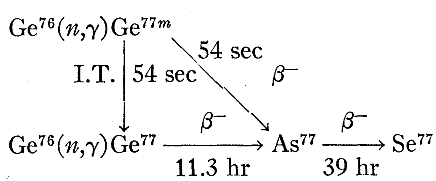
Radioactive Ge^{77} and Ge^{77m}

W. S. LYON AND J. S. ELDRIDGE
Oak Ridge National Laboratory, Oak Ridge, Tennessee*
(Received February 25, 1957)

Pile neutron activation cross sections for production of Ge^{77} and Ge^{77m} have been obtained. In addition, the half-lives of Ge^{77} and Ge^{77m} have been measured as well as the γ/β^- branching in the beta decay of Ge^{77m}.

NEUTRON capture by Ge^{76} can lead either to Ge^{77} directly, or to an excited level, Ge^{77m}, which in turn decays, either to Ge^{77} by emission of a 0.16-Mev γ-ray, or to As^{77} by beta decay. This capture and decay sequence is shown in the following diagram.[1,2]



Reynolds[3] has reported a cross section for total production of Ge^{77} as $\sim$0.4 barn. Arnold and Sugarman[4] stated that the cross section for production of Ge^{77m} was about 10% higher than that for Ge^{77}. Recently der Mateosian and Goldhaber[5] have reported thermal neutron cross sections for this process. They report values of 0.06 ± 0.01 barn for the production of Ge^{77m} and 0.05 ± 0.01 barn for the production of Ge^{77}. These numbers are consistent with the rule of Segrè and Helmholtz[6] that neutron capture to form isomeric states favors the level with spin closest to that of the compound nucleus. As pointed out by der Mateosian and Goldhaber, previous results on these cross sections had indicated Ge^{77} to be an only exception to this rule. Burson *et al.*[2] determined the γ branching in the beta decay of Ge^{77} and found it to be 0.09.

During the course of determining the pile activation cross sections for the germanium isotopes, we have measured the activation cross sections for production of Ge^{77} and Ge^{77m}, the half-lives of Ge^{77m} and Ge^{77}, and the gamma branching in the beta decay of Ge^{77m}.

EXPERIMENTAL

In the experiments described below, germanium oxide enriched in Ge^{76} to 79.3% was used. The cross section for production of Ge^{77m} was obtained by measuring (a) the induced Ge^{77m} which decayed by β^- emission to As^{77} and (b) the induced Ge^{77m} which decayed to Ge^{77} by emission of the 0.16-Mev γ-ray. In addition, a branching ratio for the beta decay of Ge^{77m} was measured.

Weighed samples of $Ge^{76}O_2$ (together with Mn monitor) were irradiated in the pneumatic tube of the ORNL Graphite Reactor for accurately measured times of about one minute. The irradiated GeO_2 was quickly transferred to a watchglass, covered with cellophane, and placed at a known geometry between an end window type beta proportional counter covered by $\sim$100 mg/cm^2 of Al to absorb any conversion electrons and a 3 in.$\times$3 in. NaI crystal. The output from the beta counter scaler was recorded on a fast running Esterline-Angus recorder. From these data the beta counting rate as a function of time was obtained, and the half life of the Ge^{77m} was determined to be 53.6 ± 0.9 sec. The beta counting efficiency of this counting arrangement was calibrated by use of a standard containing a known disintegration rate of $Ru^{106}-Rh^{106}$. Thus, the total amount of induced Ge^{77m} decaying by beta emission was found, and by use of the flux determined from the manganese monitor, the pile cross

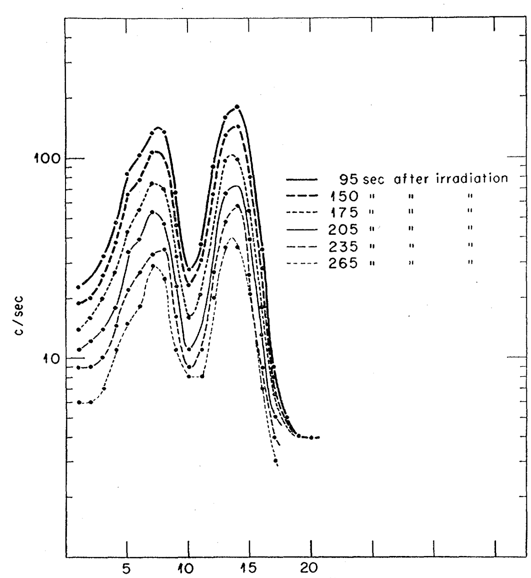


FIG. 1. γ-ray spectrum of Ge^{77m}.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Nuclear Company.
[1] D. J. Hughes and J. A. Harvey, *Neutron Cross Sections*, Brookhaven National Laboratory Report BNL-325 July, 1955 (Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., 1955).
[2] Burson, Jordan, and Leblanc, Phys. Rev. **96**, 1555 (1954).
[3] S. A. Reynolds in Oak Ridge National Laboratory Report ORNL-867, 1950 (unpublished).
[4] J. R. Arnold and N. Sugarman, Argonne National Laboratory Report Cl-3785, 1947 (unpublished).
[5] E. der Mateosian and M. Goldhaber, Bull. Am. Phys. Soc. Ser. II, **2**, 16 (1957).
[6] E. Segrè and A. C. Helmholtz, Revs. Modern Phys. **21**, 271 (1949).

section for this path was calculated to be 0.10±0.01 barn.

Simultaneously with the beta-decay measurements, data concerning the gamma-ray spectrum were being obtained from the 3 in.×3 in. NaI crystal, the signal from which was fed into a 20-channel pulse-height analyzer.[7] Cumulative counts were recorded for a ten-second interval every thirty seconds. These data showed the presence of two gamma-ray photopeaks at 0.16 Mev and 0.22 Mev (Fig. 1). In addition, a shoulder was observed on the low-energy side of the 0.16-Mev gamma ray, which was attributed to a slight amount of 0.14-Mev gamma ray from the 49-sec isomeric state in Ge^{75}. The 0.22-Mev gamma ray is associated with the beta decay in Ge^{77m},[2] and since it is presumably an $M1$ transition should be almost completely unconverted. Consequently, the ratio of total number of 0.22-Mev gamma rays to the total number of beta transitions should indicate the gamma branching in this decay. The number of gamma rays (I_γ) was obtained from the observed number ($P_{(\gamma)}$) by the expression:

$$I_\gamma = P_{(\gamma)}/E_p\Omega,$$

where E_p is the experimentally determined peak efficiency for the particular crystal and geometry and Ω is the fraction of the total solid angle subtended at the source. The ratio $0.22\theta\gamma/\beta$ was found to be 0.28 ±0.05. Burson *et al.*[2] indicated it to be about 0.09.

In a similar manner the total number of 0.16-Mev gamma rays was obtained. The cross section calculated using just the absolute number of gamma rays as the activity of Ge^{77m} isomeric transition was found to be 0.019±0.002 barn. However, nuclear shell theory predicts for the transition an upper level state of $p_{1/2}$ and a lower level of $f_{7/2}$ making this transition $E3$. The observed half-life of 54 seconds is in accord with this assignment.[8] By use of the theoretical K conversion coefficient of Rose *et al.*,[9] correction was made for conversion under the assumption of an $E3$ transition. The cross section for the total transition (gamma$+e_K$) was then calculated to be 0.037±0.005 barn.

The total cross section for the production of Ge^{77} by both processes (i.e., direct neutron capture to Ge^{77} or decay of Ge^{77m} to Ge^{77}) may be obtained by irradiating the germanium a length of time such that the production through the Ge^{77m} branch is constant, yet short enough so that no large amount of the As^{77} has built up. Irradiations of one hour were made in the reactor, and the beta decay of the Ge^{77} activity formed was followed by use of both an end-window beta proportional counter, and an end-window Geiger-Mueller counter. To minimize interference by any As^{77} or Ge^{75} found, the activity was measured through both a 270-mg/cm² aluminum absorber and a 555-mg/cm² absorber. Half-life data obtained through both absorbers were in agreement and indicated the half-life of Ge^{77} to be 11.3±0.3 hours. The counting efficiency of the counters was obtained by calibration with standard sources of 4π-counted Y^{90}. The data of Burson *et al.*[2] indicate that the decay of Ge^{77} is largely through the 2.1-Mev and 2.7-Mev beta branchings. The observation that the Ge^{77} activity calculated from the data obtained through both the 270-mg/cm² absorber and the 555-mg/cm² absorber agreed within a few percent, indicates that this assumption and the use of Y^{90} as a standard is not unreasonable. Upon using these data, the pile-neutron "total cross section" for production of Ge^{77} is found to be 0.043±0.002 barn. Since the cross section for production of Ge^{77} through Ge^{77m} (assuming an $E3$ transition) is 0.037±0.005 barn, the cross section for direct production of Ge^{77} is seen to be very low, 0.006 ±0.005 barn

TABLE I. Decay properties of Ge^{77} and Ge^{77m}.

Active product	Observed half-life	Pile activation cross section for production (barns)
Ge^{77m}		
β	53.6±0.9 sec	0.10 ±0.01
I.T. (γ)		0.019±0.002
I.T. (corr.)		0.037±0.005
Ge^{77}	11.3±0.3 hours	
Total		0.043±0.002
Direct		0.006±0.005
Ge^{77m}(0.22-Mev γ/β) = 0.28±0.05		

DISCUSSION AND CONCLUSIONS

Table I summarizes the findings of this work. The values for the activation cross sections in Ge^{76} differ considerably from earlier measurements. Our pile cross section for the total production of Ge^{77} (0.043 barn) is in good agreement with the thermal neutron cross section of der Mateosian and Goldhaber[5] (0.05 barn). Our result for the total observed production of Ge^{77m} (0.14 barn) is considerably higher than theirs (0.06 barn); however, it lends even stronger confirmation to the rule of Segrè and Helmholtz.[6]

[7] Bell, Kelley, and Goss, Oak Ridge National Laboratory Report ORNL-1278, 1951 (unpublished).
[8] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
[9] Rose, Goertzel, Spinrad, Harr, and Strong, Phys. Rev. **83**, 79 (1951).