Radioactive Decay of Zn^{72}†

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The decay of Zn^{72} (46.5h) has been investigated using standard scintillation counter techniques. Samples of Zn^{72} were obtained from the fission of Th^{232} and Ta^{181} by fast protons. Gamma rays of 51±3, 143±2, and 192±4 keV were observed. A beta-ray group of 296±6 keV was found in the singles and in coincidence with the 143-keV gamma. A decay scheme is proposed for Zn^{72}.

INTRODUCTION

ZINC 72 was first reported by Siegel and Glendenin.[1] They extracted Zn^{72} from thermal-neutron-induced fission products of U^{235} and reported its half-life to be 49 h. They also took an aluminum absorption curve of the beta rays emitted by Zn^{72}. This absorption curve was resolved into two components, one of ~0.3-MeV endpoint and ~95% intensity and another possible component of ~1.6-MeV endpoint and ~5% intensity.

The samples used in this work were obtained from fast-proton-induced fission products of heavy elements. Sample 1 was prepared from a natural Th foil exposed to the 22-MeV proton beam of the ORNL 86-in. cyclotron for ~20 μA h. Sample 2 was prepared from a natural Ta foil exposed to the 450-MeV proton beam of the Carnegie Institute of Technology synchrocyclotron for ~3 μA h. In both cases the foils were chemically processed by ion exchange procedures and the Zn activity was extracted.[2] Sample 1 contained ~1 μC of Zn^{72} while sample 2 contained ~3 μC of Zn^{72}. In both cases the chemical separations appeared to be very clean in that no activities which could not be attributed to other Zn isotopes were observed, at least in the gamma spectra. The identification of the Zn^{72} activity by chemical separation was confirmed by observing the subsequent growth of the very distinctive gamma spectrum of Ga^{72} (14h).

A preliminary version of the work reported here, based only on gamma-ray data, was presented at the April 1962 meeting of the American Physical Society.[3]

EXPERIMENTAL RESULTS

A. Gamma-Ray Spectra

Most of the singles gamma-ray spectra were taken with a $1\frac{3}{4}$-in.-diameter by 2-in.-thick NaI(Tl) crystal of 9% (Cs^{137}) resolution. In all cases the pulse-height spectra were analyzed by a RIDL 400-channel analyzer. Figures 1 and 2 compare the gamma spectra of an equilibrium mixture of Zn^{72} and Ga^{72} (sample 1) with the spectra of pure Ga^{72} taken under the same conditions. The Ga^{72} comparison samples as well as all the other comparison samples used in this work were prepared by neutron activation at the Pennsylvania State University Reactor Facility. The Ga^{72} sources were prepared from 99.999% pure Ga metal or GaO.

Figures 1 and 2 indicate that gamma rays of 143±2 and 192±4 keV can be assigned to Zn^{72}. The energy of the intense Zn^{72} gamma rays was measured by observing them simultaneously with the peaks from Pb x rays and Hg^{203} thus eliminating any effects due to changes of gain with count rate or other drifts. The intensity of the 192-keV gamma was measured by the photopeak method to be 8±2% with respect to the 143-keV gamma. The peak at ~1.13 MeV in Fig. 2 was revealed by subtracting a normalized Ga^{72} spectrum from the

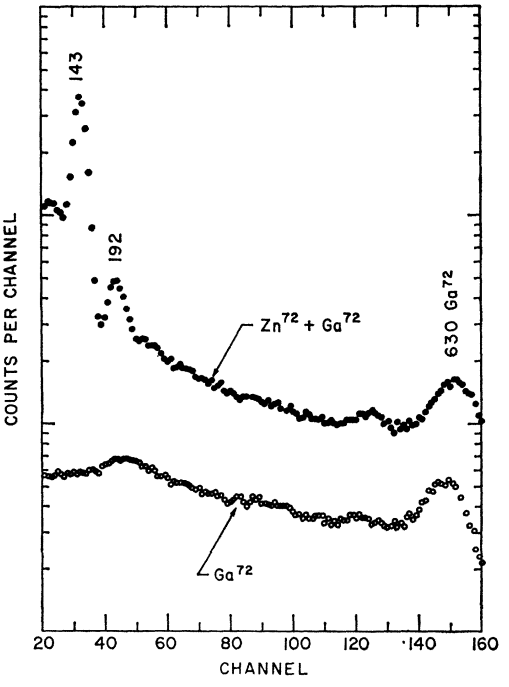

FIG. 1. The solid points are the gamma spectrum of an equilibrium mixture of Zn^{72} and Ga^{72} and the open points are a gamma spectrum of pure Ga^{72} taken under the same conditions. The Ga^{72} spectrum has been multiplied by an arbitrary factor so that it will not overlap the equilibrium spectrum. The 143-keV and the 192-keV gammas are assigned to Zn^{72}.

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[1] J. M. Siegel and L. E. Glendenin, J. Am. Chem. Soc. 68, 2411 (1946). J. M. Siegel and L. E. Glendenin, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1951), National Nuclear Energy Series, Plutonium Project Record, Vol. 9, p. 549.
[2] The chemical processing was performed by the Nuclear Science and Engineering Corporation of Pittsburgh, Pennsylvania.
[3] T. T. Thwaites, Bull. Am. Phys. Soc. 7, 341 (1962).

spectrum of the equilibrium sample. It was found to have a half-life of several months or longer and is attributed to Zn^{65} (245 days). There is no evidence for any high-energy gamma rays which could be attributed to Zn^{72}. The 143- and 192-keV gammas were also observed in a $\sim 0.1\ \mu$C sample of chemically separated Zn^{72}.

The data presented in Fig. 3 were taken with a $1\frac{1}{2}$-in. diameter by $\frac{1}{4}$-in. thick NaI(Tl) crystal in order to reduce the height of Compton tails from high-energy gamma rays. This counter was used in a shield of steel bricks in order to eliminate the Pb x rays which are excited when a source is placed in a lead shield. These data were taken with sample 2. A peak is revealed in the Zn^{72}, Ga^{72} equilibrium sample at an energy of 51 ± 3 keV. On comparison with the spectrum of pure Ga^{72} taken under the same conditions it is seen that this peak cannot be due to Ga^{72}.

The reality of the 51-keV gamma was checked in a number of ways. First the 51-keV peak is not at the energy which would be expected (92 keV) for a backscatter peak due to the 143-keV gamma and also its intensity was not changed by removing the shielding in back of the source. Second, there was no peak at this position in the gamma-ray spectrum of the 145-keV gamma of Ce^{141} taken under the same conditions. Third, an Fe absorber of a thickness which reduced the 143-keV gamma to 48% of its previous intensity was used. The ratio of the absorption coefficients for the 143-keV gamma and a 51-keV gamma is ~ 8.6. The 51-keV peak vanished with the use of this absorber while the 143-keV peak behaved in the expected manner. The intensity of the 51-keV gamma was found to be $2\pm 1\%$ with respect to the 143-keV gamma.

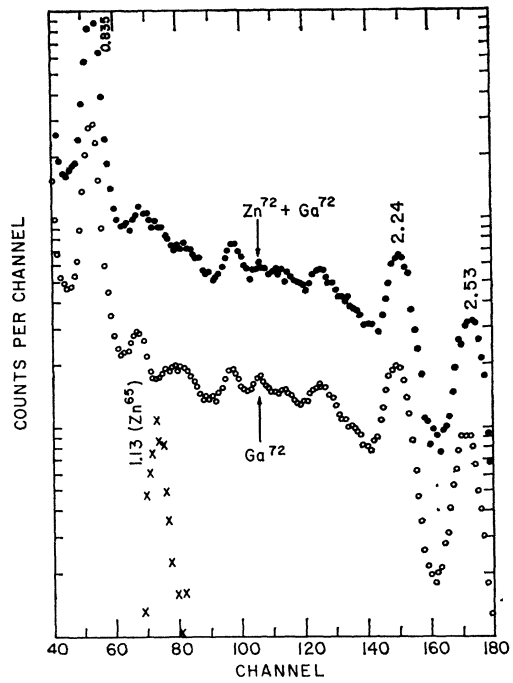

FIG. 2. The solid points are the gamma spectrum of an equilibrium mixture of Zn^{72} and Ga^{72} in the high-energy region and the open points are a pure Ga^{72} spectrum taken under the same conditions. The extra gamma ray with energy ~ 1.13 MeV was found to have a half-life of several months or longer and is assigned to Zn^{65} (245 days). The Ga^{72} spectrum has been multiplied by an arbitrary factor.

There is no evidence in Fig. 3 for a gamma ray of 100 keV. A comparison made between the Zn^{72} spectrum and a Ce^{141} spectrum in this region yielded an upper limit of 1% on a 100-keV gamma. A 100-keV isomeric

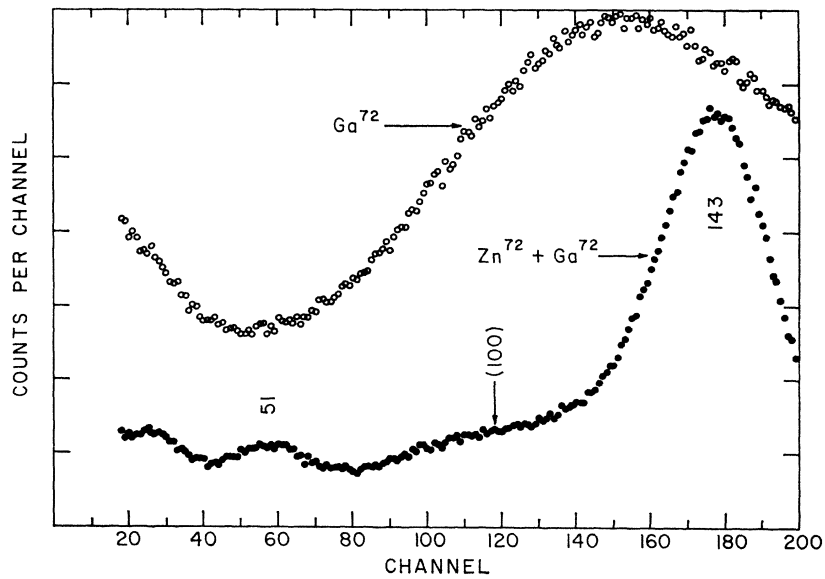

FIG. 3. The solid points are a gamma-ray spectrum of an equilibrium mixture of Zn^{72} and Ga^{72} taken with a $1\frac{1}{2}$-in.-diameter by $\frac{1}{4}$-in.-thick NaI(Tl) crystal. The open points are a pure Ga^{72} spectrum taken under the same conditions and they show that the peak at 51 keV cannot be due to Ga^{72}. The Ga^{72} spectrum has been multiplied by an arbitrary factor. See text for arguments concerning the reality of the 51-keV gamma and its assignment to Zn^{72}. There is no indication of a 100-keV gamma.

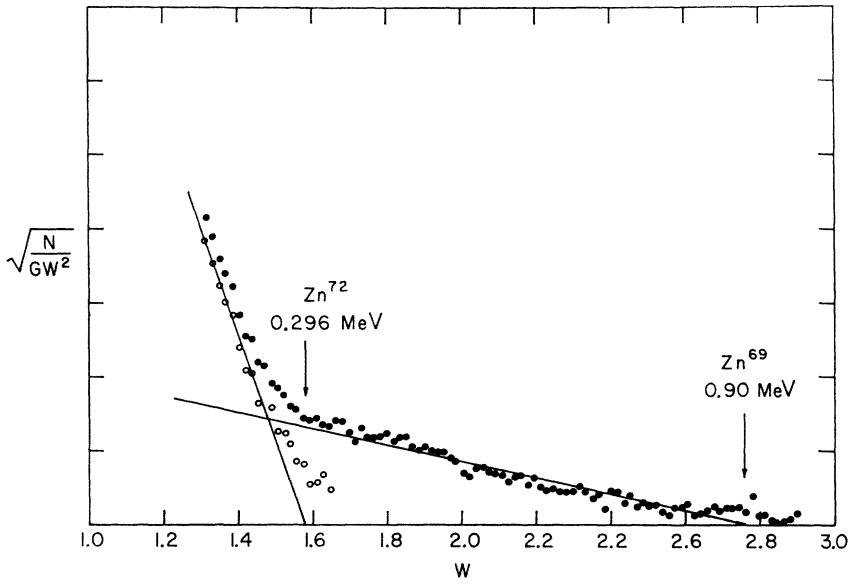

FIG. 4. Fermi-Kurie plot of singles beta-ray spectrum. The high-energy beta group was assumed to be due to Zn^{69} (14h) which was observed in the gamma spectrum of this sample. The extraction of the interior component was made accordingly.

transition of 40 msec half-life has been observed in Ga^{72}.[4–6]

Coincidences between the 143- and 192-keV gammas were searched for using a coincidence circuit with a $2\tau \approx 2$ μsec. Both the 143- and 192-keV gammas were used to gate the multichannel analyzer. The accidentals were found to be only 2 or 3%, at worst, but no peaks were observed in the true coincidences corresponding to either the 143- or 192-keV gammas. Using a sample of pure Ga^{72} of approximately the same strength, the true coincidences were shown to be due for the most part at least, to coincidences between Compton tails and backscatter peaks of various Ga^{72} gamma rays. Coincidences between the 143- and 51-keV gammas were not searched for due to lack of source strength.

The decay of the 143-keV gamma was followed for several weeks and a least-square fit to the data gave a half-life of 46.5±0.1 h in excellent agreement with the value reported by Kjelberg *et al.*[7]

B. Beta-Ray Spectra

Beta sources were prepared by evaporation of active material on 0.00025-in.-thick Mylar films. The Zn source was from sample 2. Beta spectra were taken with a 2-in. diameter by 1-in.-thick anthracene crystal of 16% (Cs^{137}) resolution. Internal conversion line sources (Sn^{113}, Cs^{137}, and Bi^{207}) were used to calibrate the spectometer. A check on the calibration and the procedure was made by observing the beta spectrum of Sc^{46}. An endpoint within 1 keV of the accepted value of 357 keV[8] was obtained from a Fermi-Kurie plot of this spectrum.

The singles beta spectrum contained contributions from the equilibrium Ga^{72} and contaminant Zn^{69} as well as Zn^{72}. The gamma response was subtracted by means of an absorber. A pure Ga^{72} spectrum was taken, normalized to the other spectrum beyond the endpoint of Zn^{69} and then subtracted. A Fermi-Kurie plot of the resulting spectrum is shown in Fig. 4. It was next assumed that the remaining high-energy component was due entirely to Zn^{69} which was observed in the gamma spectrum of sample 2. The known endpoint of the Zn^{69} beta spectrum was then used in extrapolating this component under the low-energy component. No backscatter correction was made to these data but the effects of neglecting them are evidently not too severe as the Fermi-Kurie plot of the interior group which was extracted gives a fairly good line and an endpoint in agreement with the beta-gamma coincidence data.

A spectrum of beta rays in coincidence with the 143-keV gamma was taken with a coincidence circuit of $2\tau \approx 2$ μsec. Genuine beta-gamma coincidences due to Ga^{72} were also observed. These were subtracted by raising the gamma gate to an energy above the 143-keV gamma. A Fermi-Kurie plot of the resulting spectrum is shown in Fig. 5. The endpoint is in reasonable agreement with the singles and an end point of 296±6 keV is thus indicated for Zn^{72} beta rays.

Using the beta-gamma coincidence apparatus, an attempt was made to measure the half-life of the state involved in Ga^{72} but the resulting delay curve was

[4] E. C. Campbell and P. F. Fettweis, Nucl. Phys. **13**, 92 (1959).
[5] K. F. Alexander and V. Bredel, Nucl. Phys. **17**, 153 (1960).
[6] P. F. Fettweis and E. C. Campbell, Nucl. Phys. **33**, 272 (1962).
[7] A. Kjelberg, H. Taniguchi, and L. Yaffee, Can. J. Chem. **39**, 635 (1961).

[8] *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences–National Research Council, Washington 25, D. C.).

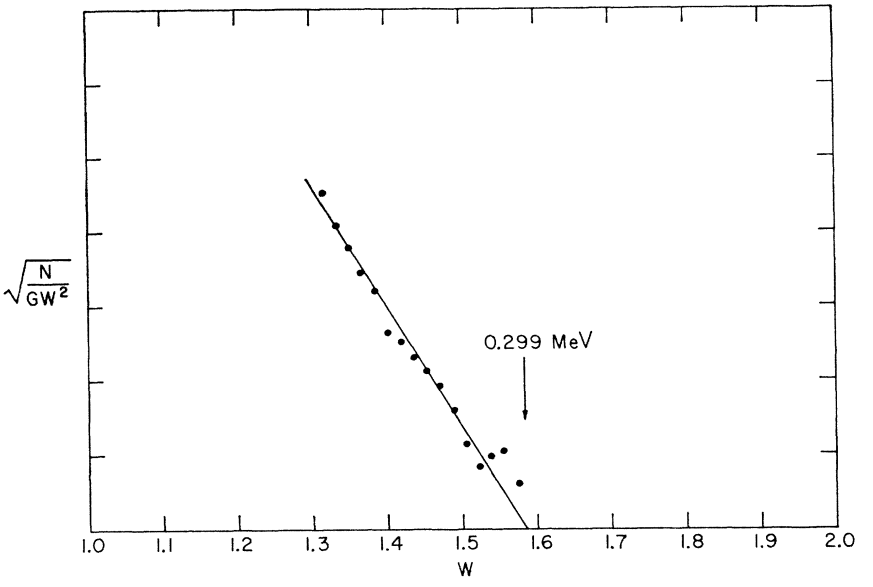

FIG. 5. Fermi-Kurie plot of beta rays in coincidence with 143-keV gamma rays. The endpoint appears to be in agreement with that of the singles spectrum.

indistinguishable from a prompt delay curve. It was thus concluded that $t_{1/2} \lesssim 2$ μsec.

CONCLUSION

Figure 6 shows a decay scheme for Zn^{72} suggested by the data. The 246-keV beta group is inferred; it was not observed in this work. From the log ft values of the beta transitions it would appear that they are both allowed.

If the isomeric transition from the 100-keV state is indeed of $M2$ character, as proposed by Fettweis and Campbell,[6] then this state must be 5^+ instead of 1^+ since there is no evidence for a beta group to it. This $M2$ transition would appear to be retarded by a factor of $\sim 10^3$.

An assignment of 1^+ to the 143- and 192-keV levels would permit faster gamma transitions to the ground state of Ga^{72} than would an assignment of 0^+. However, the $M2$ transitions which would result are still too slow, as evidenced by the upper limit on the half-life of the 143-keV transition and the branching ratio of the 192-keV transition. Both of these $M2$ transitions would have to be enhanced in order to fit the decay scheme of Fig. 6. Although the speeds of only three $M2$ transitions in heavy elements are known,[9] none of them are enhanced, and this requirement is a serious objection to this decay scheme. An unobserved state lying below 25-keV excitation may be implied.

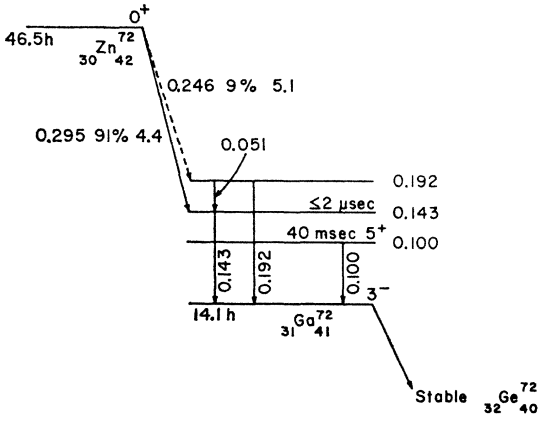

FIG. 6. Proposed decay scheme of Zn^{72}. See text for discussion. The decay of Ga^{72} is indicated but all details are omitted.

The coincidences observed between the 143-keV gamma rays and the 296-keV beta group and the apparent absence of any other Zn^{72} gammas of intensity comparable to the 143-keV gamma would appear to fix the total decay energy of Zn^{72} at 439±7 keV. This value is in disagreement with that of ~1.6 MeV expected from the beta-decay energy systematics.[10]

ACKNOWLEDGMENTS

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[9] D. H. Wilkinson, in *Nuclear Spectroscopy*, edited by F. Ajzenberg-Selove (Academic Press Inc., New York, 1960), p. 852.

[10] K. Way, R. W. King, C. L. McGinnis, and R. van Lieshout, in *Nuclear Level Schemes, A=40 A=92*, compiled by Atomic Energy Commission Report TID-5300 (U. S. Government Printing Office, Washington, D. C., 1955); K. Way and M. Wood, Phys. Rev. **94**, 119 (1954).