FIRST OBSERVATION OF EXCITED STATES IN ^{140}Dy*

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A new 7 μs isomer in the drip line nucleus ^{140}Dy was selected from the products of the ^{54}Fe (315 MeV) + ^{92}Mo reaction by a recoil mass spectrometer and studied with recoil-delayed γ–γ coincidences. Five cascading γ transitions were interpreted as the decay of an $I^{\pi} = 8^{-}$ $\{\nu 9/2^{-}[514] \otimes \nu 7/2^{+}[404]\}$ K isomer via the ground state band.

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In an experiment performed at the Holifield Radioactive Ion Beam Facility at Oak Ridge National Laboratory we observed for the first time a 7 μs isomer in the drip line nucleus ^{140}Dy [1]. The ^{140}Dy ions were populated in the $2p4n$ channel of the ^{54}Fe (315 MeV) + ^{92}Mo reaction, and selected by the Recoil Mass Spectrometer [2]. The RMS acceptance allowed us to collect the recoils produced within a half of the nominal 1 mg/cm^2 target thickness. The recoils, separated according to their mass $A = 140$ and charge $Q = +27$, with the energy of 92 MeV ($\pm$ 10%), were implanted in a passive catcher placed in the center of the Clover Detector Array for Recoil Decay Spectroscopy which consisted of 5 segmented Clover Germanium detectors. A Multichannel Plate Detector [3] provided a reference time for the recoil implantation and enabled a recoil-delayed γ–γ coincidence study.

We have identified a new cascade of γ-rays at 202, 364, 476, 550 and 574 keV with a half-life of 7.0(5) μs correlated with the implantation of the selected $A = 140$ recoils (see Fig. 1, left panel). The five γ lines are in coincidence with each other, and with Dy K X-rays, which places them in one cascade in ^{140}Dy.

Basing on the intensities and energies of the transitions a level scheme shown in Fig. 1 (right panel) was constructed. It resembles a rotational band in a deformed nucleus fed by an isomeric level. A comparison to the decay patterns of $I^{\pi} = 8^{-}$ K isomers in the less exotic $N = 74$ even isotones of ^{134}Nd, ^{136}Sm and ^{138}Gd displayed in Fig. 1 shows striking similarity. This leads us to the interpretation of the isomeric level at 2166 keV as an $I^{\pi} = (8^{-})$ $\{\nu 9/2^{-}[514]\otimes\nu 7/2^{+}[404]\}$ K isomer decaying via the $8^{+} \rightarrow 6^{+} \rightarrow 4^{+} \rightarrow 2^{+} \rightarrow 0^{+}$ cascade belonging to the ground-state band in ^{140}Dy. Our findings were recently confirmed in an independent experiment [4].

The isomeric level is placed at an excitation energy close to the 2150 keV predicted in [5] for this two-quasineutron configuration. A hindrance per degree of K-forbidness f_{ν} was determined to be 24.5(3), a value very close to the ones found for less exotic $N = 74$ isotones displayed in Fig. 1. This suggests that the configuration and properties of this K isomer in ^{140}Dy are not affected by the proximity of the proton drip line.

We measured a 40 μb cross-section (accounting for about 0.5 mg/cm^2 active target thickness) for population of the 8^{-} isomer. This value is comparable with the 30 μb total ^{140}Dy production cross-section predicted by the HIVAP code [6] and indicates that major part of the high-spin states populated in the evaporation residue deexcite via the 8^{-} isomer.

Such a sizable population of the isomer is surprising since one would expect more deexcitation strength to go through the ground state band thus bypassing the isomer. In case of the neighboring $N = 74$ isotone ^{138}Gd it has been found that only a 1.4 % fraction of the evaporation residue cross section populates the analog 8^{-} isomer [7].

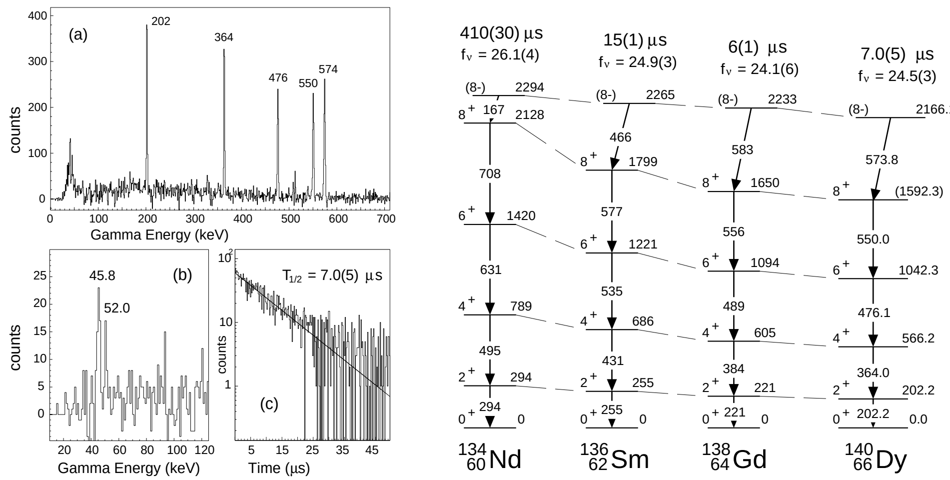

Fig. 1. ^{140}Dy γ lines from the decay of the $I^\pi = (8^-)$ isomer obtained from double γ coincidence data by adding five spectra gated on the labeled transitions — panel (a). Dysprosium K_α and K_β X rays in coincidence with the sequence of five new γ lines from triple γ coincidence data — panel (b). Decay pattern produced by double-gating on five transitions — panel (c). Systematics of the decay properties of $I^\pi = 8^-$ isomers in $Z \geq 60$, $N = 74$ isotones and the proposed ^{140}Dy level scheme — right panel.

To estimate the energy gap between the 8^- isomer and the so far unobserved 10^+ state in ^{140}Dy we used the established ground-state band energies to calculate the 10^+ energy within a cranked mean field model [8, 9]. An approximate value of 2200 keV for the 10^+ energy was obtained [10], which places the 10^+ state only 30 to 40 keV above the 8^- isomer. This is similar to the relative placing of 10^+ in ^{138}Gd where it has been found 33 keV above the 8^- isomer [7, 11]. The energy gaps between the 10^+ and 8^- states in ^{140}Dy and ^{138}Gd are alike and can not explain the difference in the isomer *vs* ground-state band population.

Following the global systematics of the ground to the first-excited 2^+ state transitions in even–even nuclei of Raman *et al.* [12] the observed excitation energy of the first 2^+ state gives a deformation parameter $\beta_2 \approx 0.234$ for ^{140}Dy. This is a somewhat smaller quadrupole deformation than the previously anticipated values (see *e.g.* [5,13]) but it is close to the $\beta_2 = 0.25$ derived from the observed level schemes of $^{141\text{gs},m}$Ho [14].

The experimental level scheme of ^{140}Dy provided reliable input for the predictions of proton emission rates from $^{141\text{gs},m}$Ho. Moreover, the precisely known energy of 2^+ state in ^{140}Dy was an essential aid in the search for a fine structure in ^{141}Ho proton decay [15].

Further experimental efforts are needed to better understand the structure of drip-line nucleus ^{140}Dy. In-beam gamma spectroscopy studies should be aimed at extending the ground state band above the 8^+ level. For such studies one should consider the use of ancillary detectors *e.g.* charged particle and neutron detectors for the selection of weak reaction channel. Also, it would be particularly interesting to establish a $K^\pi = 8^-$ band built on top of the 8^- isomer. In principle this can be accomplished with the isomer decay tagging technique but the low cross-section for ^{140}Dy production is again the limiting factor.

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