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Shape of the Beta-Ray Distribution Curve of Radium E at High Energies

LAWRENCE M. LANGER AND MARTIN D. WHITAKER
Department of Physics, New York University, University Heights, New York, N. Y.
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The beta-ray spectrum of radium E was measured by means of a magnetic spectrometer and coincident counters with special emphasis on the shape of the curve in the neighborhood of the end-point. Because of the strong source available, and the low background of the detecting mechanism, it was possible to obtain significant data much closer to the end-point than has been done heretofore. The distribution was found to end, without a tail, at $H\rho = 5330$ oersted-cm, or 1.17×10^6 electron volts. The Fermi and K-U plots of the experimental data do not give straight lines as predicted by the theory. Extrapolation of the straight part of the K-U plot gives an end-point 17 percent higher than that observed.

INTRODUCTION

SINCE the maximum energy of the beta-ray spectrum is considered, in the absence of gamma-radiation, to give the total energy of disintegration, it is of great importance to know how to determine this end-point. Experimental difficulties arise because the distribution curve approaches the energy axis gradually and, if the number of beta-particles near the end-point is not sufficiently great, the true effect may be masked by the natural background inherent in all detecting devices. Moreover, if suitable precautions are not taken, the distribution curve will have a spurious tail, due to scattered electrons, which approaches the axis asymptotically to much higher energies than the true end-point. In order to obviate these difficulties in detecting the maximum energy, it has been the practice of many experimenters to make use of the Konopinski and Uhlenbeck[1] modification of the Fermi[2] theory of beta-ray decay. In applying this theory, one extrapolates a straight line obtained from experimental data at lower energies, and gets the end-point from the intercept on the energy axis. This procedure involves the assumption that the application of the theory will give a linear relation all the way to the end-point. Recent work of Lyman[3] and Paxton[4] on the energy distribution of the electrons from Ra E and P^{32} has raised doubts as to the validity of this procedure and, indeed, raises the question as to whether the K-U theory gives a reliable description of the beta-ray process. Paxton, measuring the energy of beta-ray tracks in a cloud chamber, found an end-point for the spectrum of P^{32} at 6950 $H\rho$, which is considerably lower than the limit of 8200 $H\rho$ obtained by extrapolating the K-U curve. Lyman used a beta-ray spectrograph with single counter and obtained results on both Ra E and P^{32}. In both cases, the observed end-point was found to be less than that obtained by extrapolation of the K-U curve. The natural counting rate of the single counter used by Lyman was of the same order of magnitude as that due to beta-particles for points near the end-point. In fact, at the last measured point the natural rate was over twenty times as great as that due to the beta-particles, so that the points are considerably scattered. Since coincidence counting methods can be made to give a very low natural rate, it was thought worthwhile to try this method with the purpose of obtaining more accurate data near the end-point. Furthermore, previous work of Scott[5] had indicated an end-point at considerably higher energies than that given by Lyman. With the availability of a very strong source of Ra E, it seemed desirable to repeat the experiment.

APPARATUS

The magnetic spectrometer, with source and counter boxes in position, is shown in Fig. 1. All parts, except the lead gamma-ray absorber, are made of aluminum. The source and Geiger-

[1] E. J. Konopinski and G. E. Uhlenbeck, Phys. Rev. **48**, 7 (1935).
[2] E. Fermi, Zeits. f. Physik **88**, 161 (1934).
[3] E. M. Lyman, Phys. Rev. **51**, 1 (1937).
[4] H. C. Paxton, Phys. Rev. **51**, 170 (1937).
[5] F. A. Scott, Phys. Rev. **48**, 391 (1935).

Müller counters are contained in separate boxes, which fit into fixed positions in the spectrometer.

The radium E was deposited on the upper surface of a piece of thin sheet nickel 0.2 cm wide and 1.5 cm long. The source was placed in the position S and tilted so that its projection on the plane AB was 0.10 cm. The defining slit, AB, was 0.3 cm wide and 1.0 cm long. The perpendicular distance from the middle of the source to the plane AB was 1.50 cm. The radius of curvature of the instrument as measured from the center of the source to the center of the slit, CD, was 9.99 cm.

The beta-particles, bent by the magnetic field, pass through the openings in the scattering baffles, EF and GH, and enter the counter box through the slit, CD (0.05 cm wide), which is in the focal plane of the beam. The beta-particle beam, as defined by the slit, AB, is of the same width at the baffle positions as the openings EF and GH. The space between the side plates of the spectrometer is 2.54 cm; the length of all slits and baffles is 1.0 cm.

The spectrometer was placed between the cylindrical pole pieces of an electromagnet capable of supplying 1500 oersteds in the 3.5 cm gap. The radius of the pole faces was 15 cm and the spectrometer was mounted in such a way that the line between the slits AB and CD was on the diameter of the pole face. The magnetic field was

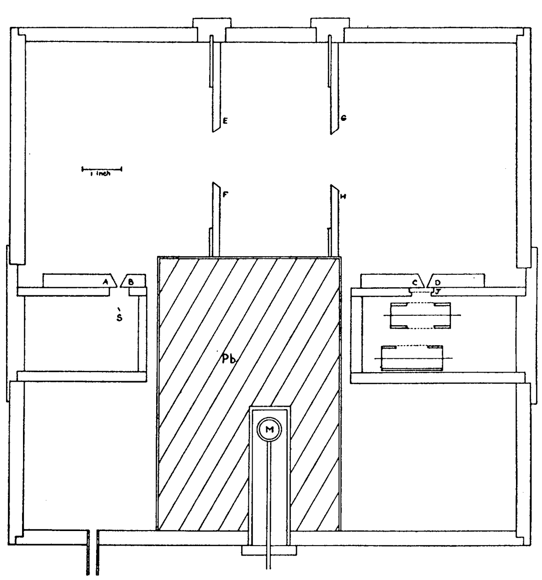

FIG. 1. Magnetic spectrometer.

measured by means of a flip coil and ballistic galvanometer which were calibrated with the help of a standard mutual inductance. The primary current in the inductance was measured by means of a precision potentiometer and standard resistance, and a curve plotted showing H as a function of the current in the magnet. The entire region of the magnetic field traversed by the electrons was found to be uniform to within 0.5 percent. Field readings were taken with the flip coil in position M and checked against values obtained from measurement of the magnet current taken simultaneously. Readings of both types, taken at the beginning and end of each observation, were found to agree to better than 1 percent. A further check was obtained by measuring the $H\rho$ value of the strong line of the radium B spectrum. The "head" of the line was observed at $H\rho = 1930$ in good agreement with the results of Ellis,[6] Scott,[7] and Rogers.[8]

The spectrometer is exhausted by a Cenco Hyvac pump which is kept in operation during an experiment. Thus, there is no material in the path of the electron beam until it reaches the (0.001″) aluminum window "J" on the counter box. This box and the G-M tubes are shown to scale in Fig. 1. The entire box is filled with argon to a pressure of 6 cm of mercury. The aluminum counters are cut away and covered by thin aluminum foil (0.00025″ thick) as shown by the dotted lines in the figure. The G-M tubes are rigidly mounted on the end of the box by means of hard rubber rods. Separate high potential leads and leads from the central wires are brought out of the box through hard rubber insulators.

The pulses from the two G-M tubes are amplified and coincidences selected by the circuit arrangement shown in Fig. 2. The amplifier was built for general utility and consequently was arranged so that it could be used as two separate amplifiers having the same or different outputs or as a coincidence selecting apparatus. The RC values of the several grid circuits are quickly adjustable for various types of work by replacing coupling condensers mounted so as to be readily

[6] C. D. Ellis, Proc. Roy. Soc. **143**, 352 (1934).
[7] F. A. Scott, Phys. Rev. **46**, 633 (1934).
[8] F. T. Rogers, Phys. Rev. **50**, 515 (1936).

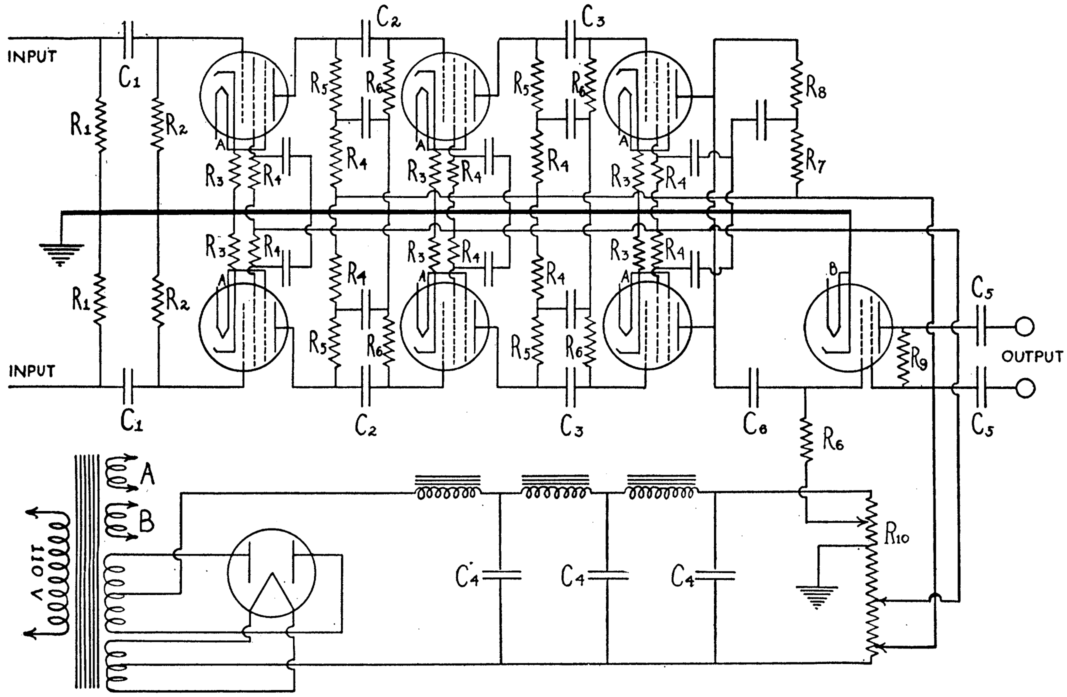

FIG. 2. Amplifier circuit.

$R_1 = 3.4\times10^{10}$ ohms	$R_9 = 7000$ ohms
$R_2 = 10^7$	$R_{10} = 20{,}000$ ohms
$R_3 = 2500$ ohms	$C_1 = 5\times10^{-11}$ farad
$R_4 = 50{,}000$ ohms	$C_2 = 3\times10^{-9}$ farad
$R_5 = 250{,}000$ ohms	$C_3 = 1.25\times10^{-10}$ farad
$R_6 = 100{,}000$ ohms	$C_4 = 8\times10^{-6}$ farad
$R_7 = 25{,}000$ ohms	$C_5 = 10^{-7}$ farad
$R_8 = 125{,}000$ ohms	$C_6 = 4.5\times10^{-10}$ farad

accessible. With the circuit constants used in this work and shown with Fig. 2, the amplification is great enough so that large pulses saturate the plate current in the second stage tubes and *all* the pulses up to counting rates of several thousand per minute produce plate current cut-off in the third stages. Therefore, the pulses fed to the grid of the selector tube are always of the same size so there is no chance of recording a large sized pulse from a single counter as a coincidence or of missing the coincidence of two small pulses. At the same time, the duration of the pulses on the selector tube grid is short enough so that chance coincidences are rare even at high single tube counting rates. A voltage stabilizer of the type designed by Evans[9] supplied the high potential for the G-M tubes. The apparatus was monitored, at all times, by a cathode-ray oscillograph. The counts were recorded on a thyratron "scale of four" counter.

[9] R. D. Evans, Rev. Sci. Inst. **5**, 371 (1934).

PROCEDURE AND RESULTS

1. High energy particles

In some preliminary experiments it was found that there were some counts for $H\rho$ values as high as 6500. In view of the fact that these counts might be due to particles scattered into the counters from lower energy regions we performed two sets of experiments designed to test this possibility. In the first set, certain adjustments were made on the baffles, *EF* and *GH*. It was found that, when the baffle, *EF*, was adjusted so as to pass a beam of electrons defined by the slit, *AB*, and having the desired energy, the high energy tail practically disappeared. On the other hand, if the baffle, *EF*, was adjusted to be wider than this beam, the high energy tail was much more pronounced. With proper adjustment of *EF*, it was found that the adjustment of *GH* produced no significant effect. This experiment lends weight to the view that the high energy tail is due to scattering.

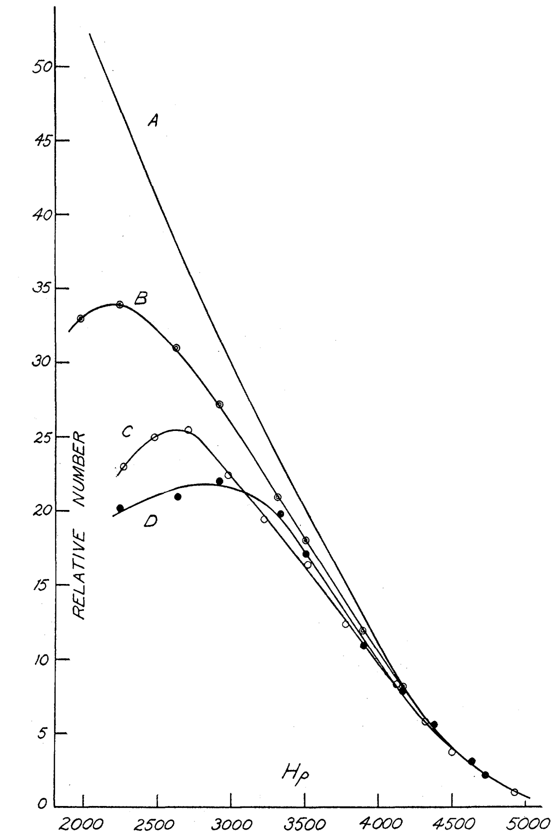

FIG. 3. Beta-ray spectrum of radium E. Curves B and D were obtained with an Al window 0.001″ thick; curve C with an additional Al; foil 0.001″ thick. Curves B and C are for data taken with a single counter; curve D is for coincident counter data. Curve A shows the distribution corrected to zero window thickness.

In order to test this possibility further, a special counter box was constructed in which the wall of the second counter had a thickness of 0.0625″ of aluminum. The combined thickness of the foils (0.439 g/cm^2) should, according to the data of Varder,[10] stop all particles of energy less than $H\rho=5025$. These counters had an unusually low coincident background of 0.17 count per minute, so that, with the strong source used, a rather weak effect should have been detectable. The data in Table I shows that no counts above the background were obtained for values of $H\rho$ greater than 5330. The decrease in the counting rate below $H\rho=5200$ is due to the presence of the thick counter wall.

It would appear, therefore, from these experiments, that the high energy particles reported by Scott[5] and others are probably due to scattering.

2. Shape of the distribution curve

The investigation of the distribution curve near the end-point was carried out using the thin wall counter system described in an earlier section of this paper. The data was taken starting at the high energy end of the spectrum and working toward lower energies. In order to preclude the possibility that the recording mechanism might not follow at high counting rates, no points were taken for which the rate was greater than 1000 per minute. The data was then checked by taking points, between those already taken, for increasing energies. This procedure was repeated from time to time relying on the decay of the source for extension of the data toward lower energies. A sufficient overlapping of the energy regions was obtained to rule out long time fluctuations.

Both single counter and coincident counter data were used in determining the complete shape of the curve (to 1900 $H\rho$). The coincident observations and those with the single counter were taken for each setting of $H\rho$. The single counter used was the one nearest the slit, CD. By introducing an extra thickness of 0.001″ of aluminum, data was obtained from which the curves could be corrected to zero window thickness. The results are shown in Fig. 3. All ordinates are expressed in relative number divided by H.

The high energy end of the spectrum is shown drawn to a larger scale in Fig. 4. An idea of the accuracy of the ordinates in the neighborhood of the end-point is best obtained from a sample of the uncorrected data from one set of observations. At $H\rho=5085$, 1840 particles were counted at a rate of 46.0 per minute; at $H\rho=5265$, 424 particles at 6.1 per minute; at $H\rho=5295$, 278 particles

TABLE I. *Counts for beta-particles near the high energy limit.*

$H\rho$	Counts/min.
5160	2.0 ±0.45
5200	3.1 ±0.32
5270	0.80±0.12
5310	0.66±0.07
5330	0.23±0.09
5370	0.17±0.04
5430	0.14±0.04
7810	0.17±0.05
8230	0.15±0.05

[10] Varder, Phil. Mag. **29**, 726 (1915).

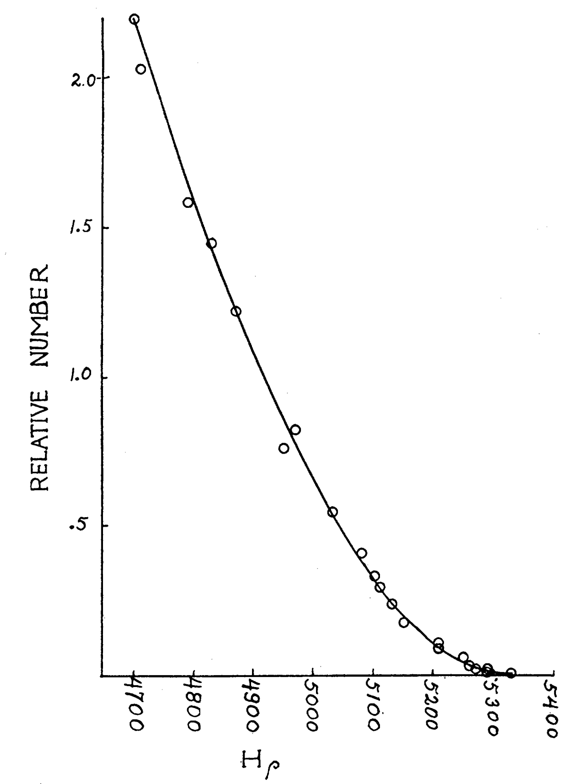

FIG. 4. Ra E spectrum showing distribution near the end-point.

at a rate of 4.6 per minute. The background was 2.5 counts per minute. The value obtained for the end-point of the radium E spectrum is $H\rho = 5330 \pm 70$ oersteds−cm, or 1.17 Mev. This agrees with the value recently obtained by Lyman.[3]

Fermi and K-U plots of the experimental data near the end-point are shown in Fig. 5 in which $(N/f)^{1/\alpha}$ is plotted against $(1+\eta^2)^{\frac{1}{2}}$ where $f = (\eta + 0.355\eta^2)$, $\eta = H\rho/1700$, $\alpha = 2, 4$ for Fermi or K-U, respectively. The extrapolated K-U end-point comes at 6250 $H\rho$ whereas the observed end-point is 5330 $H\rho$. The K-U plot was made without considering the fact that radium E is a forbidden transition. A correction to the theory

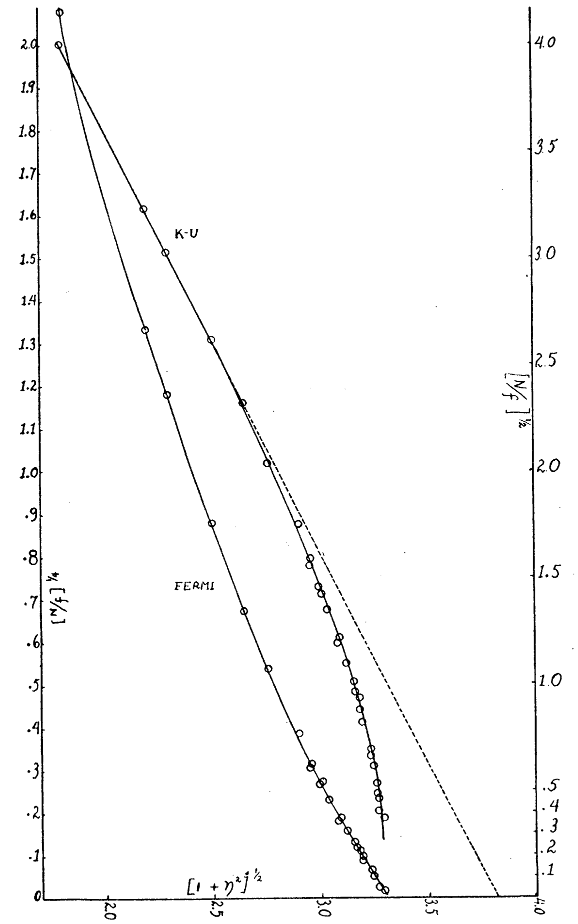

FIG. 5. Fermi and Konopinski-Uhlenbeck curves for the Ra E spectrum.

has been worked out by Lamb[3] and Pollard[11] from which it appears that the extrapolated end-point is brought into somewhat better although not complete accord with the experimental value.

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[11] W. G. Pollard, Bull. Am. Phys. Soc. February meeting, Abs. 1.