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The Beta-Ray Spectra of Mg^{27}, Cu^{62} and the Nuclear Isomers of Rh^{104}

E. C. CRITTENDEN, JR.*
Cornell University, Ithaca, New York
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The beta-ray spectra of several radioactive elements have been investigated by means of a cloud chamber in a uniform magnetic field. The spectrum of Mg^{27} gave an upper limit of 1.8 Mev on the basis of 586 tracks. The spectrum of Cu^{62} gave an upper limit of 2.6 Mev on the basis of 803 tracks. The spectra of the two nuclear isomers of Rh^{104} were found to have the same upper limit and the same shape within experimental error. Their upper limits are 2.3 Mev on the basis of 524 and 529 tracks. The similarity in shape of the two spectra indicates that a direct beta-transition from the 4.37-minute level does not occur to any appreciable extent and that as far as can be determined by this work the disintegration of the 4.37-minute isomer proceeds entirely by a gamma-ray transition to the ground state of Rh^{104} followed by a beta-transition to the ground state of Pd^{104}.

THE use of a cloud chamber in a magnetic field for the measurement of beta-ray spectra is ultimately limited by the scattering of the beta-particles in the gas which must necessarily fill the chamber and by the practical limitation on the number of tracks observable in a reasonable length of time. However, the method will give quite dependable spectra if sufficient care is exercised in the choice of tracks to be measured and if a fairly large number of tracks are utilized. This method was used to obtain the spectra of several beta-radioactive elements. The spectra of Mg^{27} and Cu^{62} have been investigated as well as the spectra of the two nuclear isomers of Rh^{104}. The latter two spectra are of particular interest as they give information concerning the course of the disintegration of the isomers.

Apparatus

The essential features of the design of the cloud chamber were taken from Kurie's modification[1] of the pressure operated sylphon chamber of Dahl, Hafstad and Tuve.[2] The active region of the chamber was 17 cm in diameter and 2.5 cm deep. The chamber was filled with helium at atmospheric pressure. Helium was employed as the gas with which to fill the chamber in order to decrease the scattering of the beta-particles. This gas was selected in preference to hydrogen as the low viscosity of the latter allowed the liquid droplets to fall too rapidly to permit sharp photography. Ethyl alcohol was employed as the liquid vapor in the chamber.

The magnetic field for deflecting the beta-particles was produced by a pair of Helmholtz coils capable of producing 900 oersteds under intermittent operation. The field was carefully checked for uniformity and found to be uniform within 2 percent over the visible region of the chamber. The magnitude of the field was measured by two independent methods agreeing within 0.5 percent.

* Now at Case School of Applied Science.

[1] F. N. D. Kurie, Phys. Rev. **47**, 97 (1935).
[2] O. Dahl, L. R. Hafstad and M. A. Tuve, Rev. Sci. Inst. **4**, 373 (1933).

Since the radioactivities investigated all had fairly short half-lives, the samples could not be placed directly in the cloud chamber. Instead, the samples were placed in a "well" in the top plate of the chamber and the beta-particles admitted through a thin aluminum window. This window had a thickness of 7 mg/cm^2 which was estimated to be equivalent to 0.01 Mev for electrons of 2 Mev.

The illumination for the cloud chamber was furnished by a bank of eight incandescent lamps of a type intended for series operation as street lamps on 32 volts and 6.6 amp. A lamp of this type has a double-coiled line filament and gave a fairly parallel beam when used with a cylindrical condensing lens. A Sept camera with an f: 3.5 lens was used for the photography. After development, the negatives were projected through a similar camera to give a full size image as determined by a template. No detectable distortion was introduced in the projection. The tracks were classified into groups differing in radius of curvature by 0.5 cm by the usual method of matching them to a series of circles. The lack of exact knowledge of the position of the tracks as a consequence of nonstereoptic photography introduced a small error in the radius of curvature. The maximum error from this cause was calculated to be 2.4 percent.

Several criteria were established which each track was required to satisfy in order to be considered acceptable for measurement. Most of these criteria have been discussed at some length by other writers[3, 4] and will be merely listed here. The criteria were as follows: (1) The track must be of the proper direction of curvature. (2) The track must be visible to 7 cm or more from the aluminum window. (3) The track must be visible to within 1 cm of the aluminum window. (4) The track must appear to have its origin in the source. (5) The track must suffer no detectable deflection from a circular path in 7 cm. In addition to the above criteria tracks which showed noticeable diffusion of the ions were excluded.

[3] E. R. Gaerttner, J. J. Turin and H. R. Crane, Phys. Rev. **49**, 793 (1936).

[4] J. R. Richardson and F. N. D. Kurie, Phys. Rev. **50**, 999 (1936).

The spectrum of Mg^{27}

Metallic magnesium was bombarded by 1.2-Mev deuterons from the cyclotron for the purpose of studying the spectrum of the 10-minute activity. The accepted reaction, assigned by Henderson,[5] is:

$$_{12}Mg^{26}+{}_1H^2\rightarrow{}_{12}Mg^{27}+{}_1H^1,$$
$$_{12}Mg^{27}\rightarrow{}_{13}Al^{27}+\beta+\gamma.$$

Na^{24}, of 14.8 hours half-life, is also formed on bombardment of Mg by deuterons. On the basis of Henderson's[5] results on the excitation functions of Mg^{27} and Na^{24}, the excitation probability of Na^{24} is estimated to be less than 0.05 percent of the excitation probability of Mg^{27} for a deuteron energy of 1.2 Mev. The Na^{24} should thus not affect the spectrum observed for Mg^{27}.

The Mg samples which were prepared for cloud-chamber measurements were first cleaned to remove the oxide coating and then bombarded directly in the deuteron beam inside the vacuum of the cyclotron chamber. The target, when bombarded, collected some deposit of carbon from the pump-oil vapor recoiled onto its surface. This carbon gave N^{13} on bombardment which has an 11-minute *positron* period and thus is easily distinguished from the Mg^{27} *electron* spectrum. For the purpose of determining the half-life, the sample was covered with a thin aluminum foil to avoid deposition of carbon and bombarded as above. The activity of the target so prepared was measured with an Edelmann

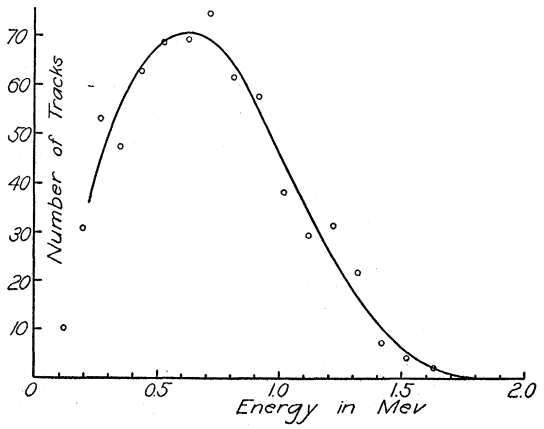

FIG. 1. Distribution in energy of 586 tracks for Mg^{27}.

[5] M. C. Henderson, Phys. Rev. **48**, 855 (1935).

electrometer and argon-filled ionization chamber. The same method of measurement was employed to obtain the data used in the other half-life determinations. For Mg, a half-life of 10.0±0.1 minutes[6] was obtained. This result is in agreement with the value of 10.25±0.25 minutes previously determined by Henderson.[4]

There were 586 acceptable tracks observed in the cloud chamber. The distribution in energy of these tracks appears in Fig. 1. Visual extrapolation of this curve to the energy axis gives an upper limit of 1.8 Mev. This is considerably lower than the results obtained by other workers using the absorption method. Henderson[4] obtained an upper limit of 2.05 Mev by the use of Feather's rule. Widdowson and Champion[7] also measured this upper limit by absorption and obtained 1.96 Mev.

K-U and Fermi plots were made for this spectrum. These led to end-points of 2.0 Mev and 1.7 Mev, respectively, the latter fitting a straight line possibly somewhat better than the former.

The spectrum of Cu^{62}

Metallic copper was bombarded by the high energy neutrons resulting from the bombardment of Li by 1.2-Mev deuterons and the beta-ray spectrum of the 10-minute activity studied. The accepted reaction, assigned by Heyn[8] is:

$$_{29}Cu^{63}+{}_0n^1\rightarrow{}_{29}Cu^{62}+{}_0n^1+{}_0n^1,$$
$$_{29}Cu^{62}\rightarrow{}_{28}Ni^{62}+e^+.$$

The bombardment of Cu by high energy neutrons, which in this case involves bombardment by neutrons of all lower energies, leads to a number of radioactive products. Only two of these products other than the one studied emit positrons. These are Cu^{64}, of 12.8 hours half-life, and Cu^{61}, of 3.4 hours half-life. These activities should not interfere with measurements on Cu^{62} as they should be excited only weakly under bombardment for a short time.

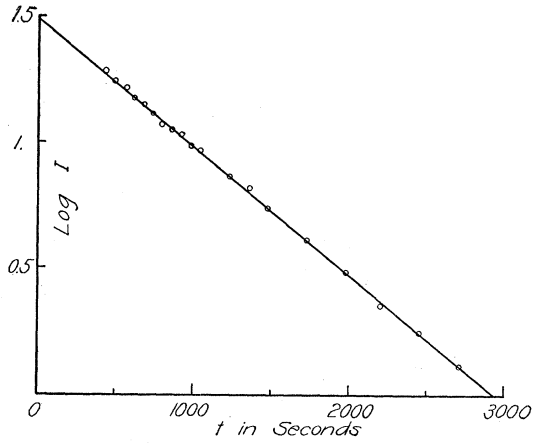

FIG. 2. Decay curve for Cu^{62}.

The samples to be exposed to the high energy neutrons were placed outside the vacuum of the cyclotron, separated from the Li target by a wall of copper 0.24 cm thick. The samples had a thickness of 192 mg/cm² which was estimated to be equivalent to 0.2 Mev for electrons of 2 Mev. Such a thickness of the sample should not appreciably alter the value obtained for the visually extrapolated end point. It may, however, cause the curve to approach the axis more slowly than if a thin source were used.

The samples were bombarded for 15 minutes with a deuteron current of 7 microamperes on the Li. The decay curve of one of the samples is given in Fig. 2. There is no evidence in this curve of the presence of the longer period activities. The half-life obtained was 9.92±0.05 minutes. This is in agreement with Ridenour and Henderson's[9] value of 10.0±0.1 minutes.

Measurements were made on 803 acceptable tracks. The distribution in energy of these tracks is plotted in Fig. 3. The curve extrapolates visually to an upper limit of 2.6 Mev. (K-U upper limit 3.0 Mev.)

The spectra of the isomers of Rh^{104}

Rh bombarded by slow neutrons gives rise to two electron activities with half-lives reported to be 44 seconds and 4.2 minutes.[10] These have

[6] The writer is indebted to Mr. B. L. Moore of this laboratory for these measurements on the Mg^{27} half-life, which were made in connection with other work. The error quoted here and for the other half-lives to be reported in this paper is the estimated error in drawing a straight line through the points in a plot of the logarithm of the intensity *vs.* time.

[7] E. E. Widdowson and F. C. Champion, Proc. Phys. Soc. **50**, 185 (1938).

[8] F. A. Heyn, Nature **138**, 723 (1937); Physica **4**, 160 (1937).

[9] L. N. Ridenour and W. J. Henderson, Phys. Rev. **52**, 889 (1937).

[10] E. Amaldi and E. Fermi, Phys. Rev. **50**, 899 (1936).

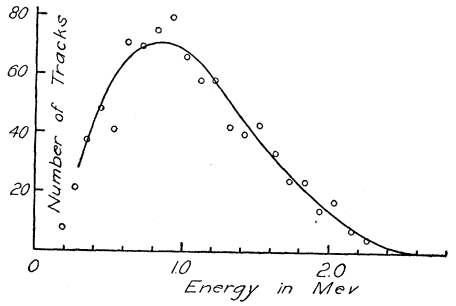

FIG. 3. Distribution in energy of 803 tracks for Cu^{62}.

been ascribed to isomers of the single isotope Rh^{104} in which one isomer represents a metastable state and the other isomer the ground state.[11] Pontecorvo[12] has found that the continuous spectrum of the 4.2-minute activity is accompanied by a homogeneous group of electrons of 35–60 kv. These he concluded are formed by internal conversion of gamma-radiation of about 80 kv emitted in a transition from the metastable state of Rh^{104} to the ground state. He further concluded that the 44-second beta-ray activity was due to transitions from the ground state of Rh^{104} to the ground state of Pd^{104}. This same transition would account for at least part of the continuous spectrum of the 4.2-minute activity.

An alternative process to the gamma-ray transition from the metastable state of Rh^{104} is a direct beta-transition to Pd^{104}. The occurrence of this direct beta-transition would probably leave the resultant Pd^{104} nuclei in one or more excited states, since a transition directly from the metastable state of Rh^{104} to the ground state of Pd^{104} would require a large change of spin. The superposition of this spectrum on the spectrum due to transition from the ground state of Rh^{104} would give the spectrum of the long period activity a shape different from that of the short period activity. A study of the shape of the spectra of the two isomers then affords a means of detecting the presence of the direct beta-transition.

Neutrons were produced by bombardment of metallic Li by 1.2-Mev deuterons. The Rh samples had a thickness of 184 mg/cm^2 which was estimated to be equivalent to 0.2 Mev for electrons of 2 Mev. These samples were placed about 4 cm from the neutron source and surrounded by paraffin. The decay curve after exposure for 17 minutes is shown in curve I of Fig. 4. Observations were taken with two instrument sensitivities indicated by the circles and crosses on the figure. The half-life of the long period activity was determined to be 4.37 ± 0.05 minutes. Subtracting the ordinates of the line from the ordinates of the decay curve for small values of the time resulted in the curve shown in curve II, Fig. 4. This gave a half-life of 42 ± 2 seconds for the short period activity. The ratio of initial intensities corrected to infinite bombardment time was determined to be 12 ± 1. This is in agreement with Pontecorvo's[11] value of 11 ± 0.7 obtained under bombardment by Rn+Be neutrons after passage through paraffin. A further measurement of the short period half-life using a bombardment time of 2 seconds gave a half-life of 41.8 ± 0.7 seconds.

For the cloud-chamber work the short period activity was separated by bombarding for 15 seconds and making the first expansion 24 seconds later followed by one expansion every 15 seconds up to 10 expansions. It was calculated that under these conditions 3.7 percent of all

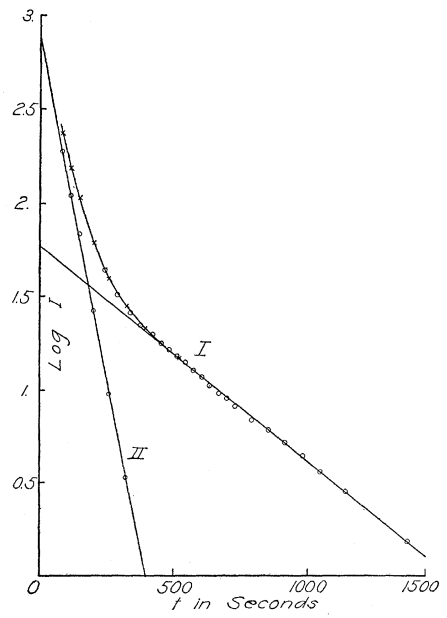

FIG. 4. Decay curves for Rh. I. Decay curve of both activities. II. Decay curve for short period activity.

[11] B. Pontecorvo, Nature **141**, 785 (1936).
[12] B. Pontecorvo, Phys. Rev. **54**, 542 (1938).

the tracks observed were due to the long period activity.

The long period activity was separated by bombarding for 17 minutes and making the first expansion 420 seconds later followed by one expansion every 15 seconds up to 40 expansions. Under these conditions 0.8 percent of all the tracks observed were due to the short period activity.

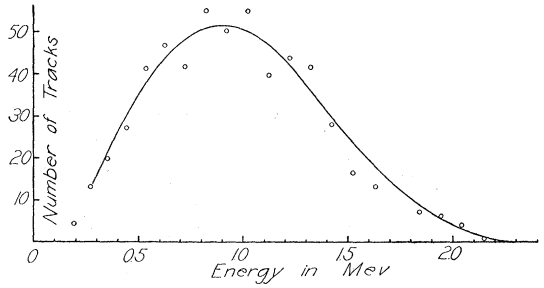

FIG. 5. Distribution in energy of 529 tracks for the short period activity of Rh.

The distribution in energy of the tracks from the short period activity is given in Fig. 5. This curve represents a total of 529 acceptable tracks. Visual extrapolation of this curve to the energy axis yields an upper limit of 2.3 Mev. The spectrum of this same activity has previously been investigated with a cloud chamber by Gaerttner, Turin, and Crane[3] who reported a K-U upper limit of 2.8 Mev. For comparison with their work a K-U plot was made for this spectrum which led to a K-U upper limit of 2.7_4 Mev.

The distribution in energy of the tracks for the long period activity on the basis of the observation of 524 acceptable tracks appears in Fig. 6. The visually extrapolated upper limit obtained from this curve is 2.3 Mev. This value is the same as the upper limit of the short period

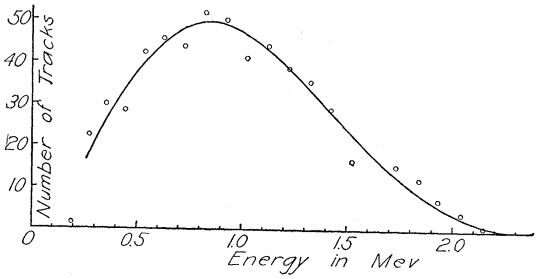

FIG. 6. Distribution in energy of 524 tracks for the long period activity of Rh.

activity. Furthermore the two spectra have shapes which are the same within experimental error, as briefly reported before.[13]

Some conclusions can be drawn from these results. (1) The common value for the upper limit of the two beta-spectra agrees with Pontecorvo's conclusion that the beta-transition from the ground state of Rh^{104} to the ground state of Pd^{104} is responsible for at least part of the continuous spectrum of the long period activity. (2) The similarity in shape of the two spectra leads to the conclusion that the direct beta-transition from the metastable state does not occur to any appreciable extent. Thus, as far as can be determined from this work, the long period activity proceeds entirely by a gamma-ray transition from the metastable state of Rh^{104} to the ground state, followed by the beta-ray emission to the ground state of Pd^{104}.

This work was aided by a grant from the Research Corporation which made possible the use of the cyclotron. The writer wishes to express his appreciation to Professor M. S. Livingston and Professor R. F. Bacher for frequent advice and helpful criticism.

[13] E. C. Crittenden, Jr. and R. F. Bacher, Phys. Rev. **54**, 862 (1938).