In search of collectivity in ^{95,97}Mo nuclei

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Medium spin states of ^{95,97}Mo$(Z=42,N=53,55)$ nuclei have been investigated through the ^{82}Se$(^{18}$O$,xn)$ reaction at $E_b=60$ MeV. In ^{95}Mo, excited states upto 7.5 MeV have been studied in the present experiment. A significant modification of the existing level scheme has been suggested. The negative parity level sequence of ^{97}Mo has been extended to 8.6 MeV. The experimental data for both the nuclei have been compared with the theoretical results from shell model and particle rotor model calculations.

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I. INTRODUCTION

In recent years experimental and theoretical investigations are being carried out in nuclei with $Z\geqslant 40$ and $N\geqslant 50$ in the $A\sim 100$ region with an aim to study the shape change, shape coexistence, onset of deformation, core breaking phenomena, etc. [1–9]. $_{42}$Mo nuclei lying in this region exhibit sphericity with neutron number $N\sim 50$ and have predominantly single-particle excitation but undergo rapid change of shape with increase of N. For this reason, both single-particle and collective modes of excitations may compete and combine to generate a rich variety of phenomena in these isotopes. In this paper we present the results of our work on ^{95}Mo and ^{97}Mo nuclei which was undertaken to study the possible shape change and other related structural characteristics.

^{95}Mo was previously studied by the $(\alpha,3n\gamma)$ reaction [8,10,11] and results are available up to 3.5 MeV excitation energies. The high spin structure of this nucleus was studied later through heavy ion induced reaction by Kharraja *et al.* [1]. These authors [1] did not observe a number of γ rays in the lower excitation region reported in the lighter ion induced reaction studies [7,8,10]. Ambiguities arising due to the placement of some of the γ transitions also exist in the level scheme [8].

The nucleus ^{97}Mo was studied previously by radioactivity [12], $(^{3}$He$,2n\gamma)$ [5], $(\alpha,xn\gamma)$ [8,10], and ^{82}Se$(^{19}$F$,p3n)$ reactions [6]. A preliminary result of ^{95,97}Mo from our present work with ^{82}Se$(^{18}$O$,xn\gamma)$ reaction has also been reported earlier [13].

II. EXPERIMENTAL DETAILS

The nuclei ^{95,97}Mo were produced through the ^{82}Se$(^{18}$O$,xn)$ reaction with beam energy of 60 MeV at the 15UD pelletron of the Nuclear Science Centre, New Delhi, India. The target thickness was 4 mg/cm^2 prepared with 86% enriched Se metal powder. At this energy, production cross sections of ^{95}Mo and ^{97}Mo nuclei were 37% and 9%, respectively, of the total reaction cross section. The resulting nuclei were investigated with standard in-beam γ-ray spectroscopy techniques, by using a γ-detector array consisting of ten Compton suppressed high purity Ge (HPGe) γ-X detectors (each of ~25% efficiency) placed at 51°, 98°, and 144° to the beam direction along with 14 element bismuth germenate (BGO) multiplicity filter. The investigation involved studies of excitation functions, γ-γ coincidences, and directional correlation (DCO) ratios. The details of the target preparation and experimental setup had already been presented in Ref. [3]. A total of 38×10^6 events corresponding to two-fold or higher-fold coincidence events in HPGe detectors were recorded. Each coincidence event was qualified with the condition that at least two BGO detectors of multiplicity filter should fire. The raw data had been sorted out to make a $4k\times 4k$ symmetric E_γ-E_γ matrix for getting the γ-gated spectra.

The multipolarities of the observed γ rays were determined through the DCO ratios. A separate $4k\times 4k$ matrix was generated with events recorded by the detectors at 144° along one axis and those recorded at 98° along the other axis. The gating transition was, as far as possible, the preceding and succeeding transitions of interest. Different gating transitions were also used to check the consistency of the assignments. The detailed procedure of analysis had been reported previously [3].

III. EXPERIMENTAL RESULTS

A. ^{95}Mo nucleus

The coincidence spectra with gates on a few γ rays of importance of ^{95}Mo nucleus are shown in Fig. 1. The energies, relative intensities, DCO ratios, and $M1+E2$ mixing ratios of the observed γ rays and their assignments in the

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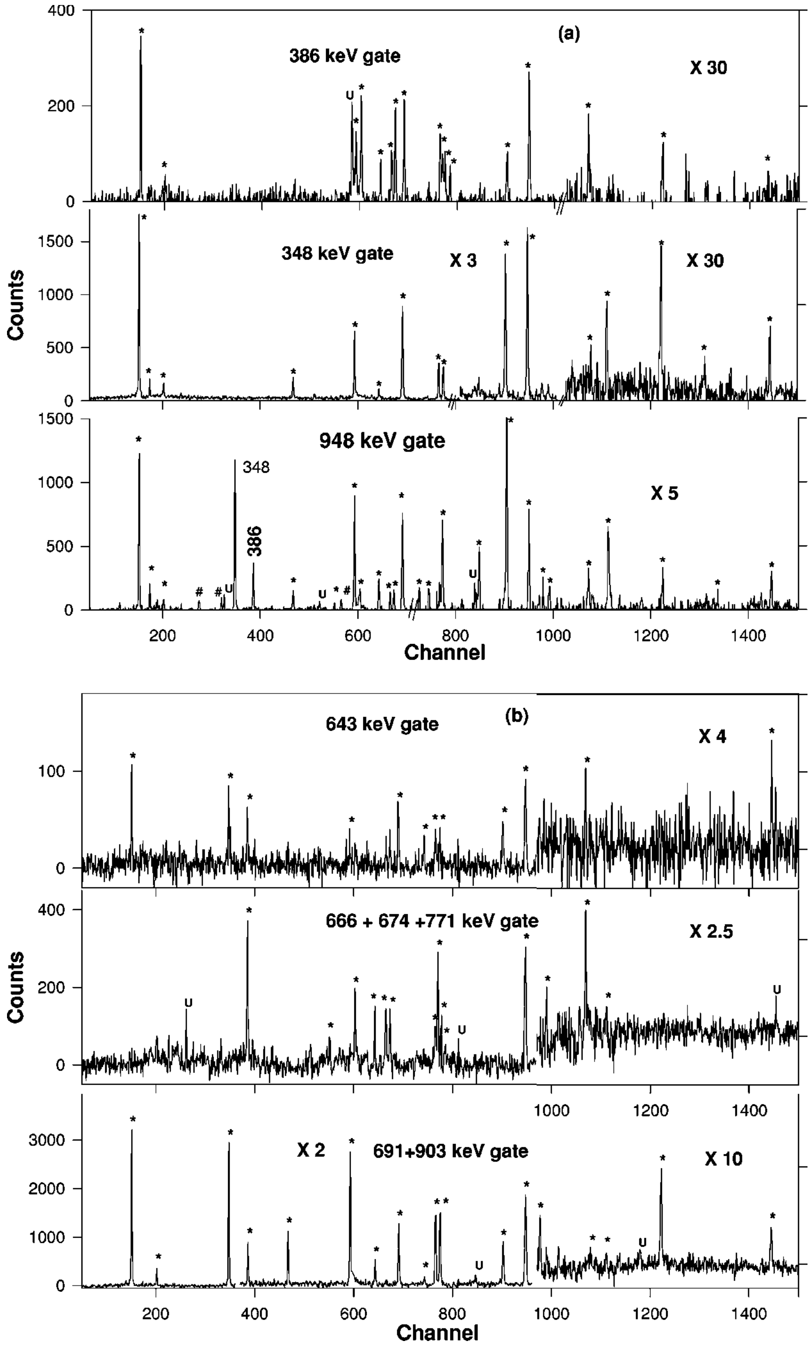

FIG. 1. (a),(b) Relevant γ-γ coincidence spectra of ^{95}Mo nucleus. The peaks indicated by "*" belong to ^{95}Mo, "#" to ^{97}Mo, and "U" are unidentified. The calibration of all the gated spectra is 1 keV/channel.

level scheme are shown in Table I. A level scheme (Fig. 2) has been constructed for ^{95}Mo on the basis of γ-γ coincidence data, the intensities of the transitions, and the multipolarities of the γ rays inferred from the DCO ratio measurements. Some of the interesting results obtained in this experiment are as follows.

(1) In the lower excitation region of ^{95}Mo (Fig. 2), we have observed, in agreement with the results of light ion induced reactions [8,10], all the transitions of the ground state level sequences (sequence 1) and the positive parity side level sequence (sequence 2) up to the excitation energies of 3673 and 2611 keV, respectively. The energies and intensities have excellent agreement with the results reported in these two previous works. The 174, 1111 keV transitions, connecting 2232 ($J^{\pi}=15/2^{+}$) to 948 ($J^{\pi}=9/2^{+}$) keV levels via 2059 keV level and 786 keV transition between 1552 ($J^{\pi}=11/2^{+}$) and 766 ($J^{\pi}=7/2^{+}$) keV levels, not reported in the earlier heavy ion induced reaction [1], have been observed in this work. In addition, the weak 521 keV transition between 2580 ($J^{\pi}=17/2^{+}$) and 2059 ($J^{\pi}=13/2^{+}$) keV levels reported in Ref. [10], but not reported in other studies, has been seen in the γ-gated spectra in the present work.

(2) One of the most important outcomes of the present investigation is the careful study of the 386 keV transition which has ultimately led to the major modification in the level scheme (Fig. 2). A 386 keV γ-ray in coincidence with known strong γ transitions of ^{95}Mo nucleus was reported by Lederer *et al.* [8]. The authors also reported the presence of another γ ray at the same energy and placed its stronger

TABLE I. Energy, relative intensity of γ rays, DCO ratios, and multipolarity mixing ratios observed in ^{95}Mo.

E_γ (keV) (ΔE_γ)	Relative I_γ [a] (ΔI_γ)	DCO (Error)	Nature of gating	Multipolarities/ δ	Assignment $E_i(J_i^\pi) \rightarrow E_f(J_f^\pi)$
151.9(5)	132.4(9)	0.52(4)	Q	$M1$	$2770.2(19/2^+) \rightarrow 2618.3(17/2^+)$
173.8(1)	13.4(4)	0.48(8)	Q	$M1$	$2232.3(15/2^+) \rightarrow 2058.5(13/2^+)$
202.3(1)	12.8(19)	0.43(9)	Q	$M1$	$3875.0(25/2^+) \rightarrow 3672.7(23/2^+)$
347.9(1)	143.5(6)	0.61(3)	Q	$M1+E2[0.4(1)]$	$2580.2(17/2^+) \rightarrow 2232.3(15/2^+)$
385.6 (1)	1.1(1)	0.52(9)	Q	$M1$	$2618.3(17/2^+) \rightarrow 2232.3(15/2^+)$
385.8(1)	1.6(1)		D	$M1$	$1937.3(13/2^+) \rightarrow 1551.5(11/2^+)$
396.4(2)	0.17(2^c)		Q		$1937.3(13/2^+) \rightarrow 1540.9(11/2^+)$
467.4(2)	31.2(10)	0.93(18)	Q	$E2$	$4140.1(27/2^+) \rightarrow 3672.7(23/2^+)$
521.4(2)	11.4(12)		Q		$2580.2(17/2^+) \rightarrow 2058.5(13/2^+)$
552.3(2)	3.5(5)^c		Q		$2611.0(15/2^+) \rightarrow 2058.5(13/2^+)$
593.1(1)	178.1(56)	0.52(3)	Q	$M1$	$1540.9(11/2^+) \rightarrow 947.8(9/2^+)$
603.5(1)	31.3(20)	0.57(7)	Q	$M1+E2/[0.07(1)]$	$1551.5(11/2^+) \rightarrow 947.8(9/2^+)$
643.4(1)	22.4(16)	1.37(11)	Q	$M1+E2/[0.13(1)]$	$5760.8(27/2^+) \rightarrow 5117.6(25/2^+)$
666.0(1)	5.9(6)	0.91 (12)	Q	$E2$	$4047.7(21/2^+) \rightarrow 3381.7(17/2^+)$
673.7(3)	22.1(11)	1.29(16)	Q	$M1+E2/[0.22(1)]$	$2611.0(15/2^+) \rightarrow 1937.3(13/2^+)$
691.4(1)	172.4(58)	0.83(5)	Q	$E2$	$2232.3(15/2^+) \rightarrow 5131(11/2^+)$
742.8(2)	7.7(8)^c		Q		$7451.5 \rightarrow 6709.0(29/2^+)$
765.9(1)	85.8(1)	0.53(7)	Q	$M1$	$765.9(7/2^+) \rightarrow 0.0(5/2^+)$
770.7(1)	11.7(3)	1.6(2)	Q	$M1+E2/[0.06(1)]$	$3381.7(17/2^+) \rightarrow 2611.0(15/2^+)$
774.9(1)	85.2(7)	1.13(10)	Q	$E2$	$1540.9(11/2^+) \rightarrow 765.9(7/2^+)$
785.6(4)	6.6(8)		Q	$E2$	$1551.5(11/2^+) \rightarrow 765.9(7/2^+)$
902.5(1)	100*	0.96(13)	Q	$E2$	$3672.7(23/2^+) \rightarrow 2770.2(19/2^+)$
947.8(1)	189.8(19)	0.88(7)	Q	$E2$	$947.8(9/2^+) \rightarrow 0.0(5/2^+)$
948.2(4)	6.9(10)	0.78(14)	Q	$M1+E2$	$6709.0(29/2^+) \rightarrow 5760.8(27/2^+)$
977.2(2)	9.3(15)		Q		$4852.2 \rightarrow 3875.0(25/2^+)$
990.1(3)	3.4(12)^c		Q		$1937.3(13/2^+) \rightarrow 947.8(9/2^+)$
1069.9(5)	7.6(15)^c		Q		$5117.6(25/2^+) \rightarrow 4047.7(21/2^+)$
1078.6(1)	3.5(8)		Q		$4953.6 \rightarrow 3875.0(25/2^+)$
1110.7(1)	21.7(6)		Q	$E2$	$2058.5(13/2^+) \rightarrow 947.8(9/2^+)$
1222.3(2)	20.3(19)	0.93(8)	Q	$E2$	$5362.4(29/2^+) \rightarrow 4140.1(27/2^+)$
1311.6(5)	6.6(7)		Q		$5451.6 \rightarrow 4140.1(27/2^+)$
1444.9(2)	9.6(15)	0.48(8)	Q	$M1$	$5117.6(25/2^+) \rightarrow 3672.2(23/2^+)$

[a]In general, the intensities have been obtained from the singles data with detectors at 51°. The intensities of γ rays marked c have been estimated from coincidence spectra.

component in the level sequence 2 but was unable to place the weaker component of the doublet. From the discrepancy of intensities of the observed singles and coincident γ spectra, Mesko *et al.* [10] also indicated the existence of two transitions with energies very close to 386 keV in this nucleus. In our work, the presence of 386 keV peak in the gated spectra of 674, 771, and 666 keV γ rays of sequence 2 has been observed with relatively higher intensity than that of other unknown γ rays [Fig. 1(b)]. It was also noted that 386 keV γ rays are not in self-coincidence [Fig. 1(a)]. Our coincidence data confirm the placement of one 386 keV transition in the level sequence 2 (Fig. 2) in agreement with Lederer *et al.* [8]. However, the observed intensity of this γ ray in 604, 674 keV gated spectra does not support its placement above 4734 $(25/2^+)$ keV level as proposed in Ref. [1]. In addition, from the intensities in the gated spectra, a different order of placement, than that in Ref. [1], is proposed for the 674, 771, and 666 keV transitions.

It has been further noted by us that in the 348 keV gated spectra, all the transitions of ground state level sequence are present except the 386 keV γ ray [Fig. 1(a)]. Similar situation is found in the 386 keV gated spectra where the 348 keV γ ray is absent [Fig. 1(a)]. This is possible if these two transitions are parallel to each other, which in turn gives a definite evidence of a second 386 keV transition in this level sequence. We propose to place this component of the 386 keV γ ray in sequence 1 based on coincidence relationships of the transitions. DCO ratio for this 386 keV transition (Table I) suggests a pure $\Delta J=1$ transition. We assign $J^\pi=17/2^+$ for the energy level at 2618.3 keV. This also sug-

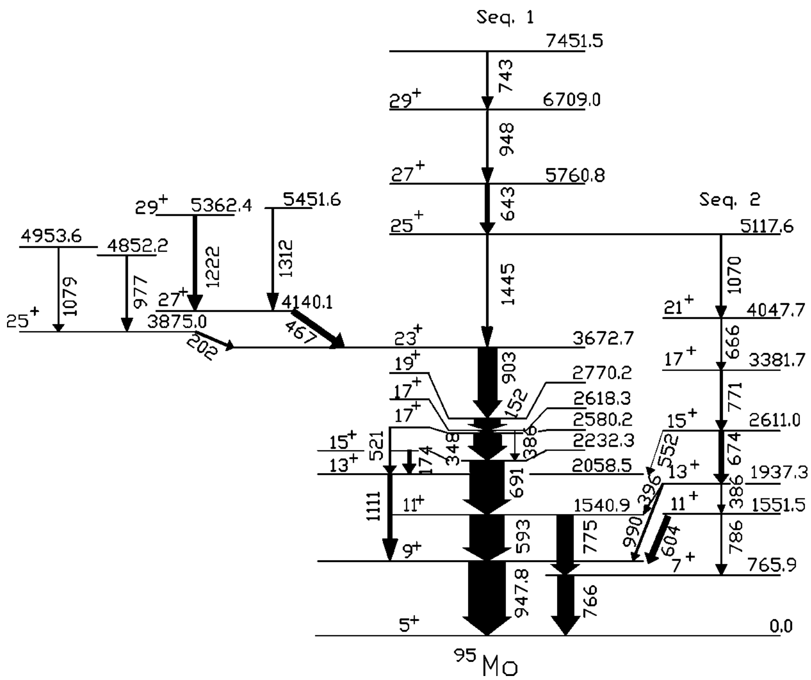

FIG. 2. Level scheme of ^{95}Mo nucleus constructed based on present work. Spins are indicated as $2J$ values.

gests the existence of a 38.1 keV transition between the levels at 2618.3 ($J^{\pi}=17/2^{+}$) and 2580.2 ($J^{\pi}=17/2^{+}$) keV which, however, could not be seen in the present work because of low energy cutoff in the experimental setup.

It would be worthwhile to point out here that a striking similarity of the positive parity level sequence (sequence 1) of ^{95}Mo is observed with major positive parity band of its isotone ^{97}Ru ($N=53$) [14]. A close lying bunch of levels was reported in the spin sequence $17/2^{+}$, $19/2^{+}$, and $21/2^{+}$ by these authors. Similar energy level bunching is also observed in ^{95}Mo nucleus in the spin region of $17/2^{+}$, $17/2^{+}$, and $19/2^{+}$ (sequence 1). The presence of strong $\Delta J=1$ transitions in this level sequence consisting predominantly of $\Delta J=2$ transitions indicates a rather weak collectivity in ^{95}Mo.

(3) The interband transitions with energies 396 and 990 keV, between the lower excited states of level sequences 1 and 2, viz., 1937 ($J^{\pi}=13/2^{+}$)$\rightarrow$1541 ($J^{\pi}=11/2^{+}$) and 1937 ($J^{\pi}=13/2^{+}$)$\rightarrow$948 ($J^{\pi}=9/2^{+}$) keV, respectively, are observed for the first time with heavy ion induced reaction in the present work (Fig. 2). Moreover, the 552 keV transition which was proposed by Mesko *et al.* [10] connecting the tentatively assigned 2611 ($15/2^{+}$) keV level of sequence 2 with the 2059 ($13/2^{+}$) keV level of sequence 1 has been confirmed in this work.

(4) Another significant deviation of level sequence from Ref. [1] lies in the higher energy region above

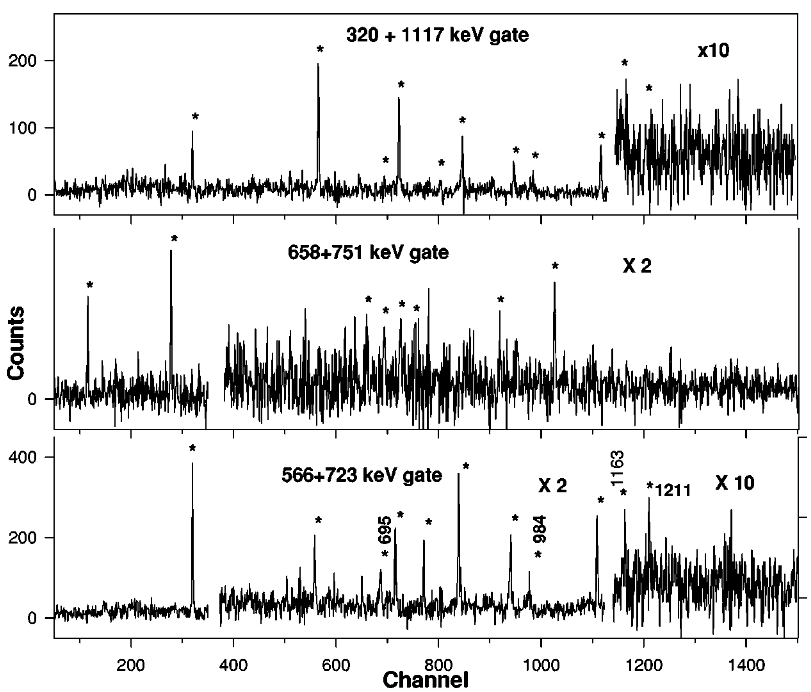

FIG. 3. Relevant γ-γ coincidence spectra of ^{97}Mo nucleus. The peaks indicated by (*) belong to ^{97}Mo nucleus. The calibration of all the gated spectra is 1 keV/channel.

TABLE II. Energy, relative intensity of γ rays, DCO ratios, and multipolarity mixing ratios observed in ^{97}Mo.

E_γ (keV) (ΔE_γ)	Relative I_γ[a] (ΔI_γ)	DCO (Error)	Nature of gating	Multipolarities/ δ	Assignment $E_i(J_i^\pi) \rightarrow E_f(J_f^\pi)$
116.6(1)	17.2(20)	0.53(5)	Q	$M1$	$2829.4(19/2^+) \rightarrow 2712.8(17/2^+)$
278.3(1)	24.7(27)^c	0.21(1)	Q	$M1$	$2712.8(17/2^+) \rightarrow 2434.5(15/2^+)$
320.4(1)	74.2(26)	0.37(7)	Q	$E1$	$1437.0(11/2^-) \rightarrow 1116.6(9/2^+)$
565.6(1)	79.6(3)	0.43(2)	Q	$M1+E2/[-0.16(3)]$	$2002.6 \rightarrow 1437(11/2^-)$
658.1(1)	173.9(23)	0.35(4)	Q	$M1+E2/[-0.27(1)]$	$658.1(7/2^+) \rightarrow 0.0(5/2^+)$
695.1(2)	19.7(24)^c		Q	$E2$	$5214.8 \rightarrow 4519.7$
722.9(2)	62.7(77)	0.85(4)	Q	$E2$	$272.5 \rightarrow 2002.6$
725.1(1)	10.9(26)				$3748.3(21/2^+) \rightarrow 2829.4(19/2^+)$
751.4(1)	28.7(45)^c		Q	$E2$	$1409.5(11/2^+) \rightarrow 658.1(7/2^+)$
778.9(1)	29.2(45)	0.73(6)	Q	$M2$	$1437.0(11/2^-) \rightarrow 658.1(7/2^+)$
803.7(2)	12.4(24)^c				$1920.3(13/2^+) \rightarrow 1116.6(9/2^+)$
846.6(2)	46.6(53)^c	0.85(4)	Q	$E2$	$3572.1 \rightarrow 2725.5$
918.9(2)	17.5(51)		Q		$4473.4(25/2^+) \rightarrow 3748.3(21/2^+)$
947.6(3)	34.8(60)^c	1.45(7)	Q	$M1+E2/[0.90(8)]$	$4519.7 \rightarrow 3572.1$
983.7(2)	9.4(12)^c	0.85(4)	Q	$E2$	$6198.4 \rightarrow 5214.8$
1025.0(1)	28.2(22)	0.92(4)	Q	$E2$	$2434.5(15/2^+) \rightarrow 1409.5(11/2^+)$
1116.6(2)	100	1.15(4)	Q	$E2$	$1116.6(9/2^+) \rightarrow 0.0(5/2^+)$
1163.1(3)	7.3(14)				$7361.5 \rightarrow 6198.4$
1211.3(8)	4.3(13)^c		Q		$8572.8 \rightarrow 7361.5$

[a]In general, the intensities have been obtained from the singles data with detectors at 51°. The intensities of γ rays marked c have been estimated from coincidence spectra.

3673 $(23/2^+)$ keV level (Fig. 2). The presence of all the γ rays of sequence 1 and sequence 2 in the 643 keV gated spectrum [Fig. 1(b)] indicate that this γ ray feeds both the sequences from higher excitation level. We have not observed any 535 keV transition with reasonable intensity in any of the coincidence spectrum. Again, the intensity of the 386 keV transition does not support its placement as a connecting transition between the 5121 and 4734 keV levels which was reported previously [1]. These suggest that the 643 keV transition decays from the 5761 keV level and feeds the 5118 keV level which subsequently decays through the 1445 and 1070 keV transitions to the 3673 (sequence 1) and 4048 keV (sequence 2) levels, respectively, (Fig. 2). The mismatch in the intensity of 643 keV and the sum intensities of 1445 keV and 1070 keV γ rays indicates that there are more transitions from the 5118 keV level. This, however, could not be seen in the present work.

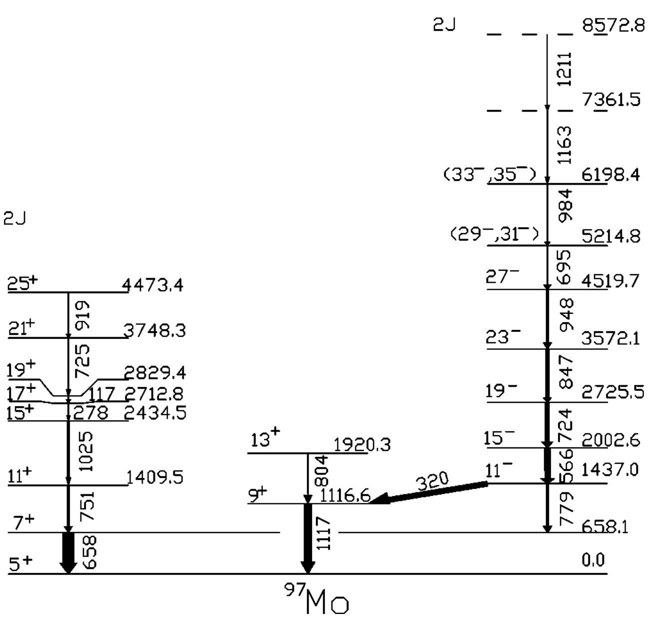

FIG. 4. Level scheme of ^{97}Mo nucleus constructed based on present work. The dotted levels are tentatively proposed.

(5) In the present work the intensities of the 1222, 1445 keV γ rays are found to be relatively stronger in the respective 467 and 903 keV gated spectra than those reported in Ref. [1]. The other reported transitions in coincidence with these γ rays by these authors were not observed in our work.

(6) The 535, 855, 950, 966, 1278, and 1671 keV transitions have not been observed in the 643, 903, and 948 keV gated spectra, instead a second 948 keV transition is found to be present in the 948 keV gate. Based on the intensity, this second 948 keV transition is placed above the 5761 keV $(J^\pi=27/2^+)$ level. We have observed some new transitions, viz., 202, 977, 1079, and 1312 keV in the strong γ-gated spectra of level sequence 1. The intensities of these transitions are given in Table I. However, due to lack of any definite coincidence relationship observed between these transitions, it is difficult to place them in either of the sequences mentioned above. They are, therefore, separately shown to feed the 3673 keV $(J^\pi=23/2^+)$ level. This proposition leads

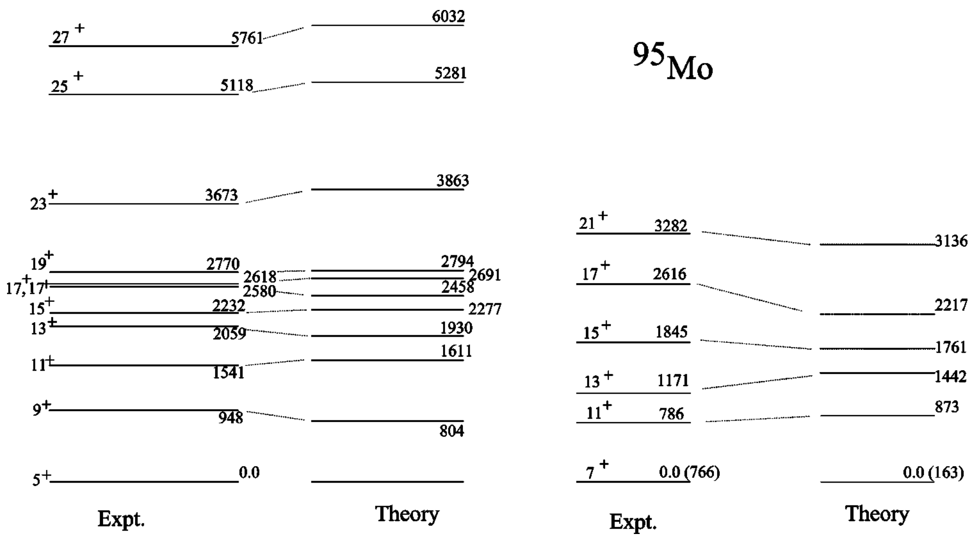

FIG. 5. Comparison of the experimental level energies with the theoretically calculated results using core particle coupling model (CPCM). $2J$ values are shown in the figure.

to another significant difference between the present results and that of Ref. [1], viz., several levels are proposed to feed the level at 3673 keV which occurs at much lower energy than that reported by Kharraja *et al.* [1], in the ground state level sequence (Fig. 2).

We have also not observed some of the weak transitions and the weak negative parity band reported by them (Ref. [1]).

B. ^{97}Mo Nucleus

The coincidence spectra with relevant γ gates of ^{97}Mo from this work are shown in Fig. 3. The energies, relative intensities, DCO ratios, multipolarities, mixing ratios δ, and the assignment of γ transitions of ^{97}Mo as observed in our work are given in Table II. A level scheme (Fig. 4) of this nucleus was constructed based on the coincidence relationship of the γ rays observed in the γ-gated spectra. The positive parity level sequence is in good agreement with the work of Bucurescu *et al.* [6] but the predicted spins of the negative parity band, based on 1437 $(11/2^-)$ keV level, which has been extended to 8.6 MeV in the present work, differs from their earlier proposed values [6]. The 695 keV γ ray observed by Bucurescu *et al.* [6], and not placed by them, is present in our work in all the γ-gated spectra of this band. Its intensity is found to be higher than that of the 984 keV transition (Table II). Based on the observed intensity we tentatively propose a new level at 5214.8 keV in the negative parity level sequence which is fed by the 984 keV transition from 6198.4 keV level (Fig. 4). In addition, the sum spectrum obtained from the spectra gated with 566 and 723 keV γ rays shows (Fig. 3) the existence of two γ rays of energies 1163 and 1211 keV which were not reported earlier. These γ rays are tentatively placed above 984 keV transition in the present work (Fig. 4)

In our work, the DCO ratios of the transitions belonging to the negative parity band do not suggest electric quadrupole nature ($E2$) to all of them (Table II). As the intensity in the DCO gates in the present work is low for this nucleus, we have, however, retained the spin values reported by Bucurescu *et al.* [6] which is also supported by our theoretical work as discussed in the following section. However, the spin values for the 5214.8 and 6198.4 keV levels, as assigned by us, are tentative because of the inconclusive result of DCO ratio for the 695 keV transition (Fig. 4).

IV. PHENOMENOLOGICAL DISCUSSIONS AND THEORETICAL ANALYSIS

A. ^{95}Mo

Shell model calculations for ^{95}Mo using OXBASH [15] with ^{88}Sr as the inert core and the valence model space consisting of $2p_{1/2}$ and $1g_{9/2}$ orbitals for protons and the $2d_{5/2}$ and $3s_{1/2}$ orbitals for neutrons were previously carried out by Kharraja *et al.* [1] with the "*gl*" interaction [16]. This interaction has been also successfully applied for other Mo isotopes [1,3]. Shell model results of level spectra for ^{95}Mo show reasonable agreement up to moderate spins $(\simeq 23/2^+)$ while for higher spins deviation was found to be larger. The authors of Ref. [1] emphasized the need for a larger model space as was also noted for ^{96}Mo in Ref. [3]. Specifically the inclusion of the $1g_{7/2}$ neutron orbital in the valence space was found to be necessary to eliminate the discrepancies in the results for the lower spin states such as $7/2^+$, $11/2^+$, etc. But as large basis calculations could not be performed due to computational limitations, the theoretical discussions were supplemented with a qualitative description of the level sequence within a weak-coupling scheme by coupling either a $2d_{5/2}$ or a $1g_{7/2}$ neutron to the ^{94}Mo core. It was observed [1] that the low-lying structure was well reproduced by this scheme.

The R_4 value for ^{94}Mo($N=52$) is 1.8 and the experimental β value is 0.1509(15) [17]. The deformation of even Mo isotopes gradually increases with neutron numbers. It is 0.1720(16) for ^{96}Mo$_{54}$ and increases to 0.311(5) for ^{102}Mo$_{60}$ [17]. These data suggest that ^{95}Mo$_{53}$ lies in a transitional region having a weakly deformed structure, initiating a transition from spherical to deformed shape. As mentioned above, earlier workers [1] have pointed out the suitability of a collective model in explaining the excitation energies of nuclei in this transitional region. So we have applied a core

TABLE III. The calculated [core particle coupling model (CPCM)] single-particle wave functions for ^{95}Mo positive parity states. The numbers within brackets in the third and fourth columns show the relative energies with respect to the lowest energy state in each sequence. Composition of Nilsson basis states: $a=1/2[431]=52\%d_{5/2}$, $b=1/2[420]=65\%g_{7/2}$, $c=3/2[422]=48\%d_{5/2}$, and $41\%g_{7/2}$, $d=3/2[411]=45\%d_{5/2}$ and $53\%g_{7/2}$, $e=5/2[413]=72\%g_{7/2}$, $f=5/2[402]=72\%d_{5/2}$, and $g=9/2[404]=g_{9/2}$.

No.	J	Energy (MeV)		Wave function components						
		Expt.	Theor.	*a*	*b*	*c*	*d*	*e*	*f*	*g*
Sequence 1										
1	5/2	0.	0.558 (0.)	0.76	−0.35	0.47	−0.21	0.12	−0.11	-
2	9/2	0.948	1.362 (0.804)	−0.71	0.30	−0.38	0.11	−0.07	0.03	0.47
3	11/2	1.541	2.169 (1.611)	0.67	−0.61	0.38	−0.15	0.05	−0.06	−0.03
4	13/2	2.059	2.488 (1.930)	−0.03	0.72	0.64	0.19	0.09	0.04	−0.12
5	15/2	2.232	2.835 (2.277)	0.75	−0.59	0.16	−0.13	−0.02	0.00	0.19
6	17/2	2.580	3.016 (2.458)	−0.79	0.49	−0.34	−0.02	0.01	0.00	−0.08
7	17/2	2.618	3.249 (2.690)	−0.11	0.41	0.88	0.18	0.07	−0.01	−0.07
8	19/2	2.770	3.352 (2.794)	0.93	0.32	−0.12	0.01	0.05	0.00	−0.05
9	23/2	3.673	4.245 (3.687)	0.61	0.71	0.30	0.11	−0.02	−0.00	0.10
10	25/2	5.118	5.840 (5.288)	0.20	0.26	−0.39	0.59	−0.39	0.46	−0.05
11	27/2	5.761	6.590 (6.032)	0.32	−0.02	−0.27	−0.52	−0.52	−0.36	0.01
Sequence 2										
12	7/2	0.766 (0.)	0.721 (0.)	0.42	0.68	0.46	0.27	0.21	0.07	
13	11/2	1.552 (0.786)	1.594 (0.873)	0.46	0.73	0.44	0.22	0.13	0.04	0.01
14	13/2	1.937 (1.171)	2.163 (1.442)	0.86	−0.29	0.40	−0.09	0.07	−0.03	0.02
15	15/2	2.611 (1.845)	2.482 (1.761)	0.53	0.73	0.37	0.18	0.09	0.03	0.02
16	17/2	3.382 (2.616)	2.938 (2.217)	0.58	0.75	−0.26	−0.12	0.06	0.03	0.02
17	21/2	4.049 (3.282)	3.857 (3.136)	0.26	0.45	0.84	−0.00	−0.08	0.01	0.06

particle coupling model (CPCM) proposed by Müller and Mosel [18] for ^{95}Mo. The advantage of this model is that the experimental energies of the core (in this case ^{94}Mo [1]) can be directly fed in as input. As the core simulation is not needed, the approach is specially suitable for very weakly deformed systems where variable moment of inertia (VMI) or constant moment of inertia (CMI) approach within the standard particle rotor model (PRM) fail due to the nonrotational nature of the core.

The theoretical calculations with CPCM have been performed with the following set of parameters. The value of the deformation parameter ($\delta=0.95\beta$) was chosen to be 0.14 [17]. The Nilsson parameters μ and κ were 0.4 and 0.0637, respectively, which gave $1g_{7/2}$ orbital at an excitation energy of 800 keV with respect to the $2d_{5/2}$ orbital at zero deformation, as suggested by previous workers [1]. The neutron Fermi level was taken at 49.0 MeV which is near the $1/2^+[431]$ and $1/2^+[420]$ Nilsson orbitals, originating pre-

TABLE IV. Comparison of experimental and calculated [core particle coupling model (CPCM)] branching ratios and mixing ratios in ^{95}Mo for the positive parity states. E_γ indicates the γ ray energy connecting the initial and final states. All energies are quoted in MeV.

J_i (Energy)	J_f (Energy)	E_γ	Branching ratio Expt.	Branching ratio Theor.	Mixing ratio Expt.	Mixing ratio Theor.
11/2(1.541)	7/2(0.766)	0.775	32.3	1.2		
	9/2(0.948)	0.593	67.6	98.8	$M1$	0.2
15/2(2.232)	11/2(1.541)	0.691	92.8	97.0		
	13/2(2.058)	0.174	7.2	3.0	$M1$	0.01
17/2(2.580)	13/2(2.058)	0.521	7.4	0.3		
	15/2(2.232)	0.348	92.6	99.7	0.4(1)	0.01
25/2(5.118)	21/2(4.048)	1.070	44.2	15.5		
	23/2(3.673)	1.445	55.8	84.5	$M1$	0.1
13/2(1.937)	9/2(0.948)	0.990	65.8	50.1		
	11/2(1.541]	0.396	3.2	48.4		
	11/2(1.552]	0.386	30.9	1.4	$M1$	0.07
11/2(1.552)	7/2(0.766)	0.786	82.6	1.6		
	9/2(0.948)	0.604	17.4	98.4	$M1$	0.4

dominantly from $2d_{5/2}$ and $1g_{7/2}$, respectively [19]. The value of the pairing gap was 1.023 MeV, inferred from odd-even mass difference [20]. The Coriolis matrix elements were attenuated by a factor of 0.88. Neutron Nilsson orbitals originating from the $N=4$ major shell (containing the spherical single-particle orbitals, namely, $1g_{9/2}$, $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$, $3s_{1/2}$) were included in our calculation. The experimental core (^{94}Mo) energies from 0^+ to 18^+ [1] were supplied as inputs.

In comparing the experimental data and theoretical results, the following criteria were adopted. The parameters were not adjusted freely to fine-tune the energy eigenvalues. The agreement between the calculated and experimental energies were taken as the first criterion to assign a particular theoretical level to the corresponding experimental one. But this is not always adequate for a definite identification. So the decay patterns and the branching ratios were utilized to finally identify a level.

The experimental level scheme (Fig. 2) shows three distinct groups of levels distinguishable by the γ transitions between the levels of each group. For example, low-lying levels from $5/2^+$ to $17/2^+$ in sequence 1 (Fig. 2) (except the $13/2^+$ level at 2058 keV) are strongly connected by intense γ transitions. In Fig. 5, we have compared the CPCM results with our experimental level scheme. The theoretical calculations reproduce these states quite reasonably. Table III contains information on the structure of the wave functions (single-particle part) from which the Nilsson single-particle parentage of the different levels can be obtained. The table shows that the states 1,2,3,5,6,8,9 definitely belong to the same group having dominant contribution from 1/2[431] originating predominantly from $2d_{5/2}$. The $13/2^+$ level at 2059 keV (state no. 4) is different from the rest in the group (origin 1/2[420]), as also indicated in Fig. 2. Its connection with the other members of the group is significantly weaker. The second $17/2^+$ level in sequence 1 (state 7) originates from 3/2[422] state. The unusual energy interval between $15/2^+$ and $19/2^+$ in sequence 1 is also reproduced. The levels 10 and 11 are weakly connected to other members of sequence 1 as well as to those belonging to sequence 2. The structure of these two levels are significantly different from the rest of the levels in both sequences 1 and 2. They originate predominantly from 5/2[413] and 5/2[402] states, respectively.

The levels of sequence 2, except for $13/2^+$, have predominant contribution from 1/2[420] arising from $1g_{7/2}$. The bandhead energy of the $7/2^+$ state is not reproduced correctly in the present calculation. A small readjustment of the Nilsson parameters may be needed to reproduce it. We have observed that the calculations for $\delta=0.04$ (as suggested by the theoretical work [21]) with same Nilsson parameters reproduce the bandhead energy at $\simeq$600 keV. But the relative spacings of the other members of the sequence are not reproduced. However, with $\delta=0.14$ **(**the experimental β value is 0.1509(15**)** [17]), the relative spacings are reproduced satisfactorily.

In our present experimental work, we have obtained information on the intensities (Table I) and so also the branching ratios. We have compared these results with the theoretical ones (Table IV). The table also includes the $(E2/M1)$ mixing ratios. The $M1$ transition rates were calculated using $g_s(n)_{eff}=0.7g_s(n)=-2.68$, $g_l(n)=0.0$, and $g_R=Z/A$ [22]. It may be noted that the results are quite encouraging. The branching ratios involving the $13/2^+$ level at 2059 keV show good agreement with experiment. The same ratios calculated for the $13/2^+$ at 1937 keV and $11/2^+$ at 1551 keV show disagreement with experimental values. But the experimental branching ratio for the $13/2^+$ level at 1937 keV may have a large error in it. This is in view of the fact that there are two 386 keV γ rays in the experimental scheme and the 990 keV γ ray also arises from an impurity in the target. The result for the $11/2^+$ level indicates some ambiguity in the theoretical

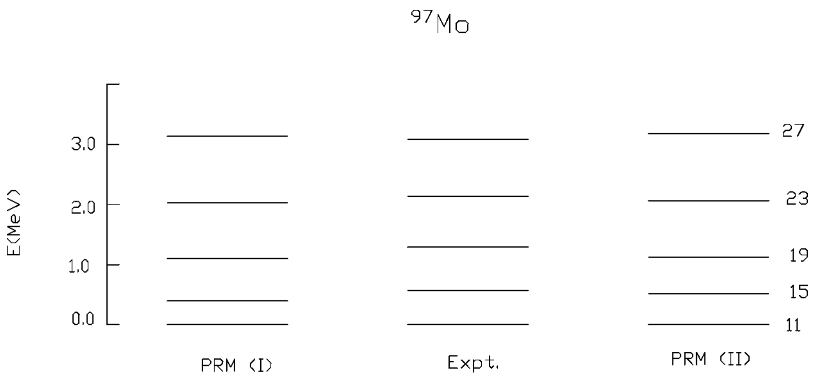

FIG. 6. Comparison of the experimental (Expt.) negative parity levels in ^{97}Mo with the relevant theoretical spectra based on $\nu\, h_{11/2}$ configuration obtained using particle rotor model (PRM) with variable moment of inertia (VMI) approach and for δ=0.08 [PRM(I)] and δ=0.15 [(PRM(II)]. 2J spin values for the states are indicated in the figure.

assignment of this level. In order to have an unambiguous identification there is a need for more accurate determination of the experimental branching ratios or level lifetimes of the two very close lying $11/2^+$ (at 1551 and 1541 keV) and $13/2^+$ (at 1937 and 2059 keV) levels.

The overall agreement of the results from the phenomenological collective model with experiment at medium spin region indicates the onset of mild collectivity in this nucleus.

B. ^{97}Mo

The theoretical study of the positive parity orbitals of ^{97}Mo within PRM calculation has been discussed in Ref. [5]. The negative parity level sequence up to $31/2^-$ level at E_x =5.5 MeV was identified as $\nu\, 1h_{11/2}$ sequence using interacting boson model [6]. CPCM as applied in the case of ^{95}Mo could not be applied effectively for the study of this nuclei because of the lack of experimental data on high spin states in ^{96}Mo. So in this case, we have used the standard particle rotor model [22] wherein the core was taken to be axially symmetric with a quadrupole deformation. The calculation was carried out in two ways, viz., (i) by assuming a CMI for all the spin states, and this was determined by varying it so as to get a best fit to the experimental level energies and (ii) by using the concept of VMI formalism, wherein the related parameter C was obtained (and then varied) following the procedure described in Ref. [22]. Same values for μ, κ, as mentioned above for ^{95}Mo, have been taken for the deformed oscillator potential. The neutron pairing gap and the Fermi level were obtained by solving the inverse gap equation. Negative parity Nilsson orbitals originating from the intruder $\nu\, 1h_{11/2}$ were only considered. As in the case of ^{95}Mo, the calculations were carried out with two sets of deformation parameters, viz., δ=0.08 and 0.15, corresponding to a very weakly and moderately deformed system, respectively. A Coriolis attenuation factor (=0.8) was needed to obtain the best fit.

It should be mentioned here that in this case, due to the lack of proper transition probability data (i.e., branching ratios, lifetimes, etc.), we had to restrict ourselves to the comparison of the energy values of the levels only. A comparison of the experimental level scheme with the results of the particle rotor model calculation for the negative parity yrast band in ^{97}Mo is shown in Fig. 6. The results are from the VMI approach since they appear to be better compared to the constant moment of inertia approach. It can be noted from Fig. 6 that between the two sets of theoretical results (viz., with δ=0.08 and 0.15), the one with δ=0.15 is in relatively better agreement with the experimental level scheme. The calculated states of spin 13/2, 17/2, 21/2, etc. (not shown in Fig. 6), are situated above the states of spin 15/2, 19/2, 23/2, etc. respectively. This indicates that they are unfavored in energy and explains why they are not seen in the experiment. It may be noted that we are not presenting the theoretical results above $27/2^-$ because it appears from the experimental data that there is a kind of back bending around this region. This simplistic PRM calculation is not suitable to explain the states above such phenomenon.

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