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Nuclear Transformations Produced in Zinc by Alpha-Particle Bombardment

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Zinc has been bombarded with 17 Mev alpha-particles and the consequent radioactivity observed. The disintegration products are mainly positrons; the half-lives of the observed activities are 19.8∓0.4 minutes, 37∓1.5 hours, 79∓2 hours and about 195 days. A chemical separation indicates that the first and third of these activities are due to gallium and the remaining two to germanium. The two gallium activities may be respectively assigned to Ga^{70} and Ga^{67}. No very definite assignment has been possible, however, with respect to the activities associated with germanium.

WITH the 17 Mev alpha-particles from the cyclotron at Berkeley the transmutations produced in the bombardment of zinc with alpha-particles have been further studied. A preliminary report of the results obtained was given at the Stanford meeting of the American Physical Society in December, 1937. The results given at that meeting, however, require modification on account of the reported long-lived activity having been found to have a much longer half-life than was estimated. As a result, the half-life of 32 hours assigned to germanium has been found to be 37 hours while that of 55 hours ascribed to Ga^{67} has been increased to 79 hours.

RADIOACTIVE PRODUCTS

The activity obtained when a piece of chemically pure zinc was bombarded for about 4 microampere hours with alpha-particles was followed by means of a Lauritsen-type quartz fiber electroscope. It was found that the resulting decay curve could be resolved into four components, representing activities having half-lives of about 20 minutes, 37 hours, 79 hours, and one of about 195 days. The last part of the decay curve, together with the corrected 79-hour activity, is shown in Fig. 1. At first it was suspected that the long 195-day activity might be due to deuteron contamination and was in fact the seven-month activity found by Livingood and Seaborg[1] on bombarding zinc with deuterons. No trace, however, of the accompanying one-hour gallium activity could be detected, so that this explanation was therefore ruled out. Extrapolated to zero time after bombardment the 20-minute, 37-hour, 79-hour and 195-day activities had intensities corresponding respectively to 0.002, 0.4, 3.0 and 40 microcuries, giving yields of 4×10^{-7}, 5×10^{-7}, 1×10^{-7} and 4×10^{-8}. The electroscope was calibrated with a uranium standard.

In order to identify the various radioactive products, a target was prepared for bombardment with a view to effecting a chemical separation. By using a chemically pure zinc sulphate bath and following the procedure given by Bar-

[1] J. J. Livingood and G. T. Seaborg, San Diego Meeting, June 1938.

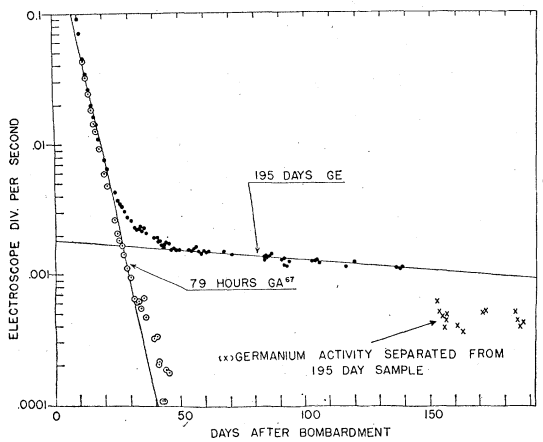

FIG. 1. Activity of zinc after bombardment by alpha-particles.

clay and Hainsworth,[2] a layer of zinc was electrolytically deposited onto a sheet of carbon to a thickness of about one-fiftieth of an inch. This target was bombarded with alpha-particles for 5.7 microampere hours; great care was taken to avoid deuteron contamination. Such contamination was not difficult to avoid since the deuteron and alpha-particle peaks were quite adequately resolved in the cyclotron.

After bombardment, the zinc target was dissolved off the carbon by boiling in a mixture of concentrated hydrochloric and nitric acids contained in a flask provided with a reflux condenser to prevent volatilization of the germanium chloride which might be present. Carriers of germanium and gallium were added and a separation for zinc, germanium and gallium carried out, according to the procedure recommended by Noyes and Bray.[3]

The solution obtained from dissolving the target to which the appropriate carriers had been added was diluted to about 6*N* and treated with hydrogen sulphide. Under this condition of acidity only germanium can be precipitated, while gallium and zinc remain in solution. The germanium precipitate was washed several times with 6*N* sulphuric acid saturated with hydrogen sulphide. The gallium and zinc filtrate was now evaporated to dryness and the residue redissolved in 6*N* hydrochloric acid. From this solution the gallium was extracted by the ether method of extraction; the ether was washed several times with acid before it was finally evaporated. The zinc in hydrochloric acid, after washing with ether, was then evaporated to dryness and the residue dissolved in water. The zinc was then precipitated by treatment with hydrogen sulphide. The results are shown plotted in Figs. 2 and 3. In Fig. 2 are shown the decay curves of the

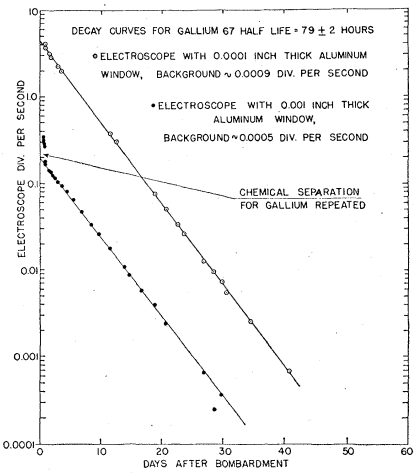

FIG. 2. Decay curves for gallium.

gallium activity observed on two electroscopes, one having an aluminum window 0.0001 inch thick and the second having an aluminum window 0.001 inch thick. In Fig. 3 is shown the decay curve of the germanium activity. The zinc showed a weak activity, having a half-life of about 38 hours, but this is probably due to a trace of germanium.

The gallium activity after a short time of rapid decay, presumably due to the 20-minute activity of Ga^{70}, settled down to a rate of decay corresponding to 79 hours, which was followed well into the background of the electroscope. The germanium activity decayed with a half-life of about 39 hours but started lengthening out just above background. By making a correction for the presence of this longer period the half-life of main activity was reduced to one of 37 hours, in agreement with that obtained without chemical analysis.

The 195-day activity is still, however, not

[2] W. R. Barclay and C. H. Hainsworth. *Electroplating* (Edward Arnold, London).
[3] A. A. Noyes and W. C. Bray. *Qualitative Analysis For the Rare Elements* (Macmillan, New York).

chemically identified. The 20-minute and 79-hour activities may be attributed to Ga^{70} and Ga^{67}, respectively. The 37-hour germanium activity is probably to be identified with that of 26 hours reported by Sagane for Ge^{69}. While the possibility of isomerism cannot be overlooked, the identification with Ge^{69} seems reasonable. The lengthening out observed in Fig. 3 leads one to suspect that the 195-day activity is due to germanium and might possibly be due to the radioactive isotope Ge^{67}. There is no sign at all that there is any long period activity due to gallium. The ratio of the 79-hour and 195-day activities in Fig. 1 extrapolated to zero time after bombardment is such that if this activity were due to gallium, then it should most certainly be observed in the data given in Fig. 2, which were obtained after a bombardment of about the same duration. If, however, the activity be due to Ge^{67}, then there should also be present activity due to Ga^{67} which would be formed by the disintegration of a Ge^{67} nucleus. Accordingly the sample from which the readings in Fig. 1 were obtained was added to another which had aged until only the 195-day period was present and a chemical separation was made for zinc, gallium and germanium. The activities obtained in the various fractions were weak. The germanium showed an activity about equal to background, the gallium about a third background, and the zinc about one-eighth background. The activity separating

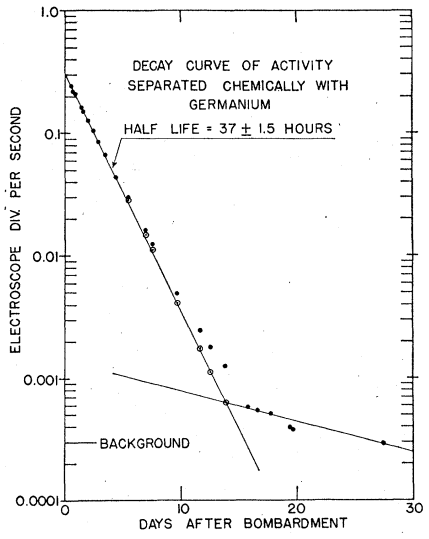

FIG. 3. Decay curves for germanium.

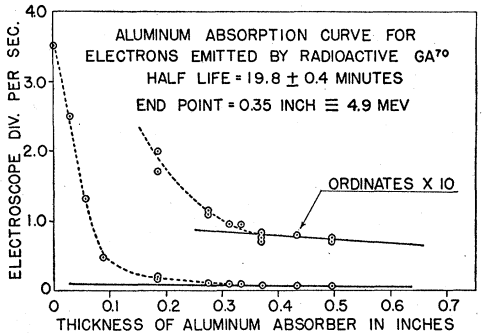

FIG. 4. Aluminum absorption curve for electrons emitted by radioactive Ga^{70}.

out with the gallium was, however, long-lived, nor did it show the characteristic absorption of Ga^{67}. Thus, as will be discussed in the next section, the soft beta-particles should have been practically completely absorbed by 0.001 inch of aluminum. This was not the case. However, since it is extremely improbable that any zinc or gallium will be precipitated in acid solution by hydrogen sulphide while any germanium left in solution would separate out with both these elements, it seems fairly reasonable to conclude that the 195-day activity should be ascribed to germanium.

With the identification of the 20-minute and 79-hour activities with Ga^{70} and Ga^{67}, correction for the isotopic abundance of Zn^{67} and Zn^{64} from which the radioactive isotopes of gallium would be formed by alpha-particle capture and emission of a proton, gives respective absolute yields of 9×10^{-6} and 3×10^{-7}.

Disintegration Products

By examination in a magnetic field, the emitted electrons were found to be predominantly positive. It is known, however, that the two gallium isotopes, Ga^{67} and Ga^{70}, give rise to negative electrons, the former by conversion of a gamma-ray and the latter by emission in the process of transforming to stable Zn^{70}. The chemically separated germanium was found to be positron active, corresponding, if the identification be correct, to a transformation from Ge^{69} to Ga^{69}. The germanium activity was investigated for soft x-rays but none was found. Absorption measurements were made using aluminum absorbers and the results are shown in Figs. 4, 5 and 6. From Feather's empirical formula, values of 5.0

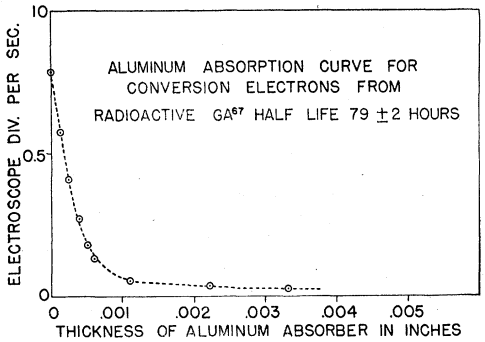

FIG. 5. Aluminum absorption curve for conversion electrons from radioactive Ga^{67}.

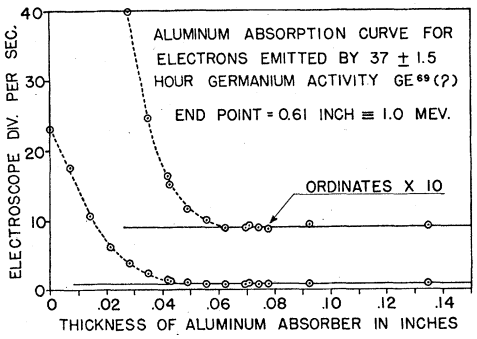

FIG. 6. Aluminum absorption curve for electrons emitted by 37±1.5 hour germanium activity Ge^{69}(?).

Mev and 1.0 Mev were obtained, respectively, for the maximum energies of the electrons emitted by Ga^{70} (19.8 minutes) and Ge^{69} (37 hours). The disintegration products of Ga^{67} (79 hours) have been exhaustively investigated by Alvarez[4] who found that Ga^{67} transformed to Zn^{67} by capture of a K shell electron followed by emission of an x-ray characteristic of zinc. The soft electrons which are emitted, the absorption curve for which is shown in Fig. 5, have been found by Alvarez to be due to conversion of a 100 kev gamma-ray in the K and L shells. In the present instance, the absorption coefficients of the x-rays have also been measured and a complete identification of the results with those obtained by Alvarez has been established.

It is again a pleasure to be able to express my thanks to Professor E. O. Lawrence and to the staff of the Radiation Laboratory for all their help and cooperation. My thanks are also due to the Commonwealth Fund for the award of a fellowship which has made my stay here possible. The research has also been aided by grants to the laboratory from the Research Corporation, the Chemical Foundation and the Josiah Macy, Jr., Foundation. The experiments have been facilitated by assistance from the W.P.A.

[4] L. W. Alvarez, Phys. Rev. **53**, 606 (1938).

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Note on K-Electron Capture in Be^7

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There is no observed positron emission in Be^7. This sets an upper limit of 2.09 mc^2 for the mass difference Be^7–Li^7 from Fermi's theory and 2.3 mc^2 from the Konopinski-Uhlenbeck theory. This upper limit is compared with other estimates of the same mass difference. The gamma-ray emission accompanying the disintegration probably takes place after the K capture from an excited state of Li^7 having a spin $\frac{1}{2}$. The K-capture transition to $i=\frac{1}{2}$ from $i=\frac{3}{2}$ is according to experiment only $\frac{1}{10}$ as weak as that to $i=\frac{3}{2}$. This speaks for the Gamow-Teller type of selection rules. The mean lives of He^6, Be^7, C^{11} are compared. It is found that the observed mean lives are relatively shorter for the lighter nuclei than Fermi's theory predicts. This is in apparent contradiction with the preference shown for the Fermi theory by the alpha-particle distribution from Li^8. From a theory without derivatives, the facts seem to point either to an appreciable increase in the many-body aspect of nuclei from He^6 to C^{11} or else to a decrease in the intrinsic β-emitting powers of nuclear particles in heavier nuclei. On the Konopinski-Uhlenbeck theory some of the disagreement can be removed but the β-particle distribution from Li^8 (Gamow and Teller) speaks strongly against using this theory for mean lives.

THE experiments of Roberts, Heydenburg and Locher[1] show that Be^7 captures its K electron to form Li^7. They observe roughly one gamma-ray quantum per every ten Be^7 atoms produced. The gamma-radiation is explained by them as being due to capture of a K electron into an excited state. Their measurements give

[1] R. B. Roberts, N. P. Heydenburg, G. L. Locher, Phys. Rev. **53**, 1016 (1938); R. B. Roberts and N. P. Heydenburg, Abstract No. 78, 1938, Washington Meeting American Physical Society.