NEW SHORT-LIVED ISOMERS As$^{75m}$ AND Ga$^{70m}$ EXCITED BY FAST PROTONS

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In earlier work we observed short-lived isomeric activity in germanium bombarded with fast protons ($E_p = 0.31$ Mev, $T_{1/2} = 17.5 \pm 2.0$ msec).\(^1\) Through comparison with the results obtained by other investigators\(^2,3\) this was identified as belonging to As$^{75m}$ from the reaction Ge$^{76}(p,2n)$As$^{75m}$. This identification has been confirmed by Vegors and Axel\(^4\) as 75 m from the reaction Ge$^{76}(p,2n)$As$^{75m}$. This short-lived isomer with $E_y = 0.01 \pm 0.01$ Mev and $T_{1/2} = 19 \pm 1$ millisecond was discovered in our laboratory during 1957\(^5\) through neutron bombardment of germanium. The good agreement of these values with those obtained in the present work suggests that the same isomeric level is involved in both instances.

There are two stable gallium isotopes (69, 71) and five stable germanium isotopes (70, 72, 73, 74, 76). An analysis of the possible reactions between protons and gallium nuclei and between neutrons and germanium nuclei which would result in the same isomeric level shows that the excited nuclei of Ga$^{70}$, Ge$^{70}$, Ge$^{71}$, or Ge$^{71}$ could be the final reaction products. Ge$^{70}$: which is an even-even nucleus, is excluded. Thus only the following proton-gallium reactions can produce these excited nuclei: Ga$^{71}(p, pn)$Ga$^{70}$, Ga$^{69}(p, n)$Ge$^{70}$, and Ga$^{71}(p, n)$Ge$^{71}$. The experimental thresholds for the production of these nuclei in their ground states are 9.4, 1.1, and 1.0 Mev, respectively.\(^10\)

Using enriched gallium isotopes (with Ga$^{69}$ enriched from 60.2 to 97.6% in one instance and depleted to 1.3% in another instance) we determined that Ga$^{71}$ is involved in a reaction where a short-lived level is formed. The experimental threshold of this reaction for a thick target is about 9 Mev. We can thus infer that the aforementioned level $E_y = 0.19$ Mev belongs to Ga$^{70m}$ produced in the reaction Ga$^{71}(p, pn)$Ga$^{70m}$. Glagolev et al. observed this level through the reaction Ge$^{70}(n,p)$Ga$^{70m}$. The half-life for an E3 transition is estimated to be of the order 10$^{-2}$ sec, which agrees with experimental results.

The ground-state spin of Ga$^{70}$ is 1$^+$. If the spin of the excited Ga$^{70}$ state is assumed to be 4$^-$, which is likely for a number of reasons, the observed short-lived isomeric transition is of the E3 type.


O. B. Likin, Приборы и техника эксперимента (Instruments and Measurement Engg.) 2, 000 (1958).


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ON A RELATION IN QUANTUM STATISTICS

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As is well known, the density matrix $\rho$ of a canonical ensemble has the form

$$\rho = e^{-\beta H}, \quad H = H_0 + H_1 = \sum [H_0(x) + H_1(x)] dx,$$

where $\beta = 1/kT$; $H$ is the Hamiltonian of the system; $H_0$ is the "free" Hamiltonian (in general it may also partially take into account the interaction between the particles, for example in the Hartree-Fock approximation); $H_1$ is the interaction Hamiltonian.

Let us take instead of $H$ the Hamiltonian $H_\lambda = H_0 + \lambda H_1$. Then

$$-\frac{\partial \rho}{\partial \lambda} = (H_0 + \lambda H_1) \rho.$$  

(2)

Following the general methods of the $S$ matrix (cf. e.g., reference 1), we write down the formal operator solution of Eq. (2):

$$\hat{\rho} = e^{-\beta H_0} T \left\{ \exp \left\{ -\lambda \int H_1(x) dt dx \right\} \right\},$$

(3)

where $T$ calls for arrangement of the operators from right to left in the order of increasing $t$, and any operator $f(x,t)$ is connected with $f(x)$ by the relation

$$f(x,t) = e^{\lambda t} f(x) e^{-\lambda t}.$$  

(4)

To determine all the thermodynamic quantities it is sufficient to know the function

$$Z = \ln \text{Sp} e^{N \lambda H},$$

(5)

where the averaging ($\text{Sp}$) is taken over a complete orthogonal system of eigenfunctions of the Hamiltonian $H$ or of $H_0$; $N$ is the operator for the total number of particles and commutes with the total Hamiltonian; $\alpha = \beta \mu$, where $\mu$ is the chemical potential. Using Eqs. (5) and (3), one can easily verify that

$$\frac{\partial Z}{\partial \lambda} = -\text{Sp} \left\{ \exp (\alpha N - \beta H_0) \times \int [\bar{H}_1(x) dx dt] \right\} \text{Sp} \left\{ \exp (\alpha N - \beta H_0) \right\},$$

(6)

where $\bar{H}_1(x) = e^{H_0} H_1(x) e^{-H_0}$ (i.e., the operator in the Heisenberg representation).

From Eq. (6) it follows that

$$Z = Z_{\lambda=0} - \int_0^1 \frac{\text{Sp} \left\{ \exp (\alpha N - \beta H_0) \times \int [\bar{H}_1(x) dx dt] \right\}}{\text{Sp} \left\{ \exp (\alpha N - \beta H_0) \right\}} d\lambda,$$

(7)

where $Z_0$ is the known expression for $Z$ when $H = H_0$. It can be shown that the expression in the integrand of Eq. (7) is

$$\frac{1}{\lambda} \int [M(x, x') G(x', x) dx dt dx'] d^3x' d^3x,$$

where $M$ is the mass operator for the "one-particle" Green's function $G(x', x)$ (integration with respect to $x$, $x'$ from 0 to $\beta$).

In the case in which $H_0$ does not contain the charge $g$, we can take the charge $g$ as the parameter $\lambda$, and $Z$ takes the form

$$Z = Z_0 - \frac{g}{\lambda} \int [M(x, x') G(x', x) dx dt dx'] d^3x' d^3x.$$  

(8)