These results have been combined with the range measurements of Lewis and Wynn-Williams to give the relation between velocity and the range for α-particles of ranges between 4 and 9 cm.

It is found that for ranges greater than 5 cm. this relation is accurately given by

$$V^{3\cdot 26} = kR.$$

The corrections for loss of velocity due to absorption at the source have been fully discussed.

The Maximum Energy of the β-Rays from Uranium X and other Bodies.

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1. *Introduction.*

It is now generally accepted that the disintegration electrons from radioactive nuclei have a continuous distribution with energy. The end-points of these distribution curves, representing the maximum kinetic energies carried by the β-rays, have been determined in a considerable number of cases and appear to be quite definite. The purpose of this paper is twofold. First, new experimental work on the β-rays from uranium X will be presented in sections 2, 3 and 4. This includes a determination of the end-point of its normal β-ray spectrum, which was found to be 2·32 million volts, and a search for β-rays having energies from 3 to 7 million volts. None were found, and an upper limit on their number was determined. Secondly, a critical survey of the data on the end-points of a number of β-ray spectra with a list of preferred values will be given in section 5. It will then be shown, in section 6, that a relation between the maximum energy emitted in a spectrum of β-rays and its disintegration constant appears to exist.

2. *Methods of Determining the End-points of Continuous Spectra.*

Three methods have been used to find the maximum energies in β-ray spectra. One direct method, carried out principally by Madgwick* and Gurney,†

* 'Proc. Camb. Phil. Soc.,' vol. 23, p. 982 (1927).

† 'Proc. Roy. Soc.,' A, vol. 109, p. 540 (1925); *ibid.*, vol. 112, p. 380 (1926).

consists of analysing the β-rays with the usual semicircular focussing in a magnetic field, and determining, from the field strength and the radius of curvature of the path, the velocity of the fastest particles that can be detected by electrical methods.

A more recent method, used by Terroux and Alexander,* and Champion,† is to photograph the tracks of the β-particles in an expansion chamber, and from the curvature produced by a magnetic field a distribution with velocity can be found. So far, this method has only been applied to the fast β-rays, with the hope of deciding whether the high velocity end-points are real or not. It seems to the writer that it is very difficult to choose an adequate criterion for rejecting those tracks whose curvatures have been appreciably affected by scattering. More satisfactory results might be obtained if the air in the expansion chamber was replaced by hydrogen to diminish scattering, and if stronger magnetic fields were applied. This method suffers from the common fault of all statistical ones in that a large number of particles have to be registered, and so the work involved is enormous. If it were extended to give the complete distribution of the β-rays with velocity the variation of the efficiency of registration of tracks with velocity during the time of expansion would have to be carefully investigated.

The high velocity limit of a β-ray spectrum can be determined in yet another way. The effective range of the β-rays is found in paper or aluminium, and this is usually ascribed to the fastest particles in the spectrum. The velocity of these may then be obtained by comparing their range with the extrapolated ranges of initially homogeneous β-rays. This procedure was followed by Chalmers‡ for thorium active deposit and by the writer§ for actinium active deposit. In order to avoid certain difficulties in interpretation, Feather‖ preferred to find the end-point of the spectrum of mesothorium 2 by comparing his value of the range with the ranges of the β-rays of radium E, thorium C and radium C, whose maximum energies are known approximately from magnetic analyses.

The first and third methods especially agree where comparison can be made, as in the cases of thorium B, thorium C, radium E, and radium C. This agreement may be partly fortuitous, because the interpretation of the experimental

* Terroux, 'Proc. Roy. Soc.,' A, vol. 131, p. 90 (1931); Terroux and Alexander, 'Proc. Camb. Phil. Soc.,' vol. 28, p. 115 (1932).

† 'Proc. Roy. Soc.,' A, vol. 134, p. 672 (1932).

‡ 'Proc. Camb. Phil. Soc.,' vol. 25, p. 331 (1929).

§ 'Proc. Camb. Phil. Soc.,' vol. 25, p. 514 (1929).

‖ 'Phys. Rev.,' vol. 35, p. 1559 (1930).

results by the third method is somewhat uncertain for reasons that will be given later. The experiments in the range method are, however, very simple and can be performed even with rapidly decaying sources. To find the range of the β-rays, the ionization caused by the β- and γ-rays which have passed through absorbing screens of different thicknesses, is measured in an electroscope. The β- and γ-ray effects may be separated by using a magnetic field as Douglas* and the writer† have done. The range may then be found from the absorption curve of the β-rays alone. Alternatively, the range may be found from the curve obtained by plotting the combined β- and γ-ray ionization against the mass per unit area of the absorbing screen. This curve is always composed of two main parts, a rapidly falling one, where the ionization is mostly due to the β-rays, and a second part at large thicknesses of absorber, where the ionization is due entirely to the γ-rays. The effective range of the β-rays, or the thickness of absorber which reduces their intensity to a quantity too small to be detected, is then fairly evident. This procedure was adopted for finding the range and thereby the end-point of the β-ray spectrum of uranium X.

3. *Experimental Results.*

An active preparation of uranium X ($= X_1 + X_2$) on a piece of filter paper was placed in a cavity, 2·5 cm. diameter and 4 mm. deep, drilled in a wooden block. This preparation was covered with another filter paper and a piece of gummed paper. The block was placed 4 cm. below the paper base of an iron electroscope, 13 cm. cube. Absorption sheets of carbon and cardboard or of aluminium were placed over the source, and readings of the ionization due to the β- and γ-rays were taken.

Very consistent readings were obtained, and sets taken on different days agreed to 2 parts in 300 when allowances were made for the decay of the source and variations in atmospheric pressure. Averages listed in Tables I and II are probably correct to 1 part in 300. The results are plotted in fig. 1, where the effective range of the β-rays is seen to be 1·06 gm./cm.^{2}. A preliminary set of measurements using a brass electroscope yielded 1·05 gm./cm.^{2}.

To the value 1·06 gm./cm.^{2} must be added the mass per unit area of the filter paper and the gummed paper over the source, also of the paper base of the electroscope. This correction amounts to 0·041 gm./cm.^{2}, making the effective range 1·10 gm./cm.^{2} in aluminium and carbon. Fajans and Göhring‡

* 'Trans. Roy. Soc. Can.,' III, vol. 16, p. 113 (1922).

† 'Proc. Camb. Phil. Soc.,' vol. 25, p. 331 (1929).

‡ 'Phys. Z.,' vol. 14, p. 877 (1913).

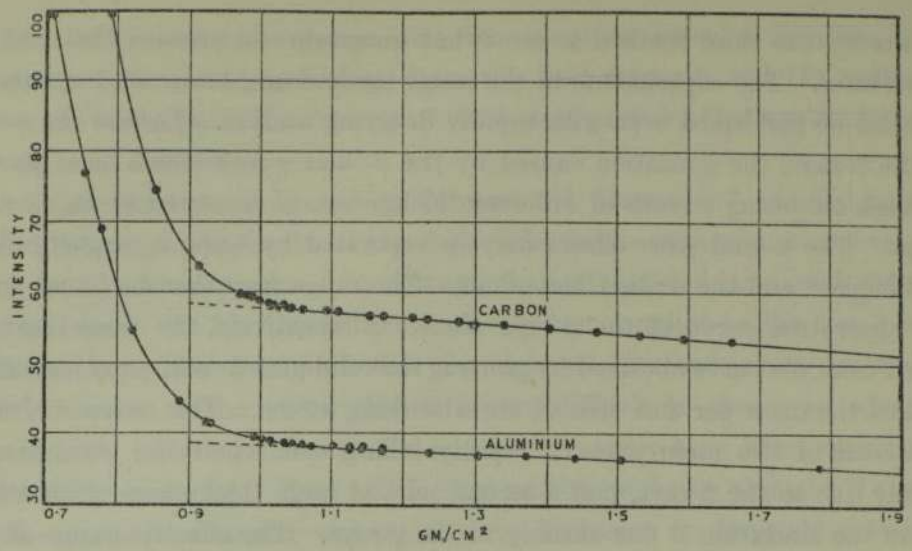

FIG. 1.

Table I.—Absorption of β-rays of U ($X_1 + X_2$) in Carbon + Cardboard.

Carbon. (gm./cm.²)	Total. (gm./cm.²)	Intensity. ($\beta + \gamma$)	Carbon. (gm./cm.²)	Total. (gm./cm.²)	Intensity. ($\beta + \gamma$)
0·785	0·792	100	0·785	1·156	56·6
0·785	0·855	74·4	0·785	1·174	56·6
0·785	0·916	63·8	0·785	1·216	56·2
0·785	0·974	59·9	0·785	1·237	56·0
0·785	0·983	59·6	0·785	1·280	55·8
0·785	0·987	59·2	0·785	1·343	55·2
0·785	1·000	58·9	0·785	1·407	55·0
0·785	1·013	58·4	0·785	1·471	54·3
0·785	1·020	58·3	0·785	1·534	53·9
0·785	1·026	57·9	0·785	1·598	53·3
0·785	1·034	58·1	0·785	1·662	53·0
0·785	1·047	57·8	1·618	1·943	53·0
0·785	1·060	57·5	2·360	2·685	50·7
0·785	1·095	57·4	3·193	3·518	47·6
0·785	1·110	57·3			

Table II.—Absorption of β-rays in U ($X_1 + X_2$) in Aluminium.

Aluminium. (gm./cm.²)	Intensity. ($\beta + \gamma$)	Aluminium. (gm./cm.²)	Intensity. ($\beta + \gamma$)
0·710	100	1·074	38·3
0·779	65·9	1·104	38·2
0·821	54·6	1·129	37·8
0·888	44·7	1·147	38·0
0·926	41·7	1·172	37·7
0·931	41·5	1·238	37·2
1·005	39·2	1·306	36·9
1·018	38·9	1·374	36·8
1·035	38·7	1·441	36·5
1·048	38·6	1·508	36·3
1·060	38·5	1·785	36·2

and others* have shown that uranium X_1 emits slow β-rays and uranium X_2 fast ones, so this range must be ascribed to the latter. If Varder's† and Madgwick's‡ values of the extrapolated ranges of homogeneous β-rays in aluminium may be applied, we find Hρ 9700 (Varder) and 8800 (Madgwick) as estimates of the end-point of this β-ray spectrum. The mean value, Hρ 9250, corresponds to an energy of 2·31 million volts. Feather's (*loc. cit.*) empirical equation,

$$R = 0{\cdot}511\,E - 0{\cdot}091,$$

connecting the range R of a β-ray spectrum with its maximum energy E, leads to 2·33 million volts for the end-point.

It should be pointed out that the absorption curves are really smooth, and no definite "kink" is evident at the range. The value 1·10 gm./cm.^{2} may be regarded as correct to 2 per cent. with the present source. The β-ray intensity at the range was not greater than 0·2 div. per minute, and the initial intensity of the source was estimated at 10,000 div. per minute. That is, the ionization of the β-rays has been reduced to 2 parts in 100,000, which is about the same order of reduction as in some previous experiments with other β-ray bodies.

It is well known that, unless the initial activity of the source is very large, the range may be underestimated. Feather§ has examined this and other points in detail. An underestimation of the range is the inevitable result of the finite sensitivity of the electroscope, and the fact that those rays, whose range we wish to measure, form only a small fraction of the whole spectrum. In fact with weak sources of actinium (B + C) the writer (*loc. cit.*) found it necessary to separate the β- and γ-ray effects with a magnetic field, and to extrapolate the absorption curve of the β-rays. The smallest intensity of β-rays that could be measured was 0·1 per cent. of the initial one. When the logarithm of the β-ray intensity was plotted against the mass per unit area of absorbing screen, it was possible to extrapolate the curve obtained in a reasonable way, with the purpose of avoiding the error just considered. On the other hand, if sufficiently active sources were available, it would be possible to overestimate the range, even if the spectrum had an end-point beyond which there were no β-rays whatever. Owing to straggling within the absorbing material

* Fleck, 'Phil. Mag.,' vol. 26, p. 529 (1913); Hahn and Meitner, 'Phys. Z.,' vol. 14, p. 758 (1913).

† 'Phil. Mag.,' vol. 29, p. 725 (1915).

‡ 'Proc. Camb. Phil. Soc.,' vol. 23, p. 970 (1927).

§ 'Proc. Camb. Phil. Soc.,' vol. 27, p. 430 (1931).

the effective range of a spectrum of β-rays would not be the extrapolated range of the fastest ones, as defined by Varder (*loc. cit.*) and Madgwick (*loc. cit.*), so their data would not be applicable for a determination of the end-point. It seems, therefore, that the good agreement among the end-points obtained by direct and indirect methods may be due, in part, to a fortunate choice of activity of the sources.

The early experimenters were mainly interested in finding the absorption coefficients of the β-rays in different materials, and so it was unnecessary to carry out the measurements to large thicknesses of absorber. There is, therefore, very little previous information about the end-point of the β-ray spectrum of uranium X. Levin's* absorption curve in aluminium shows the effective range to be about 0·95 gm./cm.^{2}, but this is only a rough estimate since his curve has not been carried quite far enough.

Many years ago Schmidt† published a rough ionization distribution curve of the β-rays using magnetic analysis. The curve indicated an end-point at Hρ 9000, but little weight should be attached to this value because the focussing was poor and no attempt was made to allow for scattered radiation.

4. *β-rays of Very High Energy.*

Of the continuous spectra containing the primary electrons due to the normal mode of disintegration, only one, radium C, has an upper limit of energy greater than 3 million volts, while four others have limits near 2 million volts (see latter). Evidence has been accumulating which seems to show that certain β-ray bodies occasionally emit electrons possessing energies of the order of 7 million volts. Indication of their presence was first given by feeble traces on photographic plates exposed in a magnetic spectrograph. While these diffuse traces may be caused by secondary electrons produced by penetrating γ-rays, at present it seems most reasonable to consider most of them, in fact those above Hρ 12,000, to be from primary electrons arising from an abnormal and infrequent mode of disintegration.‡ The evidence for such high-speed β-rays has been summarized by Rutherford, Chadwick and Ellis (*loc. cit.*), and also by d'Espine.§ Experiments by J. A. Gray and O'Leary,‖ Cave,¶

* 'Phys. Z.,' vol. 8, p. 585 (1907).

† 'Phys. Z.,' vol. 10, p. 6 (1909).

‡ Rutherford, Chadwick and Ellis, "Radiations from Radioactive Substances," pp. 381–384.

§ 'Ann. Physique,' vol. 16, p. 5 (1931).

‖ 'Nature,' vol. 123, p. 568 (1929).

¶ 'Proc. Camb. Phil. Soc.,' vol. 25, p. 222 (1929).

Cave and Gott,* Champion (*loc. cit.*), and Wang† agree in showing that in particular experiments the number of high-speed β-rays forms an extremely small fraction of those emitted in the usual spectrum. Clearly β-rays having energies of 10 million or even of 4 million volts are of great interest. While no evidence of such high-speed β-particles from uranium X has ever been given, an investigation seemed opportune when the end-point of its continuous spectrum was being determined.

The experimental arrangement was that described in section 3, and an absorption method was used. Ionization measurements were carried out until the mass of carbon and cardboard between the source and the electroscope was 3·52 gm./cm.². Relative values of the transmitted radiation are given in column 2 of Table III. At each stage the radiation issuing from the absorber was tested by passing it through a lead foil of 0·0975 gm./cm.². The percentages transmitted by the foil are given in column 3, Table III. It

Table III.

Mass of carbon, etc. (gm./cm.²)	Transmission by carbon, etc.	Transmission by lead foil (0·0975 gm./cm.²)
		per cent.
0·792	100	51·3
0·855	74·4	62·5
0·919	63·8	70·7
0·983	59·6	73·8
1·046	58·1	74·3
1·110	57·3	74·2
1·174	56·6	74·3
1·237	56·0	74·2
2·685	50·7	74·5
3·518	47·6	74·3

is seen that after 1·046 gm./cm.² of carbon the transmission remains constant for this foil at 74·3 per cent. to 1 part in 300. This shows that the radiation remains unchanged in quality. Below 1·046 gm./cm.² the presence of β-rays in the radiation issuing from the carbon absorber is well shown by the larger absorption in the lead foil.

From what follows we conclude that the radiation penetrating thicknesses of carbon greater than 1·06 gm./cm.² must be almost entirely of the γ-ray type. Its mass absorption coefficient in the lead foil is 3·05, while 2·4 gm./cm.² of carbon diminishes it to 83 per cent. of its value at 1·11 gm./cm.², or μ/ρ in

* *Vide* "Radiations from Radioactive Substances," p. 383.

† 'Z. Physik,' vol. 74, p. 744 (1932).

carbon is about 0·077. That is μ/ρ in lead is 39·6 times μ/ρ in carbon.* Only a γ-radiation can have this property, for with β-rays the mass absorption coefficient in lead is only about 1·5 times that in carbon. Without going into cumbersome details we estimate that if 0·2 div. per minute of the radiation issuing from 1·11 gm./cm.^{2} carbon were of the β-ray type it could just have been detected by these absorption measurements. This estimate is supported by an inspection of the absorption curves in fig. 1, and it provides an upper limit on the ionization produced by β-rays having ranges between 1·11 and 3·52 gm./cm.^{2} carbon. If the equivalence of carbon and aluminium is assumed we find that β-rays require energies of 2·5 and 7·0 million volts to penetrate these two thicknesses.

In order to set a limit on the fraction of high-speed β-rays the intensity of the source with no absorber in position must be known. This was roughly estimated from the ionization measurements given in Table IV. These have

Table IV.

Absorber (gm./cm.^{2}).		β-ray activity (div./min.)
Carbon.	Lead.	
0·458	—	700
0·458	0·0975	235
Lead plate containing small hole over source.		
—	—	220
—	0·0975	59·0
0·458	0·0975	3·90

* The effective wave-length of the γ-rays issuing from 1·1 gm./cm.^{2} carbon or aluminium can be approximately calculated. The mass absorption coefficients measured with the experimental arrangement were 0·075 (carbon), 0·088 (aluminium), 0·140 (cardboard) and 3·05 (lead foil). These when corrected for the oblique passage of some of the γ-rays through the absorption sheets become 0·068, 0·079, 0·126 and 2·68 respectively. For this correction a formula given by W. and F. M. Soddy and Russell ('Phil. Mag.,' vol. 19, p. 725 (1910)) was used. Since much of the radiation scattered in the forward direction enters the electroscope a further correction has to be applied, particularly for the light substances in which the photoelectric absorption is small. Compton's formula ('Phys. Rev.,' vol. 21, p. 483 (1923)) for the distribution of scattered radiation with angle, regarded as satisfactory for these wave-lengths, was used. The mass absorption coefficient in carbon then becomes 0·144, which corresponds to an effective wave-length of 0·093 A. The coefficient in lead, 2·68, corresponds to 0·083 A. It is believed that the lead foil contains a fairly high percentage of impurity so that $\lambda = 0{\cdot}083$ is probably too small. It should be noticed that the apparent absorption coefficient in cardboard is about twice that in carbon. The cardboard must contain a considerable amount of heavy materials in order that the photoelectric absorption can be appreciable.

been corrected for γ-rays. The first two were obtained by using the whole source. A lead plate containing a small hole was then placed over the source in order that the intensity of the β-rays coming through could be directly measured. The initial β-ray intensity of the whole source is $220 \times 235/3 \cdot 90$ or 13,200 div. per minute. It is also seen that 0·458 gm./cm.^{2} carbon cuts down the intensity from 59·0 to 3·90 div. per minute, *i.e.*, to 6·6 per cent. The second estimate of the initial activity is therefore $700 \times 100/6 \cdot 6 = 10{,}600$ div. per minute. It was found later by using a thin layer of the active material that 0·458 gm./cm.^{2} carbon transmits 7·1 per cent. of the β-radiation incident on it. This agrees with 6·6 and with figures obtained in another connection, 6·1 per cent. for the same mass per unit area of paper and 5·75 for cardboard. If 7·1 per cent. is taken the initial activity is 9800 div. per minute. These estimates are accurate enough for the present purpose, and a round figure 10,000 div. per minute is adopted as the final value of the initial β-ray activity.

The conclusion reached is that out of a total of 10,000 div. per minute less than 0·2 penetrate 1·11 gm./cm.^{2} carbon. The ionization of the fast β-rays has been diminished by this carbon, and at this point it is necessary to assume a value for their initial energy. If we take 7 million volts, Madgwick's* curves show that about 55 per cent. of the initial intensity is transmitted. On the other hand, if we take 3 million volts as the energy of the β-rays, in passing through 1·11 gm./cm.^{2} carbon their ionization is reduced to 18 per cent. of its initial value. The initial intensity of the fast β-rays is therefore either 0·36 or 1·10 div. per minute in a total of 10,000, *i.e.* either 1 in 28,000 or 1 in 9,000. The ionizing power of the fast β-rays is less than that of the average ones (average energy 820,000 volts). Allowing for this we find that uranium X emits less than one β-ray of 3 million volts energy in 6,500 normal ones, and less than one β-ray of 7 million volts energy in 15,000 normal ones.

5. *Collected Results for several β-ray Bodies.*

Uranium X_1.—Absorption curves obtained by Levin (*loc. cit.*), Schmidt (*loc. cit.*), Fajans and Göhring (*loc. cit.*), and Hahn and Rothenbach† for the β-rays of uranium ($X_1 + X_2$) show a group of very absorbable β-rays to be present. Their range lies between 0·014 and 0·021 gm./cm.^{2} aluminium, and the mean 0·018 gm./cm.^{2} is here chosen. These β-rays must come from uranium X_1. Using Schonland's‡ and Varder's (*loc. cit.*) values for the ranges of homo-

* 'Proc. Camb. Phil. Soc.,' vol. 23, p. 970 (1927).

† 'Phys. Z.,' vol. 20, p. 194 (1919).

‡ 'Proc. Roy. Soc.,' A, vol. 104, p. 235 (1923); vol. 108, p. 187 (1925).

geneous β-rays, we find that this range corresponds to Hρ 1300, or 130,000 volts energy. Meitner,* in her magnetic analysis of the line spectrum, found a band extending from 108,000 to 124,000 volts. If this contains the disintegration electrons its maximum energy agrees very well with that found from the range.

Radium B.—From Schmidt's† absorption curve the range of the β-rays of radium B is estimated at 0·216 gm./cm.² of aluminium. This corresponds to Hρ 3380 (Varder) or to Hρ 3170 (Madgwick). The mean, Hρ 3280, should be compared with Gurney's (*loc. cit.*) value Hρ 3470, obtained by magnetic deflection.

Radium C.—A number of estimates, ranging from Hρ 11,000 to Hρ 16,000, of the end-point of the β-ray spectrum of radium C have been made. Madgwick and Gurney‡ found Hρ 12,000 by magnetic analysis when care was taken to eliminate scattered β-rays. D'Espine‡ found the end-point to lie between Hρ 11,000 and Hρ 12,000 from photographic plates exposed in a magnetic spectrograph. The range of these β-rays is estimated at 1·62 gm./cm.² from Schmidt's§ absorption curve, which yields Hρ 12,500 as the end-point. Feather‖ has determined this range very carefully and found $1{\cdot}54 \pm 0{\cdot}02$ gm./cm.², which corresponds to Hρ 12,000.

Radium E.—Many range estimates have been made and are best shown in a table (V). Choosing 0·475 gm./cm.² as the range to which Varder's and Madgwick's data may be applied we find that Hρ 5100 is the end-point of the β-ray spectrum.

Kovarik and McKeehan¶ have obtained a distribution curve of the rays of radium E by using magnetic deflection and a point-counter. This curve falls rapidly towards Hρ 5500 but extends as far as Hρ 8000. The latter is probably due to scattered β-rays. It should be noticed that for radium C they found a similar extension of the distribution curve to Hρ 16,000. Madgwick** gives Hρ 5000 for the end-point of the ray spectrum of radium E, although his distribution curve would justify choosing a slightly higher value. Champion (*loc. cit.*) finds the end-point to be about Hρ 5500, using magnetic deflection and an expansion chamber.

* 'Z. Physik,' vol. 17, p. 54 (1923).
† 'Ann. Physik,' vol. 21, p. 609 (1906).
‡ 'Phys. Z.,' vol. 8, p. 361 (1907); vol. 10, p. 929 (1909).
§ 'Proc. Roy. Soc.,' A, vol. 87, p. 487 (1912).
‖ 'Phys. Rev.,' vol. 35, p. 1559 (1930).
¶ 'Phys. Rev.,' vol. 8, p. 574 (1916).
** 'Proc. Camb. Phil. Soc.,' vol. 23, p. 982 (1927).

Table V.

Observer.	Effective range (gm./cm.²).				
	Paper.	Aluminium.	Copper.	Tin.	Lead.
H. W. Schmidt*	—	0·50	0·48	0·47	0·45
J. A. Gray†	0·477	—	—	—	—
Douglas‡	0·474	0·460	0·432	0·395	0·354
G. H. Aston§	—	—	—	—	0·40
Feather‖	0·475	—	—	—	—
Wang¶	—	—	0·47	—	—

* 'Phys. Z.,' vol. 8, p. 361 (1907); vol. 10, p. 929 (1909).
† 'Proc. Roy. Soc.,' A, vol. 87, p. 487 (1912).
‡ 'Trans. Roy. Soc. Can.,' III, vol. 16, p. 113 (1922).
§ 'Proc. Camb. Phil. Soc.,' vol. 23, p. 935 (1927).
‖ 'Phys. Rev.,' vol. 35, p. 1559 (1930).
¶ 'Z. Physik,' vol. 74, p. 744 (1932).

Thorium C″.—Chalmers' (*loc. cit.*) range measurements, 0·79 gm./cm.² in paper and aluminium, gives Hρ 7200 for the end-point. The writer has obtained an absorption curve in paper for the β-rays of thorium C″, which was carried out until the transmitted intensity was 3 per cent. of the initial one. The intensities I for thicknesses X will be given elsewhere. These values were plotted, logarithm I against X, and the curve fitted, by adjusting the abscissæ, to a similar one for the β-rays of radium E, obtained by Douglas (*loc. cit.*). This can be done quite accurately since the absorption curves have the same shape. The range 0·84 gm./cm.² in paper is found to be comparable with 0·475 gm./cm.² for the β-rays of radium E. The corresponding end-point of the spectrum of thorium C″ is Hρ 7550, in fair agreement with Chalmers.

Recently Terroux and Alexander (*loc. cit.*) find Hρ 9400 to be the end-point with an expansion chamber. This method is apt to give too high a value, for the reasons given in section 2, and also since a few recoil and photoelectrons due to the γ-rays of $2{\cdot}6 \times 10^6$ volts are apt to be included with the disintegration electrons.

In a recent paper,* Chalmers suggests, as an empirical rule, that the mass range of a β-ray spectrum is given by $7{\cdot}5\ \rho/\mu$, where μ/ρ is the mass absorption coefficient. This is satisfactory for uranium X_2, radium B, radium C, radium E, mesothorium 2 and thorium B. It is interesting to note that the ranges† found for the β-rays of actinium C″, thorium C″ and thorium C, using this

* 'Proc. Camb. Phil. Soc.,' vol. 28, p. 319 (1932).

† Chalmers (*loc. cit.*) concludes that the range of the β-rays of actinium C″ should be as low as 0·49 gm./cm.² through choosing an incorrect absorption coefficient.

rule and the generally accepted coefficients§ 10·7, 8·0 and 5·35 respectively, are 0·70, 0·94 and 1·40 gm./cm.^{2}. These should be compared with the experimental ones, 0–62, 0·79 or 0·84, and 0·98. The end-points corresponding to the calculated values are respectively Hρ 6600, 8200 and 11,000. This argues against the end-point of the thorium C″ spectrum being as high as Hρ 9400, but the disagreement of Hρ 11,000 with similar results for thorium C in Table VI is very striking. It seems desirable to redetermine these end-points.

Table VI contains a summary of the end-points of β-ray spectra, as determined by the three principal methods. The values in column 2 were found from the effective ranges of the β-rays. In order to give uniform values of Hρ it was necessary to decide on a set of ranges of homogeneous β-rays. The means of Varder's and Madgwick's values have been used throughout; this gives good agreement between the end-points obtained by the range and electrical methods. The order of reduction of the initial intensity of β-rays, forming an extended spectrum, by an absorbing screen of thickness equal to the range, is about the same for many of the β-ray bodies included in Table VI. This minimizes the effect of straggling and makes the ranges of these bodies closely comparable with each other. It seems, therefore, that the relative values of the end-points collected here must be more accurate than their

Table VI.

Element.	End-point.					Average energy (volts × 10^{-5})
	Hρ Range method.	Hρ Magnetic analysis.	Hρ Expansion chamber.	Hρ "Preferred."	Energy (volts × 10^{-5})	
UX_1	(1300)	(1300)	—	(1300)	(1·3)	—
UX_2	9250	(9000)	—	9250	23·2	8·2
RaB	3280	3470	—	3470	6·5	2·3
RaC	12000	12000	—	12,000	31·5	7·4
RaD	—	—	(650)*	(650)	(0·35)*	—
RaE	5100	5000	5500	5500	12·2	3·4
MsTh2	8350	6800†	—	8350	20·5	5·6
ThB	2500	2330	—	2330	3·6	0·89
ThC	8450	8900	—	8900	22·0	8·0
ThC″	7550	—	9400	7550	18·2	5·8
AcB	(2100)‡	—	—	(2100)	(3·0)	—
AcC″	6140	—	—	6140	14·0	4·8

* O. W. Richardson, 'Proc. Roy. Soc.,' A, vol. 133, p. 367 (1931).
† Yovanovitch and d'Espine, 'J. Phys. Rad.,' vol. 8, p. 276 (1927).
‡ New measurement, details of which are in course of publication elsewhere.
The values in brackets are regarded as less reliable than the others.

§ "Report of Radium Standards Committee," 'Phil. Mag.,' vol. 12, p. 609 (1931).

absolute values ; for completeness a number of values* for the average energy in the spectrum is also included.

6. *A Relation between the Disintegration Constant of a β-ray Body and the High Energy Limit of its Spectrum.*

When the logarithms of the disintegration constants† are plotted against the logarithms of the maximum energies emitted in the β-ray spectra, fig. 2, it is seen that, with the exception of atinium B, the twelve β-ray bodies given

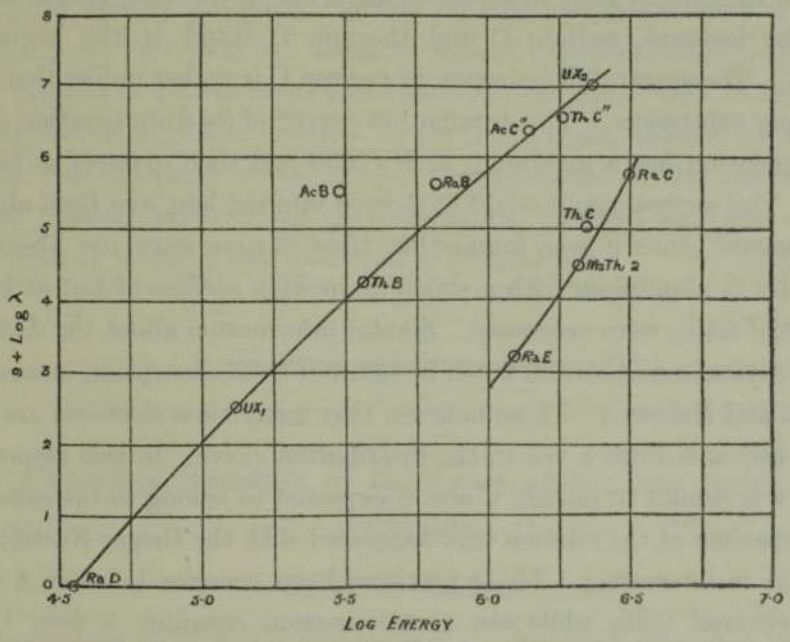

Fig. 2.

in Table VI fall into two distinct groups. (The same grouping is obtained if the maximum energy is replaced by the average energy emitted in each spectrum.)

Group I.—RaD, UX_1, ThB, RaB, AcC″, ThC″ and UX_2.

Group II.—RaE, MsTh2, ThC and RaC.

With the exception of uranium X_2 the ones in Group I are the first β-ray members of the αββα sequences and those of the αβαβ sequences. Group II contains the second β-ray members of the αββα sequences. (While the end-point of the spectrum of actinium B is rather uncertain, it definitely lies off

* Sargent, ' Proc. Camb. Phil. Soc.,' vol. 24, p. 538 (1932).

† For thorium C account has been taken of the fact that only 65 per cent. of the atoms emit β-rays.

the curve. Perhaps a third curve should be added for actinium B and actinium C″.) It is interesting to note that if the maximum energy of the thorium C spectrum is really 2·5 instead of 2·2 million volts the agreement in fig. 2 is improved. Slight evidence already given indicates that this experimental value is too low. If the relation indicated in fig. 2 applies to all β-ray bodies then the end-points of additional spectra may easily be found from their decay constants. For example, radium C″ would be expected to have an upper limit of energy at 2·2 million volts.

Certain similarities tend to separate the β-ray bodies into groups as shown here. For instance, radium C and thorium C stand at the beginning of branches. The spectral distribution of radium C is rather unlike that of most other β-ray substances. The distribution curve* of its disintegration electrons with momentum has a maximum at Hρ 2600 and then extends as far as Hρ 12,000. This general result could have been inferred long ago from absorption measurements, since it was found that these β-rays were not absorbed exponentially in aluminium with a single absorption coefficient but at least two exponential terms were necessary. Similar information about the distribution of the β-rays of mesothorium 2 can be inferred from absorption measurements by Hahn and Meitner.† These indicate that many slow electrons are emitted and the fast ones form a tail to the distribution curve. In this respect mesothorium 2 is similar to radium C and is expected to belong to the same group.

A comparison of the relation here suggested with the Geiger-Nuttall rule for α-particles is interesting. The α-particles have energies between 4 and 8·8 million electron volts while the transformation constant λ (sec.$^{-1}$) ranges from about 10^{10} to 10^{-18}. If the Geiger-Nuttall rule is expressed as $\lambda \propto (\text{energy})^x$ we find that x varies from 65 to 100. The maximum energies of the β-ray spectra range from 35,000 to 3,150,000 volts, while the transformation constant varies from 10^{-2} to 10^{-9}. For the curves of fig. 2, x lies between 3 and 7. At present the significance of this general relation is not apparent.

In conclusion, the writer wishes to express his thanks to Dr. J. A. Gray, F.R.S., and Dr. C. D. Ellis, F.R.S., for their kind interest in this work, to Mr. C. W. Clapp, B.Sc., for preparing the very active source required, and to Professor D. M. Jemmett for permission to carry out the experiments in one of the Engineering Laboratories at Queen's University.

* Gurney, ' Proc. Roy. Soc.,' A, vol. 109, p. 540 (1925).

† ' Phys. Z.,' vol. 9, p. 321 (1908).

Summary.

The range of the β-rays of uranium X_2 was found to be 1·10 gm./cm.^{2} in carbon and in aluminium. The corresponding end-point of its spectrum is 2·32 million volts. A search was made for β-rays of very high energy, but none were found. It was estimated that uranium X emits less than one β-ray for 3 million volts energy in 6500 normal ones and less than one β-ray of 7 million volts energy in 15,000 normal ones.

Collected results for the high energy end-points and average energies of twelve β-ray spectra are given. While the absolute definiteness of the end-point of a β-ray spectrum can never be proved experimentally, many experiments, designed to determine its value and to set an upper limit on the fraction of β-rays that have greater energies, in particular cases, afford a strong indication that the end-point is one of the characteristics of the spectrum. An apparent relation between the transformation constant and the maximum energy emitted in the β-ray spectrum is pointed out.

The Hyperfine Structure of the Lines of the Arc Spectrum of Rubidium.

By D. A. Jackson.

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The structure of the lines of the arc spectrum of rubidium was investigated with a reflexion echelon grating of high resolving power, the light source being a tube containing helium neon mixture at about $\frac{1}{2}$ mm. pressure and a small quantity of rubidium; this tube was fitted with external electrodes and excited with an oscillator of very high frequency. The two resonance lines—7947 and 7800—were found to possess the same fine structure, and each possessed four components: at 0·00, —0·09, —0·19 and —0·23 cm.$^{-1}$; the two outer components, 0·00 and —0·23 cm.$^{-1}$, are weak and the two inner components are strong. The lines 4215 and 4201 were found to possess three components; at 0·00, —0·09 and —0·20 cm.$^{-1}$. The line at the latter point was slightly broadened. This was presumed to correspond to the same structure as that observed in the resonance lines, the broadened line corresponding to —0·19 and —0·23 unresolved. This observed structure is