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Level structures of ^{95,97}Mo – A comparative study

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Abstract. High-spin states of ^{95,97}Mo $(Z = 42, N = 53, 55)$ nuclei have been investigated through ^{82}Se(^{18}O, xn) reaction at $E_b = 60$ MeV. The level scheme in ^{95}Mo has been observed upto $\simeq$ 10 MeV in the present experiment. The level structure shows mainly single particle character. In ^{97}Mo, the ground state level sequence has been extended to $\simeq 4.5$ MeV while the previous information had been up to 2.4 MeV. A negative parity band built on 1437 keV $(11/2^-)$ excited state has been extended to 5.5 MeV. The structure seems to show a coexistence of single particle and collective modes of excitation. Properties of both the nuclei have been compared with shell model calculations using OXBASH.

Keywords. Nuclear reactions ^{82}Se(^{18}O, xn), $E = 60$ MeV; measured E_γ, I_γ; γ–γ coincidence; ^{95,97}Mo deduced levels; shell model calculations.

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1. Introduction

Nuclei in the Sr–Mo–Pd region near $A \simeq 100$ show rapid changes in structure [1]. The rapidity in shape change results in shape coexistence in these nuclei. The isotopes of $_{42}$Mo with neutron number (N) around 50 exhibit predominantly single-particle mode of excitations, e.g. in ^{92}Mo, experimental $\beta_2 = 0.1058(33)$. As neutron number increases, collectivity sets in and gradually β_2 increases to $0.326(19)$, for ^{102}Mo$_{64}$. $^{95-97}$Mo$_{53-55}$ isotopes lie in between these two extremities. So these nuclei are interesting candidates to observe the gradual onset of deformation with increasing neutron numbers. Both single particle and collective modes of excitations may compete and combine to generate a rich variety of phenomena in these isotopes.

Among these isotopes, ^{96}Mo has been already studied by the present group [1]. Although the low-lying states of this isotope may indicate vibrational character $(R_4 = E(4_1^+)/E(2_1^+) \simeq 2.1$ and $B(E2; 0_1^+ \rightarrow 2_1^+) \approx 21$ W.u.), results of our shell model calculations within a small basis space [1] show reasonable agreement with the experimental data up to modest spins. In the present work, the high spin structures of ^{95,97}Mo have been investigated. The high spin states of ^{95}Mo $(Z = 42, N = 53)$ had been already studied by (α, xn) [4] and ^{65}Cu(^{36}S, αpn) reactions at 142 MeV [2]. The previous studies of the level structure of ^{97}Mo were made by radioactivity measurements, light particle induced reactions and by ^{96}Zr(^{3}He, $2n$) reaction [3]. In the present work, the results of shell model calculations performed using the OXBASH code have also been included.

2. Experimental details

The nuclei ^{95,97}Mo were produced through the ^{82}Se (^{18}O, $xn\gamma$) reaction with beam energy of 60 MeV at the 15UD Pelletron of the Nuclear Science Centre, New Delhi, India. Enriched ^{82}Se (86% enrichment) target of thickness $\simeq$ 4 mg/cm^2 on Au-coated ($\simeq$ 400 μg/cm^2) kapton foil (thickness $\simeq$ 23 μ) [1] was used. The resulting nuclei were investigated with standard in-beam γ-spectroscopy techniques (see ref. [1] for details) which involved studies of γ–γ coincidence and DCO ratios with the γ-spectrometer (gamma detector array (GDA)) consisting of 10 Compton suppressed HPGe γ-X detectors (each of $\sim$ 25% efficiency) positioned at 51°, 98° and 144° to the beam direction along with fourteen BGO detectors serving as multiplicity filter.

A total of 38 million events corresponding to two or higher fold coincidences in HPGe detectors was recorded in list mode. Representative coincidence spectra, one for each isotope are shown in figure 1.

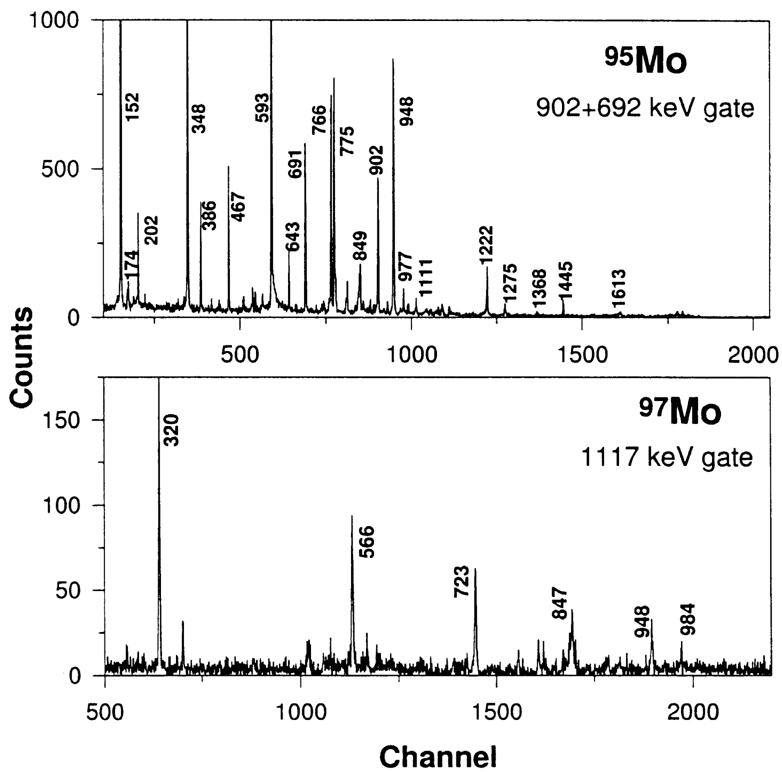

Figure 1. Representative coincidence spectra for ^{95,97}Mo.

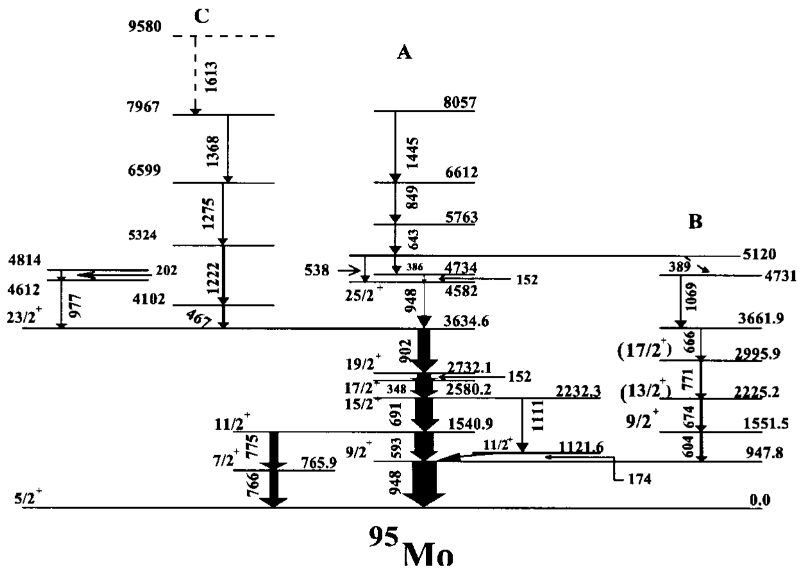

Figure 2. Level scheme of ^{95}Mo.

3. Results

The level schemes for both the nuclei (figures 2 and 3) have been constructed on the basis of energies, relative intensities and DCO ratios, wherever available. The transitions for which the intensity could be determined without any ambiguity (in this preliminary analysis) are shown in the level schemes (figures 2 and 3) with appropriate thicknesses of the arrows, proportional to their relative intensities. As far as the assignment of spin and parity through the DCO ratios is concerned, values for those states are shown in the figures which could be determined conclusively. Further analysis is in progress for other states. The result for each specific nucleus will be discussed one by one.

^{95}*Mo*

In the previous experiment with ^{65}Cu(^{36}S, αpn) reaction at 142 MeV [2], the level scheme was proposed up to $49/2^+$. In the present work involving ^{82}Se(^{18}O, $5n$) reaction, at 60 MeV, because of the lighter projectile with lower energy, the highest spin populated ($\simeq 41/2$) was lower than the above work.

However, after preliminary analysis, several interesting observations have been made.

- 174–1111 keV transitions placed in parallel with 692 and 593 keV transitions in ref. [4] have not been seen in the previous work [2]. But these transitions have been observed in the present work.
- A few differences are observed in the positive parity sequence (A) from that proposed in ref. [2]. However, further experimental and theoretical analyses are needed for a firm conclusion.

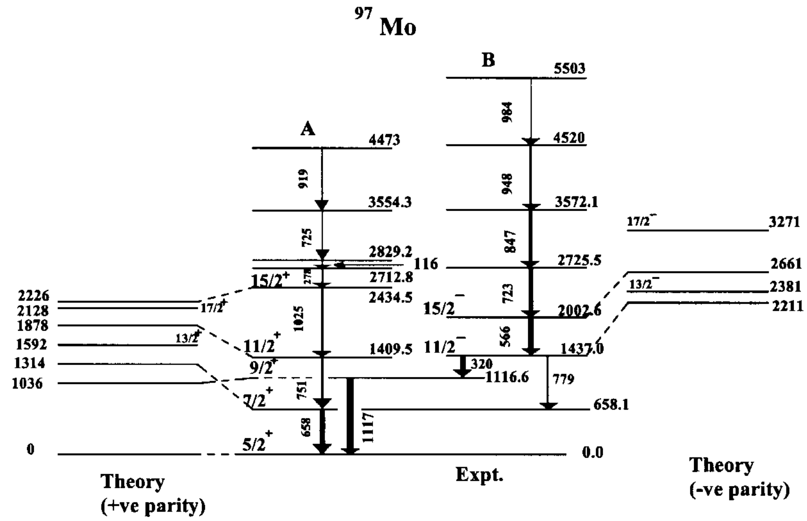

Figure 3. Experimental and theoretical level scheme of ^{97}Mo.

- In the other positive parity sequence (B), the energies differ slightly from the previous work [2]. The sequence of these transitions as proposed by us is also different from that noted earlier. This is not unexpected in view of the fact that this sequence was weakly populated in that work wherein the relative intensities of several transitions could not be properly determined. As a result, the authors [2] also expected that the actual sequence of these transitions might differ.
- The negative parity sequence from $11/2^-$ to $35/2^-$ [2] is not seen in present work.
- A new sequence (C) of levels whose spins are yet to be determined from further analysis, is seen in the present work.

^{97}*Mo*

In the previous experiment with ^{3}He beam at 11 MeV [3], the ground state level sequence (A), was populated up to 2.4 MeV. In our experiment with ^{82}Se(^{18}O, $3n$) at 60 MeV, excitation up to 4.5 MeV is seen.

After preliminary analysis, following other observations have been made.

- Our data show good agreement with the previous results [3].
- The negative parity sequence (B) on $11/2^-$ has been extended to 5.5 MeV compared to the previous observation up to 2.7 MeV. Further analysis is needed for the assignment of spins.
- The transition energies in the negative parity sequence (B) increase monotonically with spin (see figure 1), which probably suggest a rotational character for this band. However, it is still premature to make any final statement regarding the nature of this cascade before assignment of spins.

4. Discussion

Shell model calculations have been successfully applied to explain the experimental observables (spins, parities, excitation energies and transition probabilities, wherever available) in the $N = 50-54$ isotones of Mo, Tc, Ru, and Rh [1].

Spherical shell model using OXBASH [5] code has been applied to both these nuclei. The basis set has ^{88}Sr as the inert core and model space of $2p_{1/2}$ and $1g_{9/2}$ orbitals for protons and the $2d_{5/2}$ and $3s_{1/2}$ orbitals for neutrons. These calculations have been carried out with the 'gl' interaction in the OXBASH code [5]. The other relevant details of the calculation can be found in the study of ^{96}Mo [1] done by the present group.

The results for ^{95}Mo within the same formalism, basis set and interaction have been already discussed by the previous authors [2]. Therefore, these are not presented here. For lower spins ($< 19/2^+$), it is seen that the agreement is reasonable. For higher spins deviation is larger. This may be an indication of the need for a larger model space as also seen in ^{96}Mo [1].

The agreement for the positive parity sequence in ^{97}Mo is reasonable (figure 3). But the results for the negative parity states in the same spin range largely deviate from the observed data. This observation also perhaps indicates that the negative parity sequence may be a collective band.

5. Conclusion

Whereas the ^{95}Mo show predominantly single particle type of excitation, detailed analysis of the present experimental data and further theoretical calculations are needed to confirm whether ^{97}Mo has a coexistence of single particle and collective excitations[1].

References

[1] J M Chatterjee *et al*, *Nucl. Phys.* **A678**, 367 (2000); and references therein
[2] B Kharraja *et al*, *Phys. Rev.* **C57**, 2903 (1998)
[3] K D Carnes *et al*, *Phys. Rev.* **C35**, 525 (1987)
[4] C M Lederer *et al*, *Nucl. Phys.* **A169**, 489 (1971)
[5] B A Brown, A Etchengoyen, W D M Rae and N S Godwin, computer code OXBASH, 1984

[1]**Note added in proof:** After the presentation of this work in the PMDA-2000 workshop, during preparation of manuscript for publication, a recent study on ^{97}Mo nucleus with the reaction ^{82}Se (^{19}F, $p3n\gamma$) at 68 MeV, has been published in the print issue of January 2001, *Phys. Rev. C* (Observation of $\nu h_{11/2}$ sequence in the ^{97}Mo nucleus: D Bucurescu *et al*, *Phys. Rev.* **C63**, 014306 (2000)). In that work, the negative parity band has been identified as a collective band built on $\nu h_{11/2}$ orbital. This corroborates the observations in the present work.