Level Structure of $^{106}_{42}$Mo

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Received January 4, 1983

The level scheme of the very neutron rich nucleus $^{106}_{42}$Mo$_{64}$ has been studied for the first time through the $\beta$ decay of $^{106}_{50}$Nb. Six new excited states were observed in $\gamma$ singles and $\gamma$-$\gamma$ coincidence experiments in addition to the 2+, 4+ and 6+ members of the ground state band. The excitation energies and the deexcitation pattern suggest the interpretation of the levels at 710, 885 and 956 keV as the 2+, 3+, and 4+ states, respectively. The data support the assumption of a non-axial deformation of $^{106}_{42}$Mo. A half-life of $(1.02\pm0.05)$ s has been determined for the $\beta$ decay of $^{106}_{50}$Nb.

1. Introduction

A transition from spherical to deformed nuclear shapes is well established for the neutron rich nuclei around $A=100$. This transition is very rapid in the isotopic chains of Sr and Zr due to subshell effects, but it seems to develop more smoothly in the Mo isotopes. This is evident from the systematic behaviour of the energies of the first excited 2+ levels ($2_1^+$) which decrease regularly from 787 keV in $^{96}_{42}$Mo (where the $N=56$ subshell is closed) to 192 keV in $^{104}_{42}$Mo, while they fall off dramatically between the corresponding isotones of Sr and Zr. On the other hand the onset of deformation seems to be less pronounced in the chains of Ru and Pd as can be seen again from the $2_1^+$-energies. Thus the Mo isotopes possess an intermediate position where the change of shape around $A=100$ can be studied especially well.

The Mo isotopes with even masses have been subject to recent theoretical studies of the change of nuclear structure in this mass region. Federman and Pittel [1] explained (with the Hartree-Fock Bogoliubov method) the transition from spherical to deformed shapes on the basis of the monopole interactions of $g_{\nu/2}$ protons with $g_{\nu/2}$ neutrons. Sambataro and Molnár [2] performed calculations in the Interacting Boson Approximation (IBA) where the breaking of sub-shell closures was incorporated. Both theories indicate that the transition is located at $^{96}_{42}$Mo, $^{100}_{42}$Mo and that the heavier isotopes are deformed in the ground states. This is in agreement with the experimental findings, for example with the trend of the energies of the first excited 0+ levels ($0_2^+$) which have a minimum at $^{100}_{42}$Mo. Also in the shape coexistence pattern of Sheline et al. [3] $^{102}_{42}$Mo is interpreted as the first isotope with a deformed ground state.

The heaviest isotope which has been studied in detail up to now is $^{104}_{42}$Mo. The investigations of Kern et al. [4] showed that this nucleus has a deformed structure without being a classical rigid rotor. For $^{104}_{42}$Mo only the $2_1^+$, $4_1^+$ and $6_1^+$ levels have been observed by Cheifetz et al. [5]. The excitation energies indicate a smooth trend between $^{104}_{42}$Mo ($E_{2^+}=192$ keV) and $^{106}_{42}$Mo ($E_{2^+}=171$ keV) with an increase of deformation ($E_{4^+}/E_{2^+}=2.92$ and 3.04 for $^{104}_{42}$Mo and $^{106}_{42}$Mo, respectively). Jared et al. [6] measured the half-life of $(1.25\pm0.03)$ ns for the $2_1^+$ level which also indicates a slight increase of defor-
mation between $^{104}$Mo and $^{106}$Mo ($\beta = 0.32 \pm 0.02$ and $0.35 \pm 0.02$, respectively). The beta-decay half-life for $^{106}$Nb has been reported to be $(1.0 \pm 0.1)$ s by Wilhelmy [7] and $\sim 1$ s by Ahrens et al. [8].

The results of [5] and [6] were obtained by the study of the $\gamma$ radiation which the fragments from the spontaneous fission of $^{252}$Cf emit promptly after fission. Since these nuclei are produced with rather high spin, it is difficult, however, to identify in this way states like the heads of the $\beta$ and $\gamma$ bands which are especially sensitive to details of nuclear structure. Therefore, the $\beta$ decay of $^{106}$Nb has now been used to study the level scheme of $^{106}$Mo at the fission product separator JOSEF [9]. The major aim of these investigations was to identify – if possible – further excited low-spin states in order to check whether $^{106}$Mo is a classical symmetric rotor.

2. The Experiments

2.1. Identification of the $\gamma$ Radiation of $^{106}$Mo

At JOSEF [9] the products from thermal neutron induced fission of $^{235}$U are separated according to their masses and nuclear charges but the beam is not isotopically pure. Consequently, the nuclei of interest have to be studied in the presence of a considerable background. This is a handicap especially for nuclei with low fission yields like $^{106}$Nb, and its investigation reached the intensity limits for experiments at JOSEF.

The identification of the emitter of an investigated radiation is carried out by measuring the intensity distribution of the $\gamma$ rays as a function of the magnetic rigidity $B\rho$ of the separator. The position of its maximum $(B\rho)_{\text{max}}$ is compared with the calibration determined from known isotopes [9, 10].

For the identification of $^{106}$Mo, a $B\rho$ measurement was carried out with a gas pressure of 4 Torr He in JOSEF. A 30 cm$^3$ intrinsic Ge detector having an energy resolution of 0.7 keV at 122 keV was installed at the “off-beam” position, which is $\sim 30$ cm away from the beam deposit area. The moving tape system MARIA [10] was operated in a cycle of 2 s collection and measuring time and 0.4 s transport time. Data were accumulated for 4 h per $B\rho$ value. $B\rho$ distributions are shown in Fig. 1a for some of the $\gamma$ rays which are assigned to $^{106}$Mo. The $(B\rho)_{\text{max}}$ vs fission fragment mass calibration lines [10] are shown in Fig. 1b. The singles spectrum measured at $(B\rho)_{\text{max}}$ is shown in Fig. 2.

2.2. Beta-Decay Half-Life of $^{106}$Nb

The measurement of the half life of the $\beta$ decay of $^{106}$Nb was carried out with the 30 cc detector. In order to optimize the measurement for the $^{106}$Nb decay with respect to intensity, an electrostatic chopper was installed which can deflect the beam at the exit of JOSEF. The moving tape system was operated in a cycle of 4 s collection and measuring time and 0.4 s transport time. The fission product beam was interrupted for the first 2 s and was allowed to pass for the next 2 s. The fission products were then transported to the measuring position and the decay was observed for 4 s while a new sample

![Fig. 1. a $B\rho$ distributions for $\gamma$ rays assigned to $^{106}$Mo. The distribution of the 350.7 keV $\gamma$ ray ($4^+ \rightarrow 2^+$) is well separated from that of the 352 keV $\gamma$ ray emitted in the decay of $^{100}$Y. b $(B\rho)_{\text{max}}$ vs fission product mass. The 171.6 keV $\gamma$ ray is clearly emitted in the decay of $^{106}$Nb.](image)