DET KGL. DANSKE VIDENSKABERNES SELSKAB
MATEMATISK-FYSISKE MEDDELELSER, BIND XXIII, NR. 8

DEDICATED TO PROFESSOR NIELS BOHR ON THE OCCASION OF HIS 60TH BIRTHDAY

IONIZATION MEASUREMENTS ON SINGLE RECOIL PARTICLES FROM Po, ThC, AND ThC′

BY

B. S. MADSEN

KØBENHAVN
I KOMMISSION HOS EJNAR MUNKSGAARD
1945

CONTENTS.

Printed in Denmark.
Bianco Lunos Bogtrykkeri A/S

REPRINTED 1948 TUTEIN OG KOCH

The first determinations of the energy in α-recoil were performed by Makower and Russ (1) and by Evans and Makower (2); the values found are in good agreement with those calculated from the mass ratio. Wertenstein (3) has examined the ionization of the recoil atoms; in contradistinction to the specific ionization curve of the α-particles, the specific ionization curve of the recoil particles shows a uniform decrease along the track and, for the ratio $\frac{E_R}{E_\alpha}$ in air, where E_R and E_α are the energy loss per pair of ions of the recoil particle and the α-particle, respectively, Wertenstein found a value between 2 and 8. By means of ionization chamber measurements, Gerthsen and Grimm (4) found $\frac{E_R}{E_\alpha}$ in air to be almost one. Wertenstein used RaC, while Gerthsen and Grimm applied ThC′ to their measurements.

In the present paper, an experiment will be described which gives $\frac{E_R}{E_\alpha}$ in argon with a small (5 %) admixture of air.

I. Method.

In view of the small amount of ions produced by the recoil particles, the measurements were carried out with a proportional counter, *i. e.* a Geiger-Müller counter for which the working potential was chosen somewhat smaller than the potential used for actual counting. Ions produced by a primary ionization in the counter will give rise to a secondary ionization due to collision and, in this way, an amplification is obtained which is effective only for the ions and not for induced electrical disturbances. In the combination of a proportional counter with a valve amplifier, the background of electrical noise can be reduced to a higher degree than in an ordinary ionization chamber in connection with a valve amplifier. This method of ionization measurements was suggested by RUTHERFORD and GEIGER (5).

WERNER (6) has shown that ions produced by irradiation of the inner side of the proportional counter wall with ultraviolet light are amplified proportionally; he further pointed out the relation between the proportional counter and the G.-M. counting tube. GEIGER (7) too has found a proportional amplification; α-rays from ThC-C′ were sent into the counter perpendicular to and directed against the wire. When particles hit the wire, the impulses produced were precisely half as great as those which originated from particles having passed through the whole diameter. This shows that the specific ionization can be regarded as a constant on the part of the α-particle track inside the counter. The experiment gives, however, no information about the amplification as a function of the locality where the primary ions are formed.

In the present experiments, the counter voltage was taken from a high tension rectifying supply giving 2800 volts d.c. 1260 volts were laid over a filter consisting of resistances and condensors. The remaining 1540 volts were stabilized by means of 11 small neon lamps. This high tension supply, which in this Institute is much used in connection with G.-M. counters, appeared to give sufficiently constant voltage. In all measurements, the voltage over the counter was chosen so that a variation of 1.5 volts caused a variation in the amplification of about 10 %. Under these conditions it was possible to obtain distinct maxima when the number of α-particle impulses was plotted against their magnitude (cf. the example in Fig. 2) and the measurements could be reproduced even after several hours.

The voltage impulses from the proportional counter were amplified further by a resistance capacity coupled valve amplifier containing two stages and a power-stage operating a mechanical oscillograph. The impulses were registered on a slip of electrocardiograph paper. Simultaneously, the amplified impulses could be observed on a cathode ray oscillograph. By means of potentiometers in the anode resistances, the total amplification could be varied within wide limits. The proportionality of the amplifier was checked by means of artificial impulses. At the highest amplification used the artificial impulses after the amplification showed a variation in size of $\pm$ 1.5 %.

Specific ionization curves for α-particles in air have been published by HENDERSON (8) and by JENTSCHKE (9). HENDERSON gives the position on the α-ray track by measuring the distance from the α-source; JENTSCHKE, on the other hand, measures the distance from the end point of the track of the single α-ray. As it would be expected from this difference in method, JENTSCHKE's curve shows for great residual ranges relatively higher values (up to 5 %) than HENDERSCN's curve. In the following experiments, the conditions were similar to those of HENDERSON and, therefore, HENDERSON's curve was taken as a basis of the comparative measurements. The number of ions per mm. produced by α-particles in argon as a function of the range can be obtained in a simple way from HENDERSON's measurements in air, since, according to GIBSON and GARDINER (10), the stopping power of argon relative to that of air as well as the energy loss per pair of ions is almost constant over the whole length of the range.

The number of ions produced in a fraction of the α-particle track was determined by the present author in arbitrary units (denoted as "Henderson units" in Table 3) by measuring the corresponding area under the ionizing curve. As it will be mentioned later, the measurements on ThC-C′ α-particles were found to be in complete agreement with the values which should be expected from the Henderson curve.

II. The Proportional Counter as a Measuring Instrument.

As the multiplication of the ions in the proportional counter takes place in the vicinity of the wire, it is to be expected that the amplification of the primary amount of ions is nearly independent of the locality where the ions are formed. This was examined by means of a proportional counter constructed as shown in Fig. 1. The tube was chosen so long that the variations of the electrical field at the ends did not cause essential irregularities. The counter was closed by two ebonite discs, through one of which four glass tubes were introduced at different distances from the axis. In each glass tube two diaphragms with circular apertures 0.5 mm. in diameter were mounted at a distance of 50 mm. Over the exterior diaphragms thin mica foils (1.3 mg./cm.²) were placed. All joints were sealed with picein. The counter wire, a platinum wire 0.15 mm. in diameter, was introduced through tapered glass tubes. Grounded guard rings screened it against creeping currents.

The counter was filled with argon with an admixture of 5 % air. Pure argon appeared to be inexpedient. Even small con-

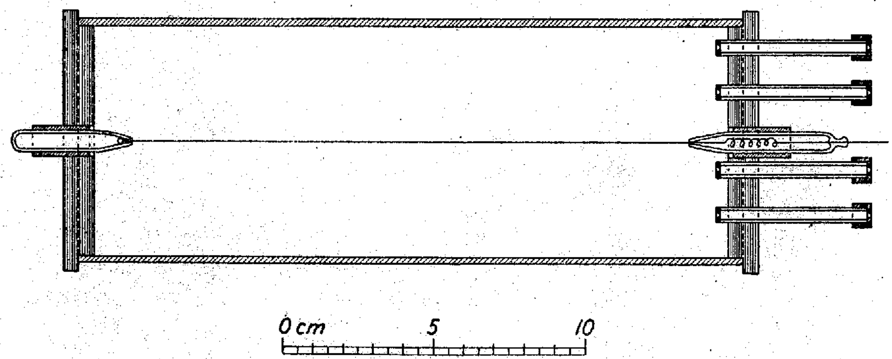


Fig. 1.

taminations influenced greatly the mobility of the ions and, hence, the amplification yielded by the proportional counter, and materials such as ebonite and picein will for a long time give off gases. When air was added to the filling gas the proportional counter worked unchanged for several weeks.

A ThC-C′ preparation was alternately placed in front of the four mica windows, the distance from the window being kept constant. When the α-particles from ThC and ThC′ passed through the whole length of the counter, statistics were produced like that in Fig. 2. Table 1 gives the mean impulse sizes relative to the four distances of the α-beam from the axis. The values

Table 1.

Distance from the axis (mm.)		9.0	16.5	24.0	31.5
Deflections (mm.)	ThC′	26.5	26.6	26.1	25.5
	ThC	42.4	42.4	42.0	41.2

show a slight decrease with increasing distance, a decrease just exceeding the experimental error. This is possibly due to the unavoidable variations in the electrical field at the ends of the counter. Within the distances used in the following experiments the amplification can at any rate be regarded as a constant.

By placing the α-preparation at different distances from the

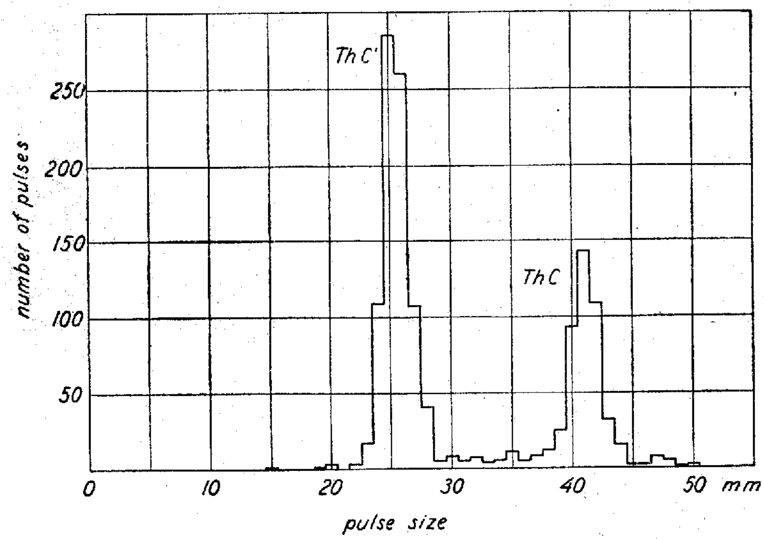


Fig. 2. Size distribution of α-particle impulses from ThC and ThC′ (3 inch counter).

axis, it was each time found that the ratio between the deflections from the ThC α-particles and the ThC′ α-particles agrees with the ratio expected from the Henderson curve within 2 %.

The amplification of the ions along the counter wire was investigated in the counter shown in Fig. 3. The counting tube, 1 inch in diameter, had a rectangular aperture, 1 mm. × 50 mm., covered by a mica foil, 1.2 mg./cm.^{2}. The counter wire, a platinum wire 0.15 mm. in diameter, was covered by steel tubes, 0.8 mm. in diameter, except for a portion of 34 mm. in the middle of the wire. The ends of the steel tubes were carefully rounded. From a ThC-C′ preparation a narrow beam of α-rays was sent into the counter at right angles to the wire. The preparation could be moved parallel to the counter axis and the position was read with an accuracy of $^1/_{20}$ mm.

The α-particles were sent into the counter partly diametrically, partly along a secant. The two cross-sections and the cor-

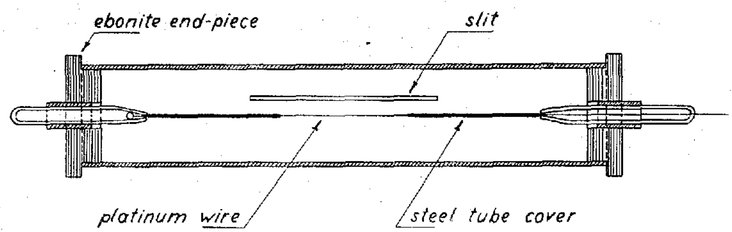


Fig. 3.

responding curves giving the variation of the amplification are shown in Fig. 4. The open and the full circles correspond to the arrangements I and II, respectively. From curve I the average amplification is 63 % of the maximum amplification.

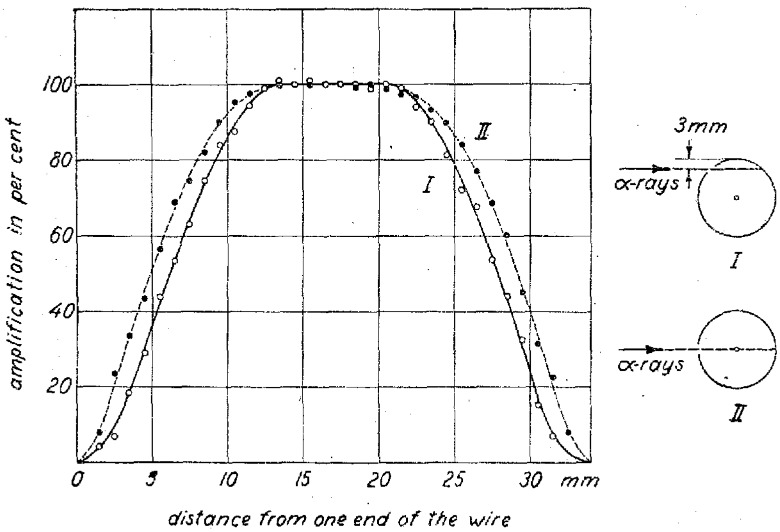


Fig. 4. Variation of the amplification along the counter wire (1 inch counter).

III. Recoil Particle Ionization Measurements.

The ionization of the recoil particles was measured by a coincidence arrangement consisting of a proportional counter and two sealed G.-M. counters enclosed in a T-shaped glass vessel closed by brass flanges. The arrangement is shown in Fig. 5. The proportional counter was made from a 1 inch brass tube, and a platinum wire, 0.15 mm. in diameter, was placed along its axis. As, in the counter shown in Fig. 3, the wire was covered by two steel tubes, 0.8 mm. in diameter, with the exception of 34 mm. in the middle. The α-particles used for comparison left the Po-α preparation as a narrow beam; subsequently, they

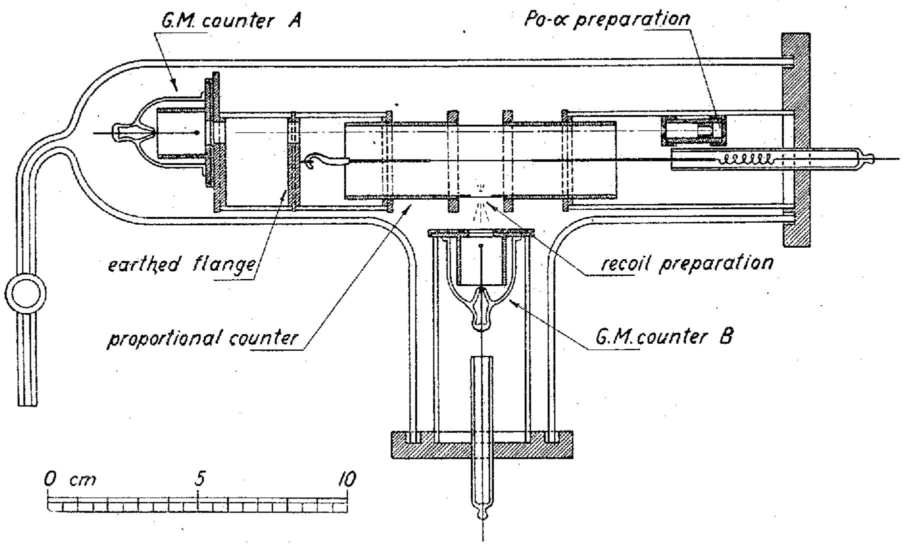


Fig. 5.

passed the proportional counter at a small distance from the wall, finally entering the G.-M. counter A through a thin mica window. In the middle of the tube, a 15 mm. piece was turned down to a wall thickness of 0.1 mm., where a hole, 5 mm. in diameter, was drilled; over the hole, a mica foil was bent which carried the source emitting the recoil particles. The mica foil was made conducting, so that the electrical field in the proportional counter was kept completely undisturbed. The α-particles from the "recoil source" could penetrate the mica foil and enter the G.-M. counter B. The windows of both G.-M. counters weighed 1.4 mg./cm.^{2}.

The recoil source was made as follows. A half-transparent layer of platinum mixed with tungsten was evaporated on a mica foil, 1.2 mg./cm.^{2}; over this, a considerably thicker silver ring was evaporated to insure a conducting connection with the counting tube. From an activated platinum wire, the radioactive deposit was evaporated on the platinum layer in a spot, 1.5 mm. in diameter. For making ThC-C′ preparations, the platinum wire was exposed to Th-Em and rinsed by heating *in vacuo* to 250° C. Activation with polonium was performed by electrolysis in a solution containing pure polonium. Donat and Phillips (11) made ThB preparations by evaporation and found that only

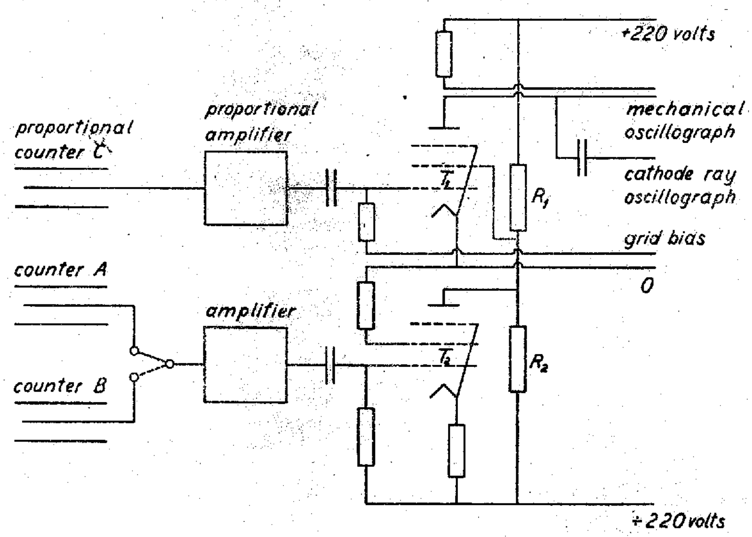
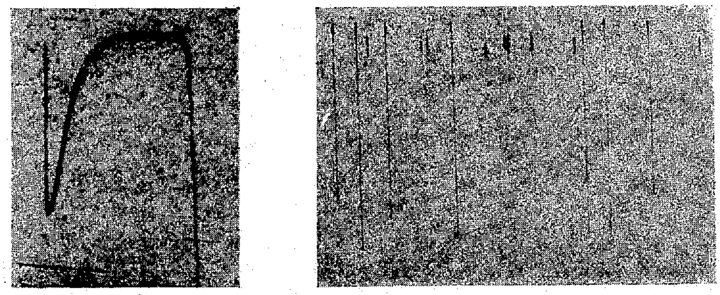


Fig. 6.

2—6 °/₀ of the ThC atoms, produced by β-ejection from ThB, would leave the layer due to their recoil energy.

By means of a small change in the circuit, the proportional amplifier was adapted to amplify only such impulses from the proportional counter which coincided with impulses from a G.-M. counter. The diagram is shown in Fig. 6. In the normal state, tube T_2 is open, and the screen grid potential of tube T_1 is so much negative that the tube is completely blocked. An impulse from one of the G.-M. counters will block T_2, and the screen grid of T_1 gets is working potential determined by the resistances R_1—R_2; subsequently, T_1 gives a proportional amplification to an impulse from the counter C. When T_2 is again opened, T_1 is blocked. Fig. 7a shows the course of potential on the anode of T_1 during a coincidence; the figure is taken from a cathode ray oscillograph. Fig. 7b shows the deflections of the mechanical oscillograph registered on photographic paper. The voltage variations on the screen grid of T_1 are made so swift that they appear only weakly on the registering slip; the slow deflections due to the proportional counter, however, stand out distinctly. The zero line is indicated by impulses from a G.-M. counter, which are not followed by impulses from the proportional counter. The



a *b*

Fig. 7.

impulses are partly due to a γ-ray source placed in the vicinity of the apparatus.

The coincidence arrangement picks out for measurement only those recoil particles which start within the cone determined by the active spot and the aperture of counter B. These recoil particles start at approximately right angles to the layer, and there is but little risk of missing branches on the track as those indicated by Akiyama (12) and Joliot (13).

In order to make direct comparisons between α-particle and recoil particle impulses possible, the coincidence arrangement was used in both cases and the G.-M. counters A and B (Figs. 5 and 6) were switched on alternately.

The measurements were carried out with recoil particles from polonium at counter pressures of 7.4 cm. and 9.2 cm. Hg and with recoil particles from ThC and ThC′ at a pressure of 9.2 cm. Hg. The distribution curves obtained are shown in Figs. 8 and 9. The width of the maxima of the recoil distribution curves was found to be a constant (about 20 %) on all curves taken; experiments with evaporated aluminium instead of the W-Pt mixture as a support of the radioactive source yielded distribution curves

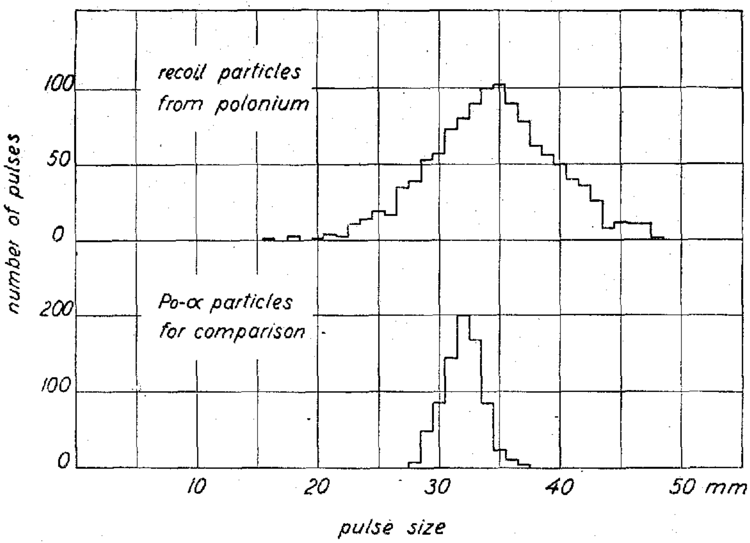


Fig. 8. Impulse size statistics taken at a pressure of 7.4 cm. Hg (argon + 5 %) air). The ratio amplification of the recoil particles to that of the α-particles is 9.8 : 1.

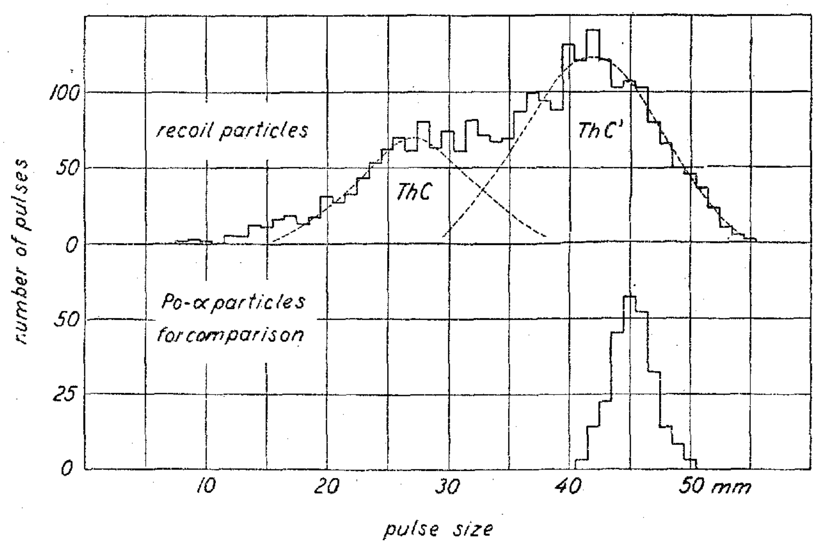


Fig. 9. Impulse size statistics taken at a pressure of 9.2 mm. Hg (argon + 5 %) air). The ratio amplification of the recoil particles to that of the α-particles is 5.0 : 1.

Table 2.

Particles	Pressure cm. Hg	Positions of the maxima mm.		Ratio of amplifications
		Recoil particles	Po α-particles	
Po recoil	7.4	34.5	32.0	9.8 : 1
	9.2	34.6	39.0	9.8 : 1
ThC recoil	9.2	27.0	45.4	5.0 : 1
ThC′ recoil	9.2	42.0	45.4	5 0 : 1

of exactly the same shape. Table 2 gives the position of the maxima of the distribution curves of the recoil particles and the α-particles used for comparison. Table 3 presents the ionization in "Henderson units". In the case of α-particles, they were found as described before; for recoil particles, the figures represent the ionization to be expected if the formation of a pair of ions by a recoil particle would claim the same energy as provided by an α-particle. E. g. for polonium recoil particles the figure 42.2 is obtained by dividing the area under the ionization curve until the residual range of 36.7 mm. (the range of Po α-particles) by

Table 3.

Particles	Pressure cm. Hg	Fraction of track in air at 0° and 760 mm. Hg mm	Energy keV*	Henderson units	$\frac{E_R}{E_\alpha}$		Number of ions
Po-α	7.4	5.5– 8.5	..	134	..		..
	9.2	6.9–10.6	..	171	..		..
Po recoil	7.4	..	104	42.2	4.5	4.4	950
	9.2	..			4.3		
ThC recoil	9.2	..	118	48.2		3.8	1240
ThC′ recoil	9.2	..	170	68.5		3.4	2000

*) The values are calculated on the basis of the corresponding α-particle energies, taken from LIVINGSTON and BETHE (14).

the mass ratio $\frac{206}{4}$. From these values, the ratio $\frac{E_R}{E_\alpha}$ is calculated, E_R standing for the average energy which is required for a recoil particle to make a pair of ions; E_α stands for the corresponding value for α-particles. The uncertainty of the values of $\frac{E_R}{E_\alpha}$ is estimated to be $\pm 6\,\%$.

Finally, Table 3 gives the mean number of ions produced by the three kinds of recoil particles. In the calculations, E_α is put

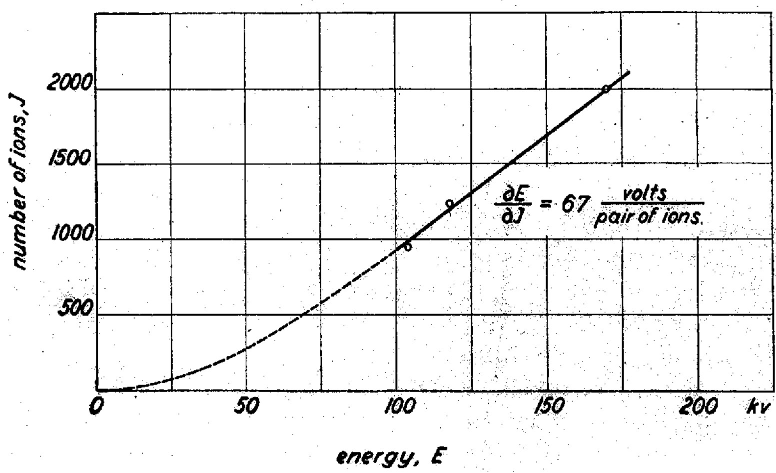


Fig. 10.

equal to 25 volts. In Fig. 10, the total number of ions is plotted against the energies, E, of the recoil particle. From the inclination of the line drawn through these points we get for E between 100 kV. and 170 kV.

$$\frac{\partial E}{\partial I} \approx 67 \text{ volts per pair of ions.}$$

In the vicinity of $E = 0$, $\frac{\partial E}{\partial I}$ will be very great, and the curve must be horizontal. On the other hand, investigations of fission fragments (15) have shown that heavy particles with high energies ionize gases with the same energy per pair of ions as do α-particles; for high energies the curve of Fig. 10 must therefore be expected to continue as a straight line with $\frac{\partial E}{\partial I} = 25$ volts per pair of ions.

Summary.

By means of a proportional counter and a proportional coincidence arrangement the ionization of single recoil atoms from Po, ThC, and ThC′ was measured.

For producing a pair of ions in argon, the recoil particle was found to require on an average 4.4; 3.8; and 3.4 times, respectively, the energy required by the α-particles.

The energy-ionization curve for heavy particles gives within the energy interval 100 kV—170 kV: $\frac{\partial E}{\partial I} = 67$ volts per pair of ions.

The author wishes to express his gratitude to the director of this Institute, Professor Niels Bohr, for having put the problem. My thanks are further due Professor J. C. Jacobsen for valuable advice and encouraging interest during the work.

Institute of Theoretical Physics,
University, Copenhagen.

References.

1) Makower and Russ, Phil. Mag. **20**, 875, 1910.
2) Evans and Makower, Phil. Mag. **20**, 822, 1910.
3) Wertenstein, Recherches expérimentales sur le recul radioactif. Thèse. Paris 1913.
4) Gerthsen and Grimm, ZS. f. Phys. **120**, 476, 1943.
5) Rutherford and Geiger, Proc. Roy. Soc. London **A 81**, 141, 1908. Phys. Zs. **10**, **1**, 1909.
6) Werner, ZS. f. Phys. **90**, 384, 1934. ZS. f. Phys. **92**, 705, 1934.
7) Geiger, Handbuch. d. Phys. **20**, **2**, 162.
8) Henderson, Phil. Mag. **42**, 538, 1921.
9) Jentschke, Wien. Ber. II a, **144**, 151, 1935.
10) Gibson and Gardiner, Phys. Rev. **30**, 542, 1927.
11) Donat and Phillips, ZS. f. Phys. **45**, 512, 1927.
12) Akiyama, Japan J. of Phys. **2**, 287, 1924.
13) Joliot, Journ. de Phys. (**5**), **7**, 219, 1934. C. R. **192**, 1105, 1931.
14) Livingston and Bethe, Rev. of mod. Phys. **9**, 266, 1937.
15) N. O. Lassen, unpublished.

Indleveret til Selskabet den 24. Juni 1945.
Færdig fra Trykkeriet den 19. September 1945.