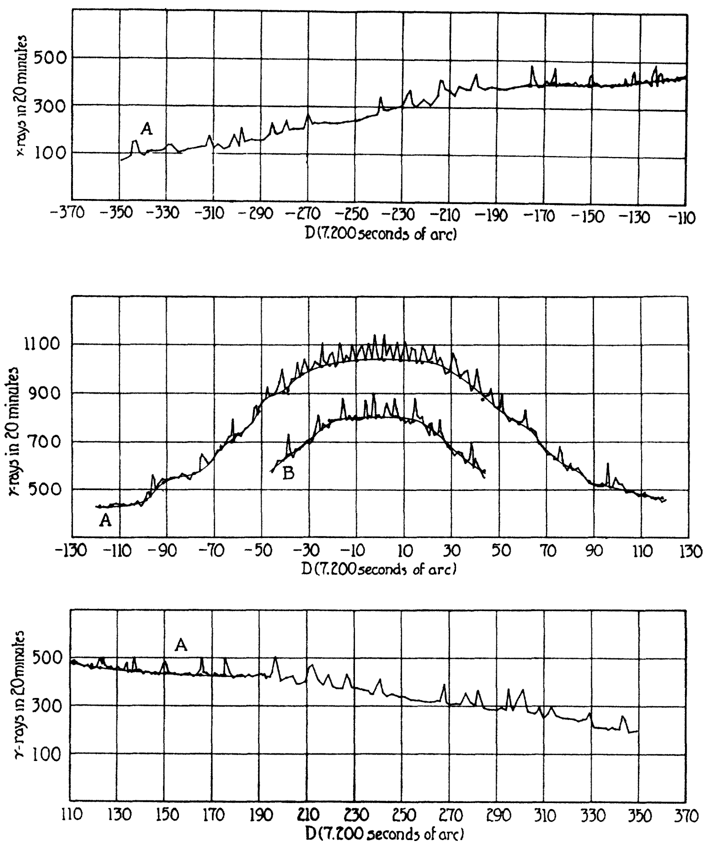

Fig. 4. Gamma-ray spectrum curves. Curve A is for the calcite, B for the diamond crystal.

which showed a large variation and average it with the other. If there was a true γ-ray intensity maximum or minimum for the position of the slit it was then confirmed, if not, the averaging process served to smooth out or reduce the magnitudes of the large deviations.

Results and Discussion

The complete intensity curve is shown in Fig. 4 and is presented in three sections on account of its length. The experimental points have been joined by straight lines. Curve B was taken with the diamond crystal. The small circles indicate the intensities obtained for the crystal turned and the base line of the spectrum has been drawn through them. The unit of the abscissa D is 7.200 sec. of arc and corresponds to a wave-length of 0.2115 X.U. for curve A and 0.0618 X.U. for curve B.

TABLE I.

D_1	$-D_2$	$(D_1-D_2)/2$	λ X.U.	Intensity	Rutherford-Andrade	Kovarik	Ellis-Skinner	Intensity	Thibaud	Frilley	Intensity	Source of Rays
1260	1260	1260	266.5		262		264			265		RaD
1096	1098	1097	232.0		229		230.3			232		RaB
683	683	683	144.5							144		RaB
547	544	545.5	115.3		115							RaC
343	343	343.0	72.5	6	71	72.2						RaC
329	329	329.0	69.6	3						77[2]	w.	RaB
312	313	312.5	66.1	4		66.1						Ra
308	308	308.0	65.2	2						65	w.	RaB
301	301	301.0	63.7	7								?
298	295	296.5	62.7	8			62.7	2				RaB
285	282	283.5	60.0	6			59.9	1				RaB
279	277	278.0	58.8	4		58.1						RaC
270	268	269.0	56.9	6								?
239	241	240.0	50.8	5			50.7	25				RaB
227	227	227.0	48.0	6		48.4						RaC
214	212	213.0	45.1	8			44.9	4				RaC
213	211	212.0	44.8	7			44.7	3				RaB
199.0	196.5	197.75	41.8	8			41.6	30	42.1	42	v.s.	RaB
175.5	175.5	175.50	37.1	8		37.0	37.1	2				RaC
165.5	165.5	165.50	35.0	7			34.9	40	35.1	35	v.s.	RaB
150.0	150.0	150.00	31.7	5			31.7	6				RaC
135.5	137.0	136.25	28.8	4			28.8	3	29.0			RaC
132.0	134.0	133.00	28.1	5		28.1						RaC
123.0	124.0	123.50	26.1	6			26.2	1	26.5	26	v.w.	RaB
121.0	122.0	121.50	25.7	4			25.6	1				RaB
98.0	99.0	98.50	20.8	4								?
95.5	96.0	95.75	20.2	10			20.2	30	20.2	20	v.s.	RaC
75.0	76.0	75.50	16.0	7					16.0	16	m.	RaC
62.0	61.5	61.75	13.1	9			13.1	7	13.2			RaC
52.0	51.5	51.75	10.95	7			10.92	13	10.94			RaC
47.0	47.0	47.00	9.94	5			9.90	7	9.92			RaC
41.0	41.0	41.00	8.67	10			8.66	16				RaC
34.5	36.0	35.25	7.46	6								?
32.0	32.0	32.00	6.77	6			6.94	8	6.95			RaC
26.5	26.0	26.25	5.55	3			5.56	3	5.57			RaC
24.0	23.0	23.50	4.97	9								?
20.5	18.5	19.50	4.13	6								?
16.5	15.0	15.75	3.33	7								?
13.5	13.5	13.50	2.86	5								?
11.5	11.0	11.25	2.38	7								?
7.5	7.5	7.50	1.59	7								?
4.5	4.5	4.50	0.95	6								?
2.0	2.0	2.00	0.42	10								?
		DIAMOND CRYSTAL										
38.5	38.5	38.50	2.38	10								?
26.0	25.5	25.75	1.59	8								?
15.5	15.0	15.25	0.94	9								?
6.0	6.5	6.25	0.39	7								?
2.5	3.0	2.75	0.17	9								?

The spectrum curve was obtained in five parts, a central portion extending to 45 units and two on either side with overlap. The parts were placed so as to give a continuous curve which was done by changing the ordinates by adding or subtracting a constant quantity. The actual intensity of the background was: 1040 γ-rays in 20 minutes at zero, 420 at 195, and 350 at 340. The intensity of the background for B was 1010 at zero, differing slightly from A because of a readjustment of the slit width. The large increase in intensity for angles less than 70 was due to γ-rays coming directly from the source. About 15 percent of the general background was made up of scattered rays. Because of the method of procedure in counting, previously described, it is estimated that the experimental error in the determination of the intensity of the background, and the intensities at most of the maximum and minimum points on the curve is about ± 15 γ-ray counts.

It is to be noted that the peaks on the curve are sharp and in general are defined by two or more points. No trouble was experienced in repeating the positions of the peaks and in fact many of the peaks were obtained several times. Taking the expected deviation to be 0.67 $(x)^{1/2}$ it is seen that their heights above the background vary from 2 to 7 times the probable deviation depending on the intensity of the background.

The numerical results are given in the Table I. D_1 and $-D_2$ are the positions of corresponding peaks on both sides of the zero of the spectrum. The region of wave-lengths longer than 72.5 X.U. was not completely investigated so that no curves are shown. The values of the γ-ray wave-lengths and their intensities as found by other investigators are also included in the table for the purpose of comparison. The experimental error in the values of λ presented herewith is ± 0.1 X.U. except for wave-lengths longer than 41.8 where it is about ± 0.2 X.U. The four γ-rays of shortest wave-length were also obtained with the diamond crystal. The error in their wave-lengths is ± 0.03 X.U. Ellis-Skinner give an accuracy to their results of one part in 300. Frilley gives an experimental error of ± 0.5 X.U. Consequently there is good agreement among all the results. Many new rays were found and the diamond crystal made it possible to detect the extremely short wave-length of 0.17 X.U. Two additional determinations gave the same value.

The following γ-ray wave-lengths, reported by others for substances certainly present, were not found:

RaB $\lambda = 51.3$ X.U.	Thibaud, $\lambda = 51.5$	Frilley
RaB $\lambda = 47.5$		Ellis-Skinner
RaC $\lambda = 29.5$		Frilley
RaC $\lambda = 23.4$	Thibaud, $\lambda = 24$	Frilley

There is additional information in regard to a few of the wave-lengths, namely:

RaD $\lambda = 265$	Meitner, $\lambda = 264$	Curtiss
RaB $\lambda = 71$	Frilley, possibly 2nd order of $\lambda = 35$	
Ra $\lambda = 66$	Hahn-Meitner	

No particular effort was made to identify higher order diffracted rays and some of those presented in the table may be of that kind.

On account of the complex nature of the radioactive preparation used in the present experiments, it was impossible to tell the exact source of any of the rays. The assignments in the last column, some of which are doubtful, are also from other papers.

The relative intensities of the γ-rays are given in column 5. The height of a peak has been taken as the intensity and a number 10 means that 100 monochromatic rays in addition to the background were counted in 20 minutes. No correction has been made for the fact that three different sizes of slit were used. Some of the peaks were repeated using double the slit width but their heights were found to be increased only about 40 percent. It was therefore considered advisable not to assume any relation between the width of the slit and the intensity of the rays and so attempt to reduce them all to the same basis. On the whole the changes in intensity along the spectrum are in agreement with the results of other observers, but the intensities do not vary as much as in the results of Ellis-Skinner. Although the present method was quite straightforward it is not certain that this disagreement is particularly significant.

It may be seen from Fig. 4 that the base line passes through or a little above the bases of the peaks but not below them as would be the case if there was a continuous spectrum of any appreciable intensity. The more precise measurements made at a wave-length of 53.9 X.U. gave a γ-ray count of 6664 for the crystal set for diffraction through the slit and 6666 in the same length of time for the crystal turned. Since the probable variation in either of these numbers is about ± 0.8 percent, and the smallest peaks on that part of the curve are found to differ from the background by about 9 percent, it would seem that a continuous radiation if existing at all raises the background intensity to less than one-tenth the height of the least prominent peaks here found. Moreover these peaks belong to some of the weakest γ-rays.

It is to be noted that the very short wave-length γ-rays represent a large amount of energy as a wave-length of 1 X.U. corresponds to the energy of an electron after falling through a potential difference of some 12×10^6 volts. The relation between these γ-rays and other high frequency radiations may be inferred from a consideration of the work of Millikan-Cameron[19] and many other investigators. No attempt has been made to correlate the new wavelengths with the nuclear energy level theories put forward by Ellis[20] and others.

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[20] C. D. Ellis, Proc. Camb. Phil. Soc. **22**, 369 (1924).