IN BEAM GAMMA-RAY SPECTROSCOPY FOLLOWING ^{90}Zr(α, 2n)^{92}Mo

By A. Bałanda, R. Kulessa, W. Waluś

Institute of Physics, Jagellonian University, Cracow*

and Z. Stachura

Institute of Nuclear Physics, Cracow

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Excited states of ^{92}Mo were studied by in-beam γ-ray spectroscopy. The reaction (α, 2n) on ^{90}Zr target was used to populate the excited states which were investigated by γ-single spectra, beam-γ, γ–γ and beam-γ–γ coincidences. The excitation function and lifetimes were also measured. Several new γ lines belonging to the ^{92}Mo and a few new levels were found. The results were compared with the level positions predicted by the nuclear shell-model.

1. Introduction

The structure of ^{92}Mo and its level properties have beenstudied in few reactions [1]. Several theoretical and phenomenological investigations [2, 3] have been devoted to the properties of multi-particle states belonging to the multiplets arising from $p_{1/2}\,g_{9/2}$ configuration space. The positions of the high spin states from the work of Lederer et al. [4] agrees with the predictions of the nuclear shell-model based on the ^{88}Sr inert core.

The results of the previous works [5, 6] show that the effective two-body interactions in the $g_{9/2}$ region differ slightly if we derive them from level positions of ^{90}Zr or from ^{91}Nb data. For nuclei with $N = 28$ in the $f_{7/2}$ region, an odd-even effect in the nuclear shell-model was observed [7]. In the present work we reinvestigate the ^{92}Mo to find additional levels which could belong to the multiplets arising from $p_{1/2}\,g_{9/2}$ configuration space (see also [8]). New information was obtained mainly from the γ–γ and beam –γ–γ coincidences. Results are presented in Section 2. In Section 3 we compare our results with

* Address: Instytut Fizyki UJ, Reymonta 4, 30-059 Kraków, Poland.

the predictions of the model using the effective two-body interactions published earlier [9], as well as interactions derived from the existing experimental data for ^{92}Mo. The effective two-body interactions derived from the present experimental data show the odd-even effect also in the $g_{9/2}$ region [10].

2. *Experimental*

The excited states of ^{92}Mo were populated using the (α, 2n) reaction on ^{90}Zr. The target was prepared from ZrO_2 enriched in ^{90}Zr on a thin mylar foil. Targets with thickness from 5–25 mg/cm^2 were used in different experiments. The measurements were performed using the C-120 cyclotron of the Institute of Nuclear Physics in Cracow. The beam size at the target position was usually 5 mm and the beam current about 2 nA or less. The cyclotron beam was bunched with a repetition time of about 100 ns. Standard ORTEC equipment was used. The experimental conditions were similar to those described in paper [5]. The data accumulation was performed using a PDP-11 minicomputer.

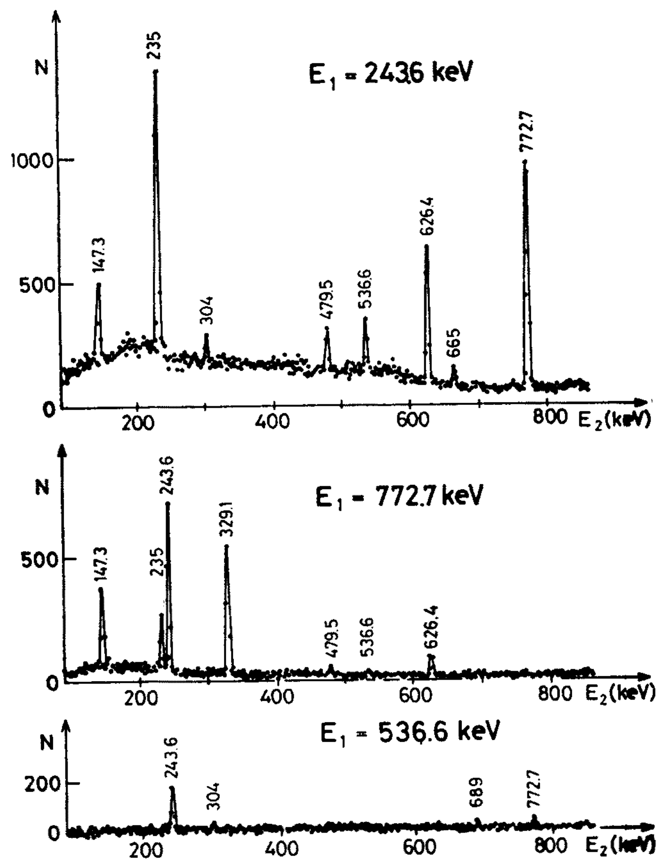

Fig. 1. Examples of the gamma-gamma coincidence spectra

A single γ-ray spectrum contains at $E_\alpha = 26$ MeV more than 50 well resolved lines. The excitation function allows us in many cases to distinguish lines belonging to the ^{92}Mo from others. The beam–γ delayed coincidences show lines which deexcite with life-times longer than few ns. Between the weaker lines in a single spectrum we see a few lines belonging to the ^{90}Nb, ^{93}Mo, ^{94}Mo and others which are usually obtained with the target containing mylar backing and oxygen.

The $\gamma-\gamma$ coincidences were performed with two Ge(Li) detectors (17 and 32 cm^3). The coincidence spectra were obtained by subtracting two spectra with the gates placed over the range of the full energy peak and over the neighbouring background of that photopeak respectively. Examples of the low energy parts of the coincidence spectra are shown in Fig. 1. The results of the $\gamma-\gamma$ coincidence measurements are presented in Table I.

TABLE I

Gamma-gamma coincidences in ^{92}Mo

Coincident γ-rays (keV)	Gate (keV)			
	243.6	536.6	772.7	1509.7
110	?			
147.3	yes		yes	yes
235	yes		yes	yes
243.6		yes	yes	yes
304	yes	yes		
329.1			yes	yes
479.5	yes		yes	weak
1509.7–1022			yes	
536.6	yes		yes	weak
626.4	yes		yes	yes
665	yes			
689		yes		
772.7	yes	yes		yes
2062–1022	weak			
1097.3	yes		yes	yes
1231	yes			
2362–1022				weak
1509.7	yes	yes	yes	

The life-times of the 11$^-$ level at 4485 keV and 8$^+$ level at 2759 keV are well known from the literature [1]. The long lifetime of the 8$^+$ state ($T_{1/2} = 188$ ns) makes impossible the direct measurements of the $\gamma-\gamma$ coincidences with lines feeding this level. To overcome these difficulties we performed beam–$\gamma-\gamma$ coincidence measurements with two Time to Pulse Height Converters. The first TPHC1 accepted fast pulses from Ge(Li) (START) and NaJ(Tl) (STOP) detectors and the second TPHC2 the pulses from NaJ(Tl) (START) and RF (STOP); see Fig. 2. The linear spectra from Ge(Li) and TPHC1 were stored in two-dimensional array by PDP-11. Both inputs (x and y) were gated by pulses from the coincidence unit (coincidences of slow NaJ(Tl) and TPHC2). In that way after a proper choosing of the time and energy cond¹⁺ions we were able to see γ-lines which could feed both above mentioned levels.

From these measurements we deduced that γ-lines with energies 2552, 1568,740 and 596 keV should be placed above the level with life-time longer than 100 ns. The lines with energies 665, 1680, 1735, 1754 and 2062 keV should probably be placed above the level

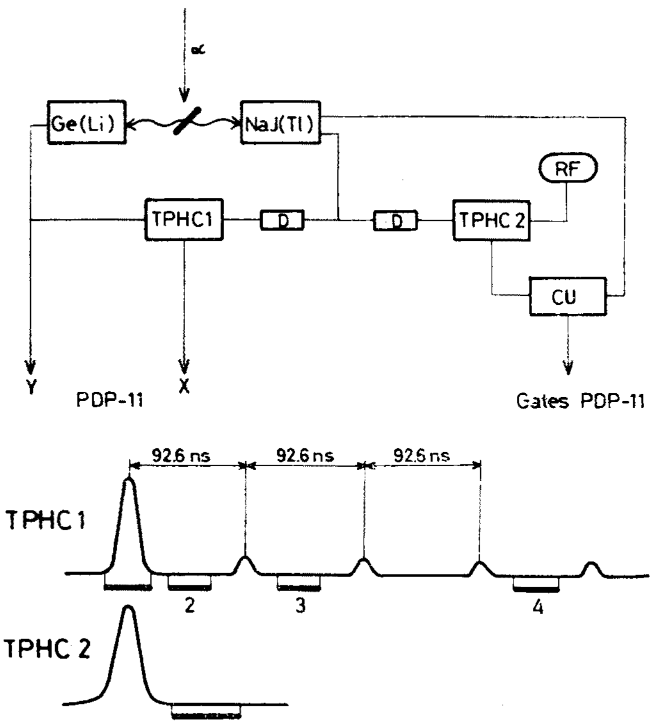

Fig. 2. The block diagram of electronics for the beam-γ-γ coincidence measurements

with much shorter life-time than 100 ns. The proposed level scheme based on paper [4] and the present paper is shown in Fig. 3.

The lines 479.5, 536.6 and 304 keV were placed between the already known levels on the bases of $\gamma-\gamma$ coincidence measurements. These measurements additionally allow us to suggest the existence of levels at energies 3872, 3757 and 3752 keV. By performing beam–$\gamma-\gamma$ coincidences we have found γ–lines which could be divided into two groups, characterized by different life-time of the levels which are fed by these lines. Such combined coincidence strongly suggests the existence of the level at 5311 keV and probably at 4327 keV. The most probable position of the previously observed 665 keV [4] is above 11^- level.

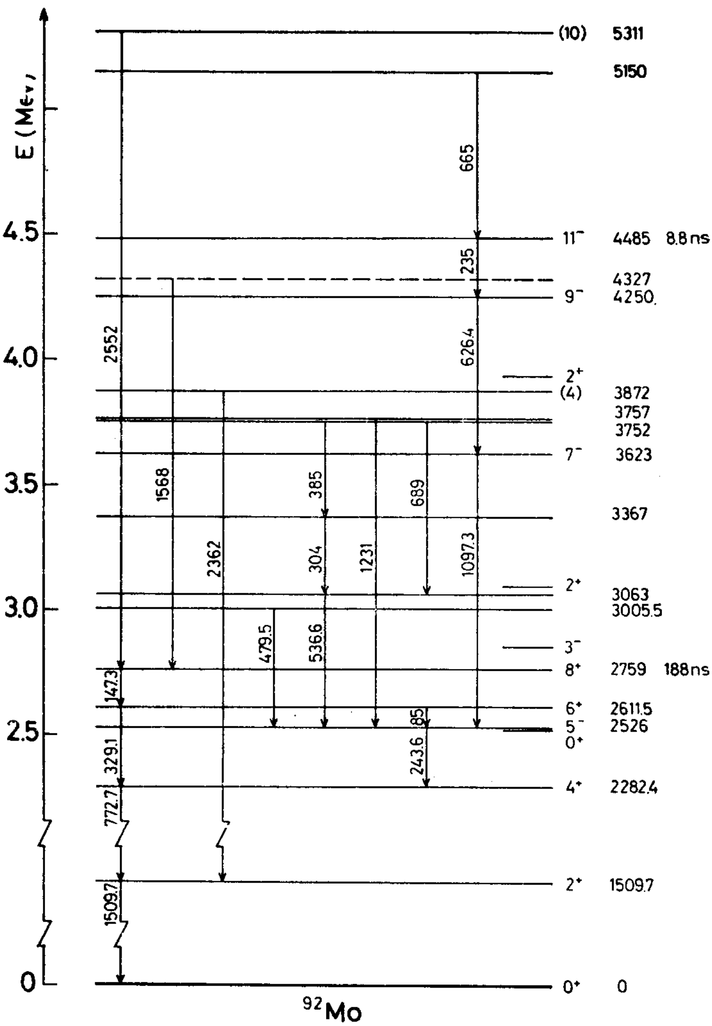

Fig. 3. Level scheme for ^{92}Mo

3. Discussion

The comparison of the experimental results and the calculated level positions are presented in Fig. 4. The energies denoted by A were obtained in the calculations based on the two-body effective interactions published by Serduke et al. [9]. All calculated energies were shifted by about 400 keV to obtain 0^+ state at the experimental position of the ground state. Results presented in papers [6, 7] suggest an odd-even effect for effective interactions when these are derived with restricted configuration space and from experimental data of single neighbouring nuclei. The energies denoted by B were obtained from the effective interactions derived from already well known levels in ^{92}Mo (work [4] and 2^+ levels at 3092 and 3930 keV). It seems that agreement of the experimental

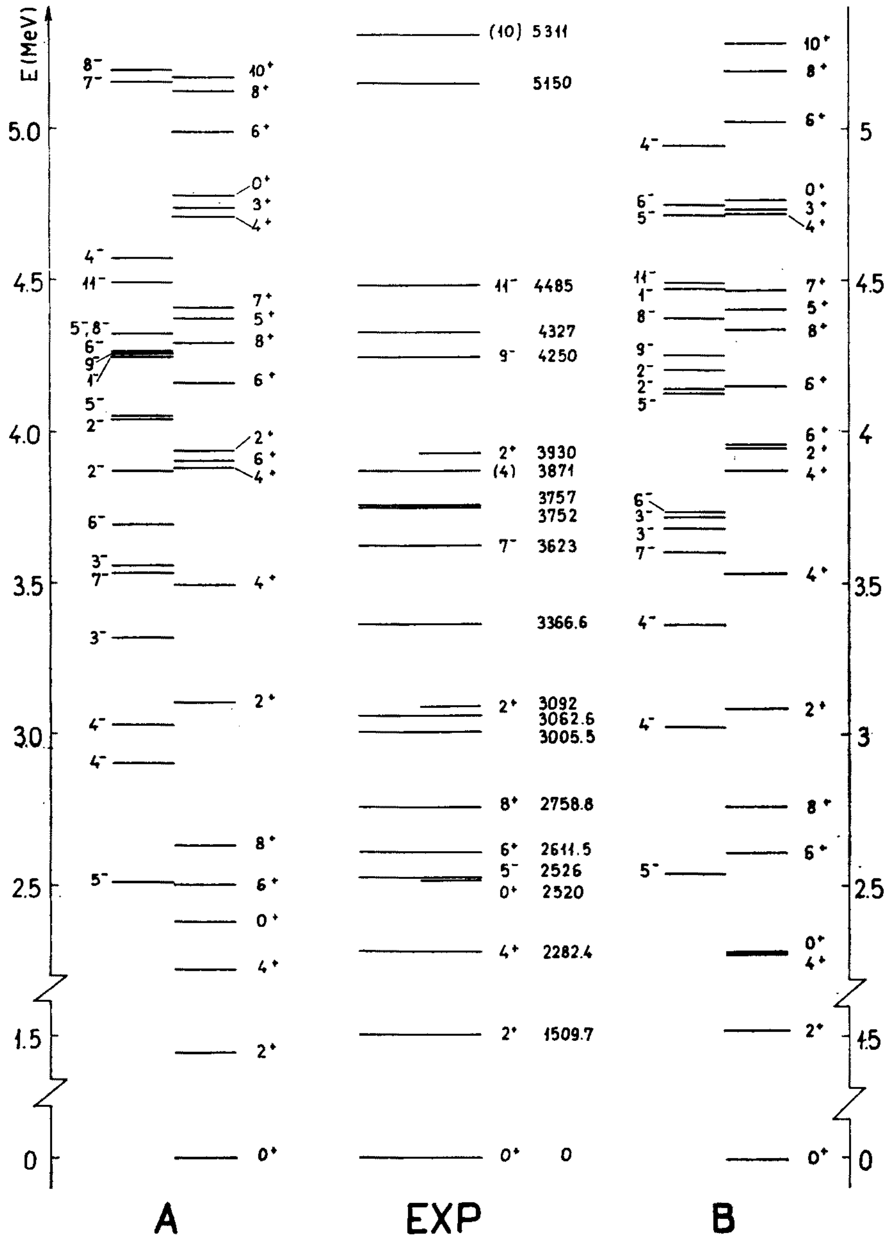

Fig. 4. Comparison between the experimental and calculated level positions for ^{92}Mo. For explanation see text

positions and these at B is very satisfactory. We leave for readers to compare the positions of our newly observed levels with those predicted by our calculations. These calculations support the odd-even effect [10].

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