DECAY OF SOME MILLISECOND ISOMERS

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Isomer states of Ge^{71}, Y^{88}, Nb^{90}, and Pm^{141} nuclei were obtained in nuclear reactions with targets irradiated with ~20-MeV protons. Energy spectra of the isomeric γ decay and of internal conversion electrons were measured. The total internal conversion coefficient was determined for all investigated isomers. A more exact value of the half-life for the isomeric state of the Nb^{90} nucleus is obtained. Possible decay schemes are discussed on the basis of the data obtained.

THE METHOD

THE work was carried out with a linear accelerator, which yielded protons with energy ~20 MeV. The general experimental setup was similar to that described earlier [1]. The isomeric activities were investigated during the intervals between the accelerator runs. The spectra of the γ rays and of the conversion electrons were measured with a single-channel pulse-height analyzer. A special circuit made it possible to subtract the background during the measurements of the γ- or β-ray spectra from the long-period activities produced on the target during the irradiation process. The γ quanta were registered with an NaI crystal measuring 30 × 15 mm, while the conversion electrons were registered with an anthracene crystal. The absolute yield of the γ rays was determined from the area of the photopeak. The photoefficiency with which our NaI crystal registered γ quanta was calculated by the Monte Carlo method in the energy range 0.06–1.5 MeV and was known under the real experimental conditions with accuracy not worse than 5%.

Thin targets (~10 mg/cm^2) were used in the measurements, namely Ge and Zr metal foils in the investigation of Ge^{71m} and Nb^{90m}, and oxide films (on an organic substrate) of SrO and Nd_2O_3 for the measurement of the activities of Y^{88m} and Pm^{141m}. The monitoring was with a Faraday cylinder by the proton current through the target.

RESULTS

Ge^{71m}. The isomer Ge^{71m} was obtained as the result of two reactions: $Ge^{72}(p, pn)Ge^{71m}$ and $Ga^{71}(p, n)Ge^{71m}$. [2] In both cases γ radiation with energy $E_\gamma = 170 \pm 10$ keV and half-life $T = 19.5 \pm 0.5$ msec was observed. The spectrum of the isomeric γ radiation (Fig. 1a) also has a weak peak corresponding to $E_\gamma = 130–140$ keV, which we assume to be the peak of the emission of the iodine x-radiation from the NaI crystal. The conversion-electron spectrum (Fig. 1b) consists of one peak corresponding to a transition with energy 170 keV. The total internal-conversion coefficient which we obtain for this transition is $\alpha = 0.12 \pm 0.03$. This value corresponds to two possible types of transition, either M2 with calculated value $\alpha_{theor} = 0.12$ [3] or E2 ($\alpha_{theor} = 0.09$).

Thus, the data we obtained confirm the assumption that the isomeric transition is the 23-keV transition to the 175-keV level, known from the As^{71} decay [4].

$$ {}^9/_2{}^+ \xrightarrow{23\,\mathrm{keV}} {}^5/_2{}^- \xrightarrow{175\,\mathrm{keV}} {}^1/_2{}^- . $$

Y^{88m}. The isomeric state of Y^{88m} with half-life $T = 13.5 \pm 0.5$ msec is obtained from the reactions

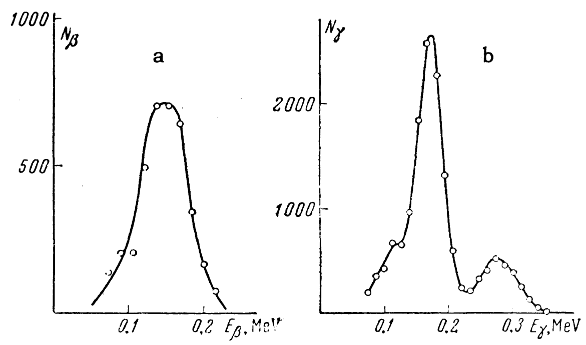

FIG. 1. Spectrum of γ radiation (a) and of the conversion electron (b) of Ge^{71m}. The abscissas represent the energy and the ordinates the number of counts in the analyzer channel. The 0.28-MeV peak in the γ-ray spectrum corresponds to radiation of the isomeric As^{75m}, which is produced on the Ge target in accord with the reaction $Ge^{76}(p, 2n)As^{75m}$.

$Sr^{88}(p, n)Y^{88m}$ and $Y^{89}(p, pn)Y^{88m}$ when Sr and Y are irradiated with protons [5].

The γ-radiation spectrum consists of two transitions of approximately equal intensity, $E_\gamma = 0.23 \pm 0.01$ and $E_\gamma = 0.45 \pm 0.01$ MeV. The total conversion coefficient measured on a SrO target turned out to be $\alpha < 0.04$ for the 0.23-MeV transition and $\alpha < 0.01$ for the 0.45-MeV transition. From a comparison of the obtained values of α with the calculated ones it follows that for the 0.23-MeV transition the possible γ-transition multipolarities are E1, E2, and M1 (most probably E2, $\alpha_{theor} = 0.049$), while for the 0.45-MeV transition the possible multipolarities are E1, E2, and M1.

It follows from these results that probably neither of the observed transitions is isomeric. The energy spectrum of the γ rays of Y^{88m} was measured by us down to ~ 30 keV. It must therefore be suggested that the isomeric transition in Y^{88} is a transition with energy < 30 keV, and the observed two γ lines are in cascade with it (Fig. 2).

$\underline{Nb^{90m}}$. The millisecond isomer Nb^{90m} is produced in the $Zr^{90}(p, n)Nb^{90m}$ reaction [5]. The levels of the Nb^{90} nucleus were investigated in the decay of Mo^{90} by Mathur and Hyde [6], who, however, were unable to establish the exact types and multipolarities of the two isomeric transitions in Nb^{90}. In the present work we investigated the millisecond transition in Nb^{90} from the 0.37 MeV level to the 0.12 MeV level [7]. The value we obtained for the total conversion coefficient at 0.25 MeV is $\alpha = 0.3 \pm 0.05$. From a comparison with the calculated values of α for the different transitions, namely 0.17, 0.74, 0.09, 0.4, and 1.86 for the E3, E4, M2, M3, and M4 transitions, respectively, it follows that this is an M3 transition. From the data [8] on the β decay of Mo^{90} to the 0.37 MeV level of Nb^{90} it follows that the spin and parity of this level should be 1^+.

According to the existing empirical rule for odd-odd nuclei [9] with one proton and one neutron hole in one and the same state ($1g_{9/2}$ level for Nb^{90}), the ground-state spin should be one less than the maximum possible, i.e., the ground state of Nb^{90} should be ascribed a spin 8 and even

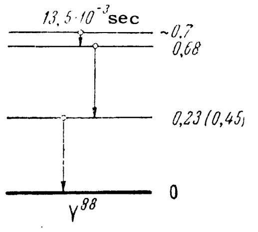

FIG. 2. Scheme of decay from the isomeric level of Y^{88} (the level energies are in MeV).

parity. Then, taking our data into account, the $Mo^{90} \rightarrow Nb^{90}$ decay scheme should have the form

$$0^+ \xrightarrow{\beta+} 1^+ \xrightarrow{M3} 4^+ \xrightarrow{E4} 8^+.$$

It must be noted that an analysis based on nomograms for the radiative-transition probabilities [10] shows that for a transition from the 0.12-MeV isomeric level of the Nb^{90} nucleus to the ground state we obtain a much better agreement with the experimental value of the half-life (T = 24 sec) if this transition is regarded as magnetic octupole. Thus, $T_{theor} = 5 \times 10^7$ sec for a transition of the E4 type and $T_{theor} = 40$ sec for the M3 transition. In this case we must assume for the ground state of the Nb^{90} nucleus a value of 7 for the spin and even parity, as given by Dzhelepov and Peker [7].

We measured the half-life of Nb^{90m} from the 0.37 MeV level using a multichannel time analyzer. The value we obtained, $T = 6.5 \pm 0.5$ msec, is much shorter than given in [6,5]. The γ-ray and conversion-electron spectra are shown in Fig. 3.

$\underline{Pm^{141m}}$. The isomer Pm^{141m} (T = 2.2 msec) was investigated by us in accordance with the $Nd^{142}(p, 2n)Pm^{141m}$ reaction. [11] In measuring the spectrum of the conversion electrons we obtained a clear-cut peak corresponding to a transition with energy ~ 200 keV, and a weak peak due to a 430-keV transition (Fig. 4b). For the 430-keV transition we have $\alpha \approx 0.03$. This result refutes our previous assumption regarding the decay scheme of Pm^{141m} [11]. For the 430-keV transition the possible multipolarities are M1 ($\alpha = 0.024$) or E2 ($\alpha = 0.019$). Our assumption that the 430-keV transition is of the M3 type was based on the intensity of this γ line being approximately half the intensity of the line with ~ 200 keV. We can now attribute this fact to the presence in the 200 keV region of two γ lines, which we did not resolve in energy. Indeed, a more thorough investigation shows that the peak is split in the 200 keV region (Fig. 4a).

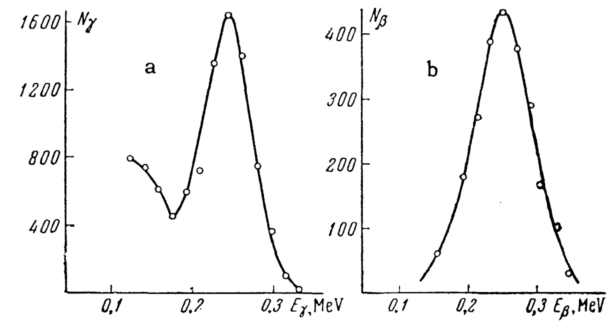

FIG. 3. Spectrum of γ radiation (a) and conversion electron (b) of the millisecond transition in Nb^{90}.

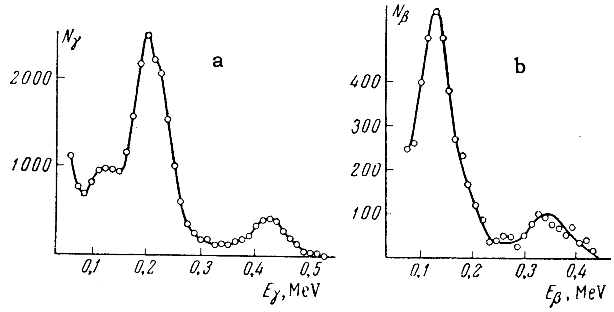

FIG. 4. Spectrum of γ radiation (a) and conversion electrons (b) of Pm^{141m}.

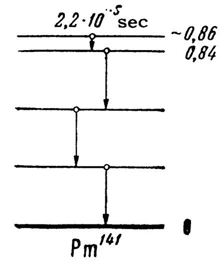

FIG. 5. Scheme of decay from the isomeric level of Pm^{141} (the level energies are in MeV).

We can now regard it as established that the spectrum of the γ radiation from Pm^{141m} consists of lines with energies $E_\gamma = 190 \pm 10$ keV, $E_\gamma = 220 \pm 10$ keV, and $E_\gamma = 430 \pm 10$ keV. The 430-keV transition is apparently not isomeric. Either the 190- or the 220-keV can be isomeric. Since we were unable to resolve these two lines, our data can be used only to estimate the value of α for one of the transitions, neglecting conversion in the second transition. According to this estimate $\alpha = 0.4$. The theoretical values are 0.04, 0.18, 0.93, 0.21, 1.17, and 5.4 for E1, E2, E3, M1, M2, and M3, respectively. We see that the obtained value of α agrees with neither of the theoretical values. We note that an account of the conversion from the second line should reduce the obtained estimate. This indicates that these two transitions are likewise not isomeric. We propose that the conversion of both lines is approximately the same ($\alpha \approx 0.2$). Then the possible multipolarities of the 190- and 220-keV transitions are M1 and E2. Consequently, the transition with low energy should also be isomeric. We have investigated the γ spectrum of Pm^{141m} down to ~ 50 keV. The isomeric transition apparently has therefore an energy less than 50 keV (Fig. 5).

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