SHORT-LIVED ISOMERS OF Ga, Ge, AND As PRODUCED BY 19.2-Mev PROTONS

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Improved data are presented relating to the short-lived isomers previously observed when gallium, germanium, and arsenic were irradiated with fast protons.[1,2] A more detailed investigation revealed two short-lived activities in germanium, one of which is produced in the reaction $Ge^{76}(p, 2n)As^{75m}$ and the other apparently in $Ge^{72}(p, pn)Ge^{71m}$. The isomeric activities which followed the bombardment of gallium and arsenic were shown to result from $Ga^{71}(p, n)Ge^{71m}$ and $As^{75}(p, p')As^{75m}$, respectively. The energy dependence of the cross sections for $Ga^{71}(p, n)Ge^{71m}$ and $Ge^{76}(p, 2n)As^{75m}$ were measured from the reaction threshold to 19.2 Mev.

THE present experiments were stimulated by the fact that in earlier irradiation of gallium with fast protons an error in the reaction-threshold measurement led to incorrect identification of the reaction which produced a short-lived isomer.[2] The technique used in the present measurements was described in detail in reference 3. As in the earlier work, a proton beam impinging on an internal target was used in the measurement of excitation curves. Protons were counted by means of a current integrator connected to the target.

Arsenic. The present investigation showed that the gamma emission which we had detected in proton-irradiated metallic arsenic[2] has the energy $E_\gamma = 0.29 \pm 0.01$ Mev and half-life $T_{1/2} = 15.6 \pm 0.4$ millisec, in good agreement with our earlier results.[2] The excitation curve of the isomeric activity was measured using a thick arsenic target. Figure 1 shows that the isomeric level is excited by protons with $E_p \leq 2$ Mev. This result, as well as the good agreement with the corresponding data for As^{75m} from arsenic irradiated with 22-Mev gamma rays[4] ($E_\gamma = 284 \pm 5$ kev and $T_{1/2} = 17 \pm 1$ millisec), confirms our earlier identification of the reaction as $As^{75}(p, p')As^{75m}$.[2]

Gallium. In the investigation of short-lived gamma rays from metallic gallium bombarded with fast protons we improved our earlier data for the isomer,[2] obtaining $E_\gamma = 0.18 \pm 0.01$ Mev and $T_{1/2} = 19.4 \pm 0.4$ millisec (instead of $E_\gamma = 0.19 \pm 0.01$ Mev and $T_{1/2} = 19.0 \pm 1.0$ millisec). Experiments with enriched gallium isotopes confirmed the fact that this isomer is produced through a reaction in Ga^{71}. Figure 2 represents the measurement of the cross section for the production of this isomer as a function of proton energy. The shape of the curve and the measured reaction threshold (below 2 Mev) indicate the reaction $Ga^{71}(p, n)Ge^{71m}$. Numerous measure-

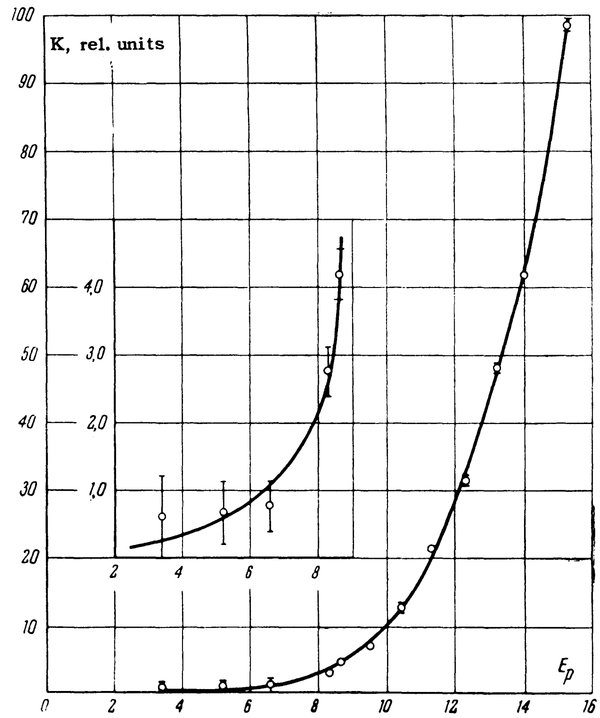

FIG. 1. Yield of short-lived isomer As^{75m} (from a thick arsenic target) as a function of proton energy. Statistical errors are indicated. The background from a neutral (carbon) target was taken into account. The pulse-height analyzer had a 10-volt channel width; the photomultiplier gate of length $\tau = 55$ millisec was delayed 3.7 millisec following the start of the proton pulse. The isomer yield at the reaction threshold is also shown on a larger scale.

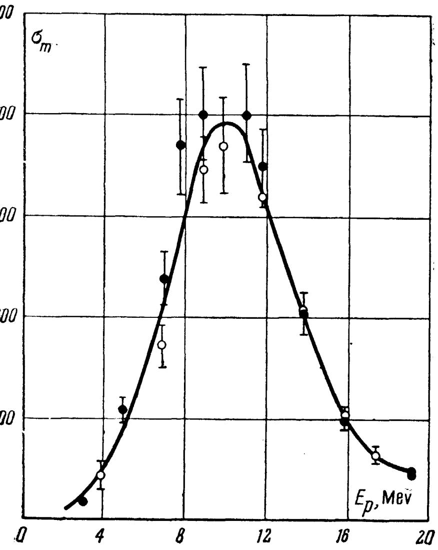

FIG. 2. Cross section (in millibarns) for Ge^{71m} production as a function of proton energy. The target was gallium oxide with 24.7 mg/cm² surface density. The black and open circles represent measurements on different days. The rms errors were calculated from the formula for the reaction threshold given in reference 3.

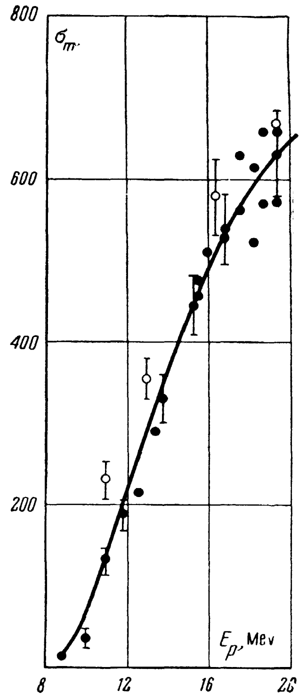

FIG. 3. Cross section (in millibarns) for As^{75m} production as a function of proton energy, from a 28.1-mg/cm² germanium oxide target.

ments yielded $\sigma_m = 50 \pm 6$ mb for the production of the isomer by 19.2-Mev protons.

The decay scheme of Ge^{71} is known. Transition energies of ~23 and ~175 kev in the decay of As^{71} have been reported in references 5 and 6. It was established that the two lines are in cascade and belong to Ge^{71}. Both groups of investigators have proposed a decay scheme for Ge^{71} on the basis of shell theory, β-decay theory, and data from other authors. The more likely scheme, in our opinion, is given in reference 6:

$$g_{9/2} \xrightarrow[M2]{23,3\text{ keV}} f_{5/2} \xrightarrow[E2]{174,5\text{ keV}} p_{1/2}.$$

The lifetime of the $f_{5/2}$ level is $\sim 0.07 \times 10^{-6}$ sec.[5] No measurements were obtained for the lifetime of the $g_{9/2} \rightarrow f_{5/2}$ transition, although $\sim 10^{-3}$ sec was the expected value.[6] In the different decay scheme given in reference 5, spin and parity $7/2^+$ are assigned to the 198-kev level, in conjunction with a $7/2^+ \rightarrow 5/2^-$ electric dipole transition. We have estimated $\lesssim 10^{-11}$ sec for the lifetime of a ~23-kev E1 radiative transition.

A comparison of the short-lived emitted energy which we observed in Ge^{71} decay with the data in references 5 and 6 indicates clearly that $T_{1/2} = 19.4$ millisec pertains to a ~ 198-kev level. Our value $E\gamma = 0.18$ Mev agrees with the value ~ 175 kev given in references 5 and 6. Low-energy emission (~ 23 kev) was not registered by our apparatus. We note that the theoretical[6] internal conversion coefficient for an M2 transition at ~23 kev is ~500.

A 0.17-Mev emission with half-life 16 ± 1 millisec was also observed when germanium was bombarded with 14-Mev neutrons.[7] The cross section (~ 0.3 barn) for isomer production in this case indicated the highest likelihood of a (n, 2n) reaction, and that this reaction cannot occur in Ge^{73} and Ge^{76}. Assuming that the radiation which we had previously observed[1] in proton-bombarded gallium and the radiation from neutron-bombarded germanium belong to the same isomer, and assuming also that the level scheme of Ge^{71} includes a 0.17-Mev state, it was suggested in reference 7 that Ge^{71m} had most probably been detected.

Germanium. When metallic germanium was irradiated we observed not one,[2] but two γ lines with $E\gamma_1 = 0.17 \pm 0.01$ Mev and $E\gamma_2 = 0.30 \pm 0.01$ Mev, and with half-lives 19.2 millisec and 16.3 ± 0.3 millisec, respectively. It has been shown in our earlier work that the 0.30-Mev line with 16-millisec half-life belongs to As^{75m} from $Ge^{76}(p, 2n)As^{75m}$.[2] This identification is confirmed by the shape of the curve (Fig. 3) representing our measurements of the production cross section for this isomer as a function of proton energy. The computed threshold for $Ge^{76}(p, 2n)As^{75}$ is ~ 9.2 Mev.

Several measurements yielded $\sigma_m = 6.35 \pm 60$ mb for the production of As^{75m} by 19.2-Mev protons.

The good agreement between the results $E\gamma_1 = 0.17$ Mev and $T_{1/2} = 19.2$ millisec from proton-

Target	Gamma-ray energy, Mev	Half-life, millisec	Cross section, mb	Yield from thick target, rel. un.	Reaction
Ga	0.18±0.01	19.4±0.4	50±6	2	Ga^{71} (p, n) Ge^{71m}
Ge	0.17±0.01	19.2	—	—	Ge^{72} (p, pn) Ge^{71m}
	0.30±0.01	16.3±0.3	635±60	2	Ge^{76} $(p, 2n)$ As^{75m}
As	0.29±0.01	15.6±0.4	—	0,2	As^{75} (p, p') As^{75m}

irradiated germanium, and the emission that we observed in gallium ($E\gamma = 0.18$ Mev, $T_{1/2} = 19.4$ millisec) and which we identified as belonging to Ge^{71m}, suggests that in proton-irradiated germanium in addition to As^{75m} an isomer of Ge^{71} is formed [Ge^{72}(p, pn)Ge^{71m} with the computed reaction threshold ~ 11.2 Mev].

We also measured the yields of isomeric activities in thick targets of gallium ($E\gamma = 0.18$ Mev), germanium ($E\gamma = 0.30$ Mev), and arsenic ($E\gamma = 0.29$ Mev), irradiated with 19.2-Mev protons. These yields were, as previously, compared with that of the short-lived isomeric activity ($E\gamma = 0.37$ Mev) from a thick tantalum target.[3]

The results of the present investigation are given in the table.

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