Chapter 4

High Spin Spectroscopy and Shape Coexistence in $^{73}$As

4.1 Introduction

Structure of nuclei in mass $A \approx 70$ region is of special interest in nuclear $\gamma$ spectroscopy, because it is an ideal testing ground for understanding of quasiparticle influence over the evolution of shape of the nuclei with increasing angular momentum. Shape changes and shape coexistence are observed with increasing proton and neutron number as well as with increasing spin and excitation energy were attributed to the dynamical interplay between single particle and collective degrees of freedom. Presence of oblate deformed subshell gaps at $N$ or $Z = 34$ and 36, the prolate deformed subshell gaps at $N$ or $Z = 34$ and 38 favors the existence of competing oblate and prolate structures which coexist within narrow spin ranges, this phenomenon is often referred to shape coexistence. Several even-even nuclei were studied and shape coexistence have been observed and/or theoretically predicted in the neutron deficient region with mass number $A \approx 70$. Experimental evidence for shape coexistence at low spin comes mainly from the study of the positive-parity bands in the even-even nuclei. They consists of the observation of low lying excited $0^+$ states, which can be interpreted as the ground state of a different shape such as prolate or oblate shape. The first experimental evidence for such a state was reported in $^{72}$Se by Hamilton et al., [1]. The identification of similar low-lying $0^+$ states in $^{72,74}$Kr [2, 3] nuclei confirmed the predicted scenario of oblate-prolate shape coexistence in this mass-region.

Microscopic structure of nuclei in this mass region are determined by $g_{9/2}$, $f_{5/2}$ and
p\textsubscript{3/2} orbitals. The predicted shape competition or shape coexistence in this region are due to the competition between the closure of the f\textsubscript{5/2}, p\textsubscript{3/2} subshells and the intruder levels of the g\textsubscript{9/2} shell. Therefore the structures built on these orbitals favors the appearance of different minima in the potential energy surface and the competition and/or coexistence of different shapes at low energies. Several light neutron deficient nuclei have been studied across this region, exhibiting very large values of deformations for prolate as well as oblate [4, 5] shapes and triaxial deformations at low excitation energies. Nazarewicz et al [6] have calculated competing minimum at quadrupole deformations $\beta_2 \approx +0.38$ (prolate) and $\beta_2 \approx -0.30$ (oblate) for Kr and Sr ($N < 40$). The coexistence of different shapes has been investigated in other even-even nuclei in the region, like $^{72-74}$Se [1, 7] and $^{76-78}$Kr [8, 9] but limited studies has been reported so far for odd-A nuclei.

Study of yrast bands which involve g\textsubscript{9/2} orbital in the odd-A nuclei would offer best experimental evidence for changes in structure with increasing nucleon number. Investigations revealed positive parity yrast structures showing decoupling bands in odd-A As and Br isotopes [10, 11, 12]. The decoupled nature of these bands is interpreted based on configuration involving particles filling the g\textsubscript{9/2} proton orbit which decouples from core due to strong Coriolis force. Since the structure of those bands depend on core deformation (oblate or prolate) the spectroscopic study of decoupled configurations built on the deformation driving g\textsubscript{9/2} orbit offers a unique experimental possibility for investigating the shape evolution in this mass region. With the advent of present day experimental facilities like heavy ion accelerators and high efficiency Ge detector arrays make it possible to extend the investigations of structures of nuclei to high spin. The study of nuclei at high spin especially in odd-even, odd-odd nuclei allowed to study Pauli blocking effect due to odd-valance particles.

Despite extensive experimental and theoretical efforts, there are still difficulties in understanding the complex structures of nuclei in mass 70 region. These difficulties arise mainly due to incomplete experimental information about structure of several nuclei. There are still nuclei whose experimental bands could be observed only in a very limited spin range and information about the electromagnetic properties of corresponding states are still missing. $^{73}$As is one such nucleus. In this context, study of odd-A $^{73}$As nucleus
will give insight into nuclear shape evolution with increasing angular momentum and the
delicate interplay between different configurations based on f-p-g shell nucleons.

Structure of light odd-A Arsenic nuclei $^{67}$As [13], $^{69}$As [14] and $^{71}$As [15] have been
studied in the past and level schemes consisting of both positive and negative parity
sequences were identified in low and medium spins. Study of $^{67}$As gives evidence for little
oblate collectivity in it, which has one proton hole with respect to the $N = Z = 34$ core
and this nucleus is more readily described in terms of weak coupling of $g_{9/2}$ proton-hole to
the $^{68}$Ge core. In case of $^{69}$As shape change has been observed from an oblate at low spins
evolving to a prolate as it reaches to high spin. This shape change in $^{69}$As was interpreted
as being due to the alignment of a pair of $g_{9/2}$ neutrons. Whereas quite contrast behavior
has been observed in case of $^{71}$As. The shape calculations for positive parity states in
$^{71}$As predict great deal of $\gamma$-softness at low rotational frequencies and at higher rotational
frequencies triaxial shapes with varying $(\gamma > 0^\circ)$ values are reported. In the case of
negative parity states, the shape calculations predict a deformed prolate shape at low
rotational frequencies evolving to highly deformed triaxial shape at higher frequencies
($\hbar\omega > 0.5$ MeV). Indeed, recent observation in $^{71}$As [16] reported the negative-parity band
based on the proton $f_{7/2}$ hole state was evidence for a large prolate deformation as it is
only at such deformations that this orbital approaches Fermi surface.

The results of the experimental studies in lighter odd-A As isotopes reveal that,
the shape of these isotopes has strong dependence on number of quasiparticles outside
the core. For example, nuclear shape transition has been observed in these isotopes, as
neutron number increasing from $^{67}$As ($N = 34$) to $^{71}$As ($N = 38$). Hence it would be
interesting to study $^{73}$As along the chain of odd-A As isotopes to understand the nuclear
structure and shape evolution with the addition of neutron pair to $^{71}$As.

4.2 Structure of $^{73}$As from earlier works

The energy levels of $^{73}$As was studied earlier in 1970’s using light ion beams and with
few Ge(Li) detectors by $\gamma$ spectroscopic methods from $^{73}$Se $\beta^+$ decay by Marlow and Fass
[17], Meeker and Tucker [18] and Ten Brink et al [19], from ( p, n$\gamma$) reaction by Van
der Merwe et al [20]. The structure was also studied by single proton transfer reaction by Ramaswamy et al [21]. These studies extended knowledge on the structure of $^{73}\text{As}$ considerably, nevertheless they are somewhat inconsistent, as some of the levels were observed only in one or another work, and the level spins are different in different studies. All these previous studies of $^{73}\text{As}$ were able to establish the low spin structure of $^{73}\text{As}$ with levels up to excitation energies 1.9 MeV. Heits et al [22] employed the heavy ion reactions $^{58}\text{Fe} (^{18}\text{O}, \text{p2n})^{73}\text{As}$ and $^{71}\text{Ga} (\alpha, \text{2n})^{73}\text{As}$. They were able to extend levels up to 4.1 MeV and 33 transitions are found and placed in the level scheme with 6 new spin assignments. The collective positive parity band was established, built on 6 $\theta$ isomeric $9/2^+$ level at 428 keV and extended to $25/2^+$ and the negative parity band built on a low lying $3/2^-$ state was also extended to $17/2^-$. The results of the earlier experiments of $^{73}\text{As}$ confirms that there are few problems which are not clarified in previous works. The experimental information about non-yrast states are very little. The study of these states would offer important evidence about the shapes involved at low excitation energies. The ground state band in this nucleus is known only up to $25/2^+$. Extension of this ground state band above $25/2^+$ is very important because it can provide information about the stability of deformation of the ground state band.

4.3 Experimental details and data analysis

In the present experiment, medium and high spin states of $^{73}\text{As}$ were populated using fusion-evaporation reaction $^{64}\text{Ni}(^{12}\text{C}, \text{p2n})^{73}\text{As}$. Beam of $^{12}\text{C}$ ions with energy 55 MeV and beam current of 1 pnA was provided by 15UD/16MV Pelletron accelerator [23, 24] at the Inter University Accelerator Center (IUAC), New Delhi. The target used in this experiment was isotopically enriched $^{64}\text{Ni}$ with thickness $\approx 1.5 \text{ mg/cm}^2$ on gold(Au) backing having thickness 7 mg/cm$^2$. A thin layer of Indium ($\approx 70 \mu\text{g/cm}^2$) was used in between the target and the backing to stick the two materials. Indium was evaporated on both the target and backing material, inside a high vacuum evaporation chamber and then both were rolled once again with Indium evaporated surfaces facing each other. The de-excited
gamma rays from residual nuclei were detected with the *Gamma Detector Array* (GDA) [25] at IUAC, New Delhi. This facility contains 12 Compton suppressed n-type Hyper Pure Germanium (HPGe) detectors, separated into three groups each consisting of four detectors and are mounted co-axially in Anti-Compton shields making an angle 45°, 99°, 153° with respective to the beam direction and are tilted ±25° with respect to the horizontal plane. The information of this facility and experimental details are explained in Chapter 3 in detail.

The online CAMAC based data acquisition system CANDLE [26] was used to record $\gamma - \gamma$ coincidences in event mode. A total of more than 130 million two and higher fold events were recorded in list mode. About 20% of the recorded events corresponds to the nucleus of interest i.e. $^{73}$As. The list mode data were sorted into a two dimensional 4k $\times$ 4k total $E_\gamma$-$E_\gamma$ matrix from which the coincidence spectra were generated using the program INGASORT [27] with a dispersion of 0.5 keV/channel. This was the primary data set used for the construction of level scheme. Energy and efficiency calibrations of the detectors were performed using the $^{152}$Eu and $^{133}$Ba radioactive sources. The subprogram EFFICIENCY and a subroutine of the main program INGASORT was used to obtain $\eta$, the relative full-energy peak detection efficiency of detectors as a function of $\gamma$-energy. The program does both the polynomial and exponential fitting of two data sets (Eu and Ba) with proper normalization. The polynomial fitting coefficients were given as input in the program INGASORT for finding relative intensities of the $\gamma$-transitions. The construction of level scheme, checking of different projections and coincidence relationship between different transitions were done with the program escl8r of RADWARE [28]. The placement of $\gamma$-transitions in level scheme is based upon their coincidence relationships, energy sums and intensities. In addition an angle dependent matrix was constructed with the $E_\gamma$ of events recorded at 99° taken in one axis and those recorded at 45° or 153° taken in the other axis. This matrix enable us to determine DCO ratios for each transitions, which yields the multipolarity nature of the $\gamma$-transitions. The experimental DCO ratio for present work is defined [29, 30] as the intensity(I) of a measured transition in detector of 45° or 153° when gated on a reference $\gamma$-ray in detector of 99°, divided by the intensity of a measured transition at 99° when gated on a reference $\gamma$-ray at 45° or 153° (where the
reference $\gamma$-ray is of known multipolarity) and is given by

$$R_{DCO} = \frac{I_{\gamma_1} \text{ at } 45^\circ \text{ gated by } \gamma_2 \text{ at } 99^\circ}{I_{\gamma_1} \text{ at } 99^\circ \text{ gated by } \gamma_2 \text{ at } 45^\circ} \quad (4.1)$$

In general, DCO ratio were determined by gating on transitions in the band sequence preceding or following the transition of interest. Assuming stretched transitions, when both the gating transitions and observed transitions have the same multipolarity the DCO ratio $\approx 1$. For $\gamma$-rays of different multipolarity, the intensities differed by a factor of almost 2. Details of various steps involved in data analysis are explained at length in chapter 3.

### 4.4 Results

#### 4.4.1 Level scheme of $^{73}$As

Prior to this work, the level scheme of $^{73}$As is limited only to low spin states. Low lying positive parity states up to an excitation energy 4083.2 keV have been firmly identified and reported by B.Heits et al [22]. This study also reported a rotational aligned $g_{9/2}$ positive parity band based on $\gamma - \gamma$ coincidences, angular distributions and excitation function. This band consists of 361, 609, 912, 1002, 1017, 1117 keV $\gamma$ rays with highest spin observed was $25/2^+$ and excitation energy 4083.2 keV. The DCO ratios of 609, 912, 1017, 1117 keV $\gamma$-transitions were found to be typically stretched quadrupole transitions, considered as the members of favored positive parity sequence. Where as the DCO ratio of the 865 keV transition has dipole character and it is suggested to have spin of $11/2^+$, which is a member of unfavored positive parity sequence. Along with the positive parity sequences, favored and unfavored negative parity sequence were also reported in Ref.[22] consisting of 862, 1110, 808 keV $\gamma$-rays in favored negative parity sequence with highest observed spin ($17/2^-$) at excitation energy 2848 keV, whereas unfavored negative parity sequence consisting of 861, 797, 817 keV $\gamma$-rays with the highest excitation energy 2475.7 keV having no spin assignment. The level scheme reported in Ref.[22] is shown figure 4.1.

In the present study, $\gamma$-rays belonging to various residual nuclei were identified by projecting gates on known strong $\gamma$-transitions. Figure 5.1 shows background subtracted total projection spectrum and the labeled peaks are the strong $\gamma$-transitions belonging to
Figure 4.1: The level scheme of $^{73}$As reported in previous work [22].
different residual nuclei along with the nuclei of interest $^{73}$As and $^{70}$Ge. In the present work, the level scheme of $^{73}$As is extended to $J^\pi=37/2^-$ and excitation energy $\approx 8.7$ MeV. The partial level scheme of $^{73}$As as obtained in the present work is shown in figure 5.3 and the preliminary results were presented in Ref.[31].

The level scheme consists of three main bands, labeled as B1 corresponds to favored positive parity, B2 corresponds to favored negative parity and B3 represents unfavored negative parity band. This study confirms all levels reported in Ref.[22] except few inter-band transitions. The yrast positive-parity sequence (B1) and negative-parity sequences (B2 and B3) has been extended to $37/2^+$, $37/2^-$ and $31/2^-$ respectively.

A total of 30 new $\gamma$-transitions have been assigned to the nucleus $^{73}$As and placed in the level scheme based on coincidence, intensity relationships and from directional correlation orientation (DCO) values. Relative intensities of $\gamma$-transitions are determined from the primary all coincidence matrix. The intensity values are determined from total projection spectrum and are normalized with respect to 609 keV gamma transition which was chosen as 100% in intensity. The DCO ratios are obtained by gating on known quadrupole transitions. Figure 4.4 illustrate the measured $R_{DCO}$ values of the observed for $\gamma$-transitions in $^{73}$As. For few of the $\gamma$-transitions, DCO ratios could not be measured because of their week intensities. In level scheme, some of the levels left with out spin and parity assignment and a few of the level spins are in parenthesis due to low statistics limiting measurement of DCO ratios. The measured relative intensities, DCO ratios and multipolarities of observed $\gamma$-transitions belonging to $^{73}$As are summarized in Table 4.1.

### 4.4.2 Positive parity states

The positive parity yrast band in $^{73}$As obtained in the present work is shown in figure 5.3 as band B1. Prior to present work, this band sequence was known up to $J^\pi=25/2^+$ [22]. Now this band sequence B1 is extended to spin $J^\pi=(37/2^+)$. The present study confirms the previously reported states at 428.2, 1037.5, 1950.2, 2965.4 and 4083.2 keV excitation energy, having spins $9/2^+$, $13/2^+$, $17/2^+$, $21/2^+$ and $25/2^+$ respectively of positive parity yrast band. This band is extended to high spin by adding three new $\gamma$-transitions of energy 1329, 1497, 1655 keV at level energies 5412, 6909, 8564 keV having spins $29/2^+$,
Figure 4.2: A total projection spectrum of the $\gamma$-$\gamma$ matrix showing transitions belonging to $3n\gamma(^{73}\text{Se})$, $p2n\gamma(^{73}\text{As})$ and $\alpha2n\gamma(^{70}\text{Ge})$ strong residual nuclei populated in the present experiment.
Figure 4.3: Partial level scheme of $^{73}\text{As}$ established in the present study. The bands are labeled as B1, B2, B3, G4 and G5 for reference in the text.
Figure 4.4: $\gamma$-ray anisotropy intensity ratio ($R_{DCO}$), for a number of $\Delta J = 2$ and $\Delta J = 1$ transitions of $^{73}$As. The quoted errors include errors due to background subtraction, peak fitting and efficiency correction.
33/2\(^+\) and (37/2\(^+\)) respectively. The measured DCO ratios for the 1329 and 1497 keV transitions, obtained by gating on the intense 609 keV transition (\(\Delta J=2\)) are consistent with a \(\Delta J=2\) character, suggesting an \(J=29/2\), \(33/2\) spin assignments for the levels at 5412 and 6909 keV respectively. No feeding from higher lying negative-parity states was observed. Therefore a positive parity is tentatively assigned for both the levels. Poor statistics in angular correlation matrix does not allow us in measuring DCO ratio of 1655 keV transition, but from coincidence and intensity relationships it is found to be in coincidence with all \(\gamma\)-transitions in yrast band only, hence it is considered as the member of this band and placed above the 1497 keV transition with the help of systematics and it was assigned to have tentative spin \(J^{\pi}=37/2^+\).

A group of two new positive parity structures labeled as G4 is also established in the present work, which are decaying to \(J^{\pi}=17/2^+\) of yrast 1-quasiparticle ground state band through 1101 and 1541 keV transitions. These bands are extended to \(J^{\pi}=27/2^+\) and 29/2\(^+\) respectively. An unfavored band transition 865 keV at low spins decaying from 1295.3 keV level with spin 11/2\(^+\) to the 9/2\(^+\) state at 428.2 keV. We are not able to observe the transitions above 11/2\(^+\) because of the low intensity of 865 keV. A representative coincidence gated sum spectrum on yrast transitions of positive parity band is shown in figure 4.5.

### 4.4.3 Negative parity states

The present work established two negative-parity sequences, namely B2 and B3 are built upto high spin, which are shown in figure 5.3. This present work confirms all previously found negative parity yrast levels at 67, 929, 2039, and 2848 keV having spins 5/2\(^-\), 9/2\(^-\), 13/2\(^-\) and 17/2\(^-\) respectively in favored configuration. This sequence B2 is extended to high spin by adding 5 new \(\gamma\)-transitions of energies 903, 1119, 1262, 1302 and 1354 keV at level energies 3751, 4870, 6132, 7433 and 8787 keV which are assigned to have tentative spins 21/2\(^-\), 25/2\(^-\), 29/2\(^-\), 33/2\(^-\) and (37/2\(^-\)) respectively, thereby the band B2 has been extended to 37/2\(^-\) spin level with energy \(\approx 8.8\) MeV. Whereas this work also confirms the states in unfavored configuration at level energies 861.1, 1658.4 and 2475.7 keV for which the spin is tentatively assigned only to 861.1 keV level in previous work with 7/2\(^-\). Now
Figure 4.5: Gated sum $\gamma-\gamma$ coincidence spectra of $^{73}$As gated on 609, 912 and 1017 keV of positive parity sequence. Inset portions with expanded vertical scale are drawn to show the weaker high energy transitions. Strong peaks are labeled with energies in keV.
this unfavored configuration band-B3 also extended to higher spins by adding four new 
$\gamma$-transitions of energies 1085, 897, 1229, 1051 keV at level energies 3560.7, 4457.7, 5686.7 
and 6737.7 keV which are assigned to have tentative level spins $19/2^-$, $23/2^-$, $27/2^-$
and $31/2^-$ respectively. A sequence of dipole transitions consists of five new transitions 
with energies 729, 382, 434, 373 and 712 keV which interconnects the two negative parity 
 favored and unfavored sequences has been identified. This sequence starts from $9/2^-$
level at energy 929.1 keV and connects the levels with spin $11/2^-$, $13/2^-$, $15/2^-$ $17/2^-$
and $19/2^-$ respectively. The intensity of this band is quite weak, hence we could not 
 extend this band to higher spins. Along with these several inter-band transitions are also 
identified and placed in level scheme of $^{73}$As.

A level sequence in low spin side consisting of 577, 601 and 862 keV $\gamma$-transitions 
is identified in the present work, in which 577 keV transition directly decaying to ground 
state, above which we have placed two newly identified 601, 862 keV transitions according 
to coincidence and summing energy relationships. This 862 keV $\gamma$-transition initially 
considered to be part of ground state negative parity yrast sequence, but after proper 
checking of gated sum spectra of 577, 601 keV and gated spectra of 1110 keV, we found 
that there were no connection between 577, 601 keV to 1110 keV transition. Hence it 
is confirmed that 862-keV is a new transition connecting the levels 2039.5 keV to 1178 
keV. Along with these we also identified four new transitions (named as group G5) 994, 
1122, 1276 and 1347 keV, which are found to be in coincidence with 862, 1110 and 808 
keV $\gamma$-transitions of favored negative-parity band. Hence these transitions are placed 
above $17/2^-$ level. A representative coincidence gated sum spectra on yrast transitions 
of negative parity band is shown in figure 4.6.

4.5 Discussion

Low spin structure of $^{73}$As was studied earlier by several authors [17, 18, 19, 20, 21]. The 
origin of the positive parity states in $^{73}$As below 1 MeV excitation energy was discussed in 
Ref.[32] with in frame work of Coriolis interaction calculations with prolate deformation 
$\beta \approx 0.2$ which were in good agreement with experimental energy states. These positive
Figure 4.6: A representative $\gamma-\gamma$ coincidence spectra of $^{73}$As gated on sum of 862+808 keV (lower panel) of favored negative parity sequence and 797+817 keV (upper panel) of unfavoured negative parity sequence. Peaks marked with * are contaminants from other reaction channels. Energy values are marked in units of keV.
Table 4.1: Transition energy ($E_\gamma$), Relative Intensity ($I_\gamma$), DCO ratios ($R_{DCO}$), Multipolarity of the transition (D/Q) and decay from an initial state ($J_i^\pi$) to final state ($J_f^\pi$) for transitions placed in level scheme of $^{73}$As are listed. 1. Relative intensity is calculated with respective to 609 keV by assuming its intensity as 100%.

<table>
<thead>
<tr>
<th>$E_\gamma$ (keV)</th>
<th>$I_\gamma$ (Rel.)</th>
<th>$R_{DCO}$</th>
<th>Multipolarity of transition</th>
<th>$J_i^\pi$</th>
<th>$J_f^\pi$</th>
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<td>317</td>
<td>0.6(0.2)</td>
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<td>-</td>
<td>(9/2$^-$)</td>
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<td>373</td>
<td>1.81(0.4)</td>
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<td>(D)</td>
<td>17/2$^-$</td>
<td>15/2$^-$</td>
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<tr>
<td>383</td>
<td>1.79(0.4)</td>
<td>-</td>
<td>(D)</td>
<td>13/2$^-$</td>
<td>11/2$^-$</td>
</tr>
<tr>
<td>434</td>
<td>3.31(0.9)</td>
<td>-</td>
<td>(D)</td>
<td>15/2$^-$</td>
<td>13/2$^-$</td>
</tr>
<tr>
<td>440</td>
<td>0.8(0.2)</td>
<td>-</td>
<td>(D)</td>
<td>21/2$^+_2$</td>
<td>19/2$^+$</td>
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<tr>
<td>468</td>
<td>1.2(0.2)</td>
<td>-</td>
<td>-</td>
<td>11/2$^+$</td>
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<tr>
<td>480</td>
<td>1.76(0.5)</td>
<td>-</td>
<td>-</td>
<td>11/2$^-$</td>
<td>-</td>
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<tr>
<td>510</td>
<td>5.42(0.9)</td>
<td>-</td>
<td>-</td>
<td>7/2$^-$</td>
<td>5/2$^-$</td>
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<tr>
<td>526</td>
<td>2.25(0.7)</td>
<td>-</td>
<td>(D)</td>
<td>15/2$^-$</td>
<td>17/2$^+$</td>
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<tr>
<td>563</td>
<td>2.21(0.5)</td>
<td>-</td>
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<td>(25/2$^+_2$)</td>
<td>23/2$^-$</td>
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<td>577</td>
<td>2.54(0.7)</td>
<td>1.20(0.12)</td>
<td>(Q)</td>
<td>7/2$^-$</td>
<td>3/2$^-$</td>
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<tr>
<td>594</td>
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<td>-</td>
<td>(D)</td>
<td>19/2$^-$</td>
<td>21/2$^+$</td>
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<tr>
<td>601</td>
<td>3.70(0.9)</td>
<td>0.67(0.20)</td>
<td>(D)</td>
<td>9/2$^-$</td>
<td>7/2$^-$</td>
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<td>609</td>
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<td>Q</td>
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<tr>
<td>712</td>
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<td>17/2$^-$</td>
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<tr>
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<td>-</td>
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<td>794</td>
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<td>-</td>
<td>(D)</td>
<td>15/2$^-$</td>
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Table 4.1: (Continued...)

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<tr>
<th>$E_{\gamma}$ (keV)</th>
<th>$I_{\gamma}$ (Rel.)</th>
<th>$R_{DCO}$</th>
<th>Multipolarity transition</th>
<th>$J_i^\pi$</th>
<th>$J_f^\pi$</th>
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<tr>
<td>797</td>
<td>10.5(1.3)</td>
<td>1.02(0.10)</td>
<td>Q</td>
<td>11/2$^-$</td>
<td>7/2$^-$</td>
</tr>
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<td>808</td>
<td>34.26(2.1)</td>
<td>1.10(0.09)</td>
<td>Q</td>
<td>17/2$^-$</td>
<td>13/2$^-$</td>
</tr>
<tr>
<td>817</td>
<td>14.03(1.2)</td>
<td>1.12(0.16)</td>
<td>Q</td>
<td>15/2$^-$</td>
<td>11/2$^-$</td>
</tr>
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<td>861</td>
<td>10.46(0.9)</td>
<td>1.12(0.11)</td>
<td>Q</td>
<td>7/2$^-$</td>
<td>3/2$^-$</td>
</tr>
<tr>
<td>862</td>
<td>2.56(0.5)</td>
<td>-</td>
<td>-</td>
<td>13/2$^-$</td>
<td>9/2$^-$</td>
</tr>
<tr>
<td>862</td>
<td>71.22(3.2)</td>
<td>1.01(0.09)</td>
<td>Q</td>
<td>9/2$^-$</td>
<td>5/2$^-$</td>
</tr>
<tr>
<td>865</td>
<td>2.12(0.7)</td>
<td>-</td>
<td>(D)</td>
<td>11/2$^+$</td>
<td>9/2$^+$</td>
</tr>
<tr>
<td>897</td>
<td>5.60(0.7)</td>
<td>1.28(0.15)</td>
<td>Q</td>
<td>23/2$^-$</td>
<td>19/2$^-$</td>
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<td>20.35(1.1)</td>
<td>1.12(0.02)</td>
<td>Q</td>
<td>21/2$^-$</td>
<td>17/2$^-$</td>
</tr>
<tr>
<td>912</td>
<td>78.31(2.2)</td>
<td>0.98(0.01)</td>
<td>Q</td>
<td>17/2$^+$</td>
<td>13/2$^+$</td>
</tr>
<tr>
<td>974</td>
<td>3.13(0.4)</td>
<td>1.13(0.18)</td>
<td>Q</td>
<td>23/2$^{(+)}$</td>
<td>19/2$^{(+)}$</td>
</tr>
<tr>
<td>994</td>
<td>4.55(0.5)</td>
<td>0.54(0.21)</td>
<td>(D)</td>
<td>(19/2$^{-}$)</td>
<td>17/2$^-$</td>
</tr>
<tr>
<td>1002</td>
<td>6.43(0.9)</td>
<td>-</td>
<td>-</td>
<td>13/2$^-$</td>
<td>13/2$^+$</td>
</tr>
<tr>
<td>1017</td>
<td>48.87(2.2)</td>
<td>1.05(0.09)</td>
<td>Q</td>
<td>21/2$^+$</td>
<td>17/2$^+$</td>
</tr>
<tr>
<td>1058</td>
<td>7.95(0.7)</td>
<td>0.74(0.13)</td>
<td>(D)</td>
<td>23/2$^+$</td>
<td>21/2$^+$</td>
</tr>
<tr>
<td>1085</td>
<td>6.58(0.8)</td>
<td>1.15(0.15)</td>
<td>Q</td>
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<td>15/2$^-$</td>
</tr>
<tr>
<td>1096</td>
<td>3.57(0.5)</td>
<td>-</td>
<td>(Q)</td>
<td>(25/2$^+$)</td>
<td>21/2$^{(+)}$</td>
</tr>
<tr>
<td>1101</td>
<td>9.16(0.9)</td>
<td>0.78(0.16)</td>
<td>D</td>
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<td>17/2$^+$</td>
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<tr>
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<td>41.31(2.2)</td>
<td>0.99(0.02)</td>
<td>Q</td>
<td>13/2$^-$</td>
<td>9/2$^-$</td>
</tr>
<tr>
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<td>0.98(0.03)</td>
<td>Q</td>
<td>25/2$^+$</td>
<td>21/2$^+$</td>
</tr>
<tr>
<td>$E_\gamma$ (keV)</td>
<td>$I_\gamma$ (Rel.)</td>
<td>$R_{DCO}$</td>
<td>Multipolarity of transition</td>
<td>$J_i^\pi$</td>
<td>$J_f^\pi$</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------------</td>
<td>-----------</td>
<td>---------------------------</td>
<td>-------------</td>
<td>-------------</td>
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<td>21/2$^-$</td>
</tr>
<tr>
<td>1122</td>
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<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>1229</td>
<td>1.12(0.5)</td>
<td>-</td>
<td>(Q)</td>
<td>(27/2$^-$)</td>
<td>(23/2$^-$)</td>
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<td>25/2$^-$</td>
</tr>
<tr>
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<td>-</td>
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</tr>
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<td>1.08(0.10)</td>
<td>Q</td>
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<td>25/2$^+$</td>
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<td>(Q)</td>
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<td>33/2$^-$</td>
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<td>0.9(0.2)</td>
<td>-</td>
<td>(Q)</td>
<td>(29/2$^+$)</td>
<td>(25/2$^+$)</td>
</tr>
<tr>
<td>1388</td>
<td>0.92(0.2)</td>
<td>-</td>
<td>(Q)</td>
<td>(27/2$^+$)</td>
<td>(23/2$^+$)</td>
</tr>
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<td>1438</td>
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<td>1.65(0.25)</td>
<td>-</td>
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<td>13/2$^+$</td>
</tr>
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<td>1497</td>
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<td>1.17(0.21)</td>
<td>Q</td>
<td>33/2$^+$</td>
<td>29/2$^+$</td>
</tr>
<tr>
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<td>1.85(0.22)</td>
<td>Mixed</td>
<td>21/2$^{(+)}$</td>
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<tr>
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<td>17/2$^+$</td>
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<td>-</td>
<td>(Q)</td>
<td>(25/2$^+$)</td>
<td>21/2$^+$</td>
</tr>
<tr>
<td>1655</td>
<td>1.24(0.7)</td>
<td>-</td>
<td>(Q)</td>
<td>(37/2$^+$)</td>
<td>33/2$^+$</td>
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Figure 4.7: The relation between the experimental routhians ($e'$) with respect to rotational frequency ($\hbar\omega$) for bands B1, B2 and B3 in $^{73}$As.

Figure 4.8: The relation between the kinematic Moment of Inertia versus rotational frequency ($\hbar\omega$) for bands B1, B2 and B3 in $^{73}$As.
parity states were due to excited particles in unique parity \( g_{9/2} \) shell. For the \( 1g_{9/2} \) shell, there is competition between oblate and prolate deformations. The high-\( j \), low-\( \Omega \) intruder orbitals of the \( 1g_{9/2} \) shell (\( 1/2^+ [440] \) and \( 3/2^+ [431] \) orbitals) have prolate-driving force. Particularly in collective rotation, the intruder orbitals have strong Coriolis force that can drive nucleus towards prolate deformation.

Decoupling nature of positive parity band is well explained in Ref. [22] that the odd proton is below \( g_{9/2} \) shell and the adopted deformation is smaller than 0.3, therefore one can expect decoupled band based on \( g_{9/2}^+ \) isomer state. Other explanation in Ref. [33] stated that when the Fermi level is in the region of \( K = 1/2, 3/2 \) single particle states for prolate deformation, there occurs a strong lowering of the \( 9/2^+ \) state and a decoupled band with a spin sequence \( 9/2^+, 13/2^+, 17/2^+, 21/2^+ \ldots \) is expected. This type of decoupled structures were also identified in neighboring nuclei \(^{71}\text{As}, ^{81}\text{Rb} \) and \(^{83}\text{Rb} \). This was conformed in present work that the positive parity band was observed up to \( j^\pi = (37/2^+) \) but its signature partner was identified only up to \( J^\pi = 11/2^+ \). In addition two positive parity side bands (named as group G4) were identified and placed in the level scheme.

In the present work, the positive parity yrast \( g_{9/2}^+ \) band (B1) showing simple rotational like character as it reaches high up in spin with gradual decrease in collectivity. This is evident from experimental observables experimental routhian with respect to the rotational frequency (\( \hbar \omega \)) shown in figure 4.7. The experimental routhians values are calculated based on the procedure given in Ref. [34]. The experimental routhians for the \( g_{9/2}^+ \) band B1 are showing smooth variation with increasing rotational frequency with no clear evidence for band crossing. The kinematic Moment of inertia (\( J^1 \)) as function of rotational frequency (\( \hbar \omega \)) for the positive parity band-B1 (shown in figure 4.8) depicts that the \( J^1 \) value for this \( g_{9/2}^+ \) band showing gradual increment with an average value of 18 - 20 \( \hbar^2 \text{MeV}^{-1} \) with increasing rotational frequency. The up bend around rotational frequency (\( \hbar \omega \)) \( \approx 0.5 \text{ MeV} \) giving hint for the first band crossing in positive parity band B1. To understand the alignment behavior of the investigated bands and associated shape changes, \textit{Cranked Shell Model} calculations were performed.
4.5.1 Cranked shell model analysis

The variation of alignments \( i_x \) with rotational frequency \( (\hbar \omega) \) of the observed bands in \(^{73}\text{As}\) is compared with the neighboring odd-A nuclei which are shown in figure 4.9. The alignment behavior of positive parity band in \(^{73}\text{As}\) shows the similar behavior as its neighboring isotope \(^{71}\text{As}\) and alignment behavior is quite far from \(^{67,69}\text{As}\). The positive parity 1-quasiparticle band (B1) has gradual alignment around the rotational frequency \( \approx 0.5 \text{ MeV} \) with moderate band interaction above the level \( 21/2^+ \) of energy 2966 keV. This alignment in 1-quasiparticle \( g_9/2 \) ground state band expected due to a pair of \( g_9/2 \) neutron alignment. However, since \(^{73}\text{As}\) has odd number of protons, the first proton \( g_9/2 \) crossing is Pauli blocked, therefore the alignment observed in this band must be that of a pair of \( g_9/2 \) neutrons. Therefore this alignment causes the 1-quasiparticle band structure changes to a 3-quasiparticle structure with \( \nu g^2_{9/2} \) configuration.

In negative parity band B2, first band crossing has been observed around rotational frequency \( (\hbar \omega) \approx 0.48 \text{ MeV} \) above the level \( 17/2^- \) of energy 2848 keV. This is due to the alignment of first \( \nu g_{9/2}^2 \) pair. Thus the first band crossing occurs in both positive parity band B1 and negative parity band B2 at similar rotational frequencies because of the availability of active protons and neutrons in unique parity \( g_{9/2} \) orbital. In band B2, there is a proximity for the second band crossing above the rotational frequency \( 0.65 \text{ MeV} \), which can be inferred from the up bend observed after the first band crossing in band B2 shown in figure 4.10. This second band crossing may occur due to the alignment of a pair of \( g_{9/2} \) protons. This alignment in negative parity band B2 is consistent with alignment observed in \(^{71}\text{As}\) occurred at similar rotational frequency. Whereas the first alignment in negative parity sequence of \(^{69}\text{As}\) ( at \( \hbar \omega \approx 0.65 \text{ MeV} \)) is delayed in comparison to \(^{71,73}\text{As}\), which in turn indicating a configuration change in odd-A As isotopes with increasing neutron number implying shape changing effect in these isotopes.

To understand the nature of observed alignments and band crossing frequencies in \(^{73}\text{As}\), at fixed deformation, single-particle routhians were calculated as a function of rotational frequency based on a deformed Woods-Saxon potential, including pairing interaction at different shape parameters. Figure 5.12 shows one of such plot for the quasiparticle
Figure 4.9: The relation between alignment ($i_x$) and rotational frequency ($\hbar \omega$) ($i_x$-$\hbar \omega$ graph) for positive yrast bands of odd-A As isotopes $^{67,69,71,73}$As. Here the data for positive-parity yrast band of $^{73}$As correspond to band B1 shown in figure 5.3. Data for other nuclei are taken from Ref. [13, 14, 15].
Figure 4.10: The relation between alignment ($i_x$) and rotational frequency ($\hbar \omega$) ($i_x - \hbar \omega$ graph) for the negative-parity yrast bands of odd-A nuclei $^{69,71,73}$As. Here the data for negative-parity band of $^{73}$As correspond to the band B2 shown in figure 5.3. Data for other nuclei are taken from Ref.[14, 15].
energies at shape parameters $\beta_2 = 0.242$, $\gamma \approx -63^\circ$ with respective to rotational frequency ($\hbar \omega$). It is evident that the proton crossing frequency is much delayed then neutron crossing frequency which reflects the observed experimental alignments. The neutron crossing frequency observed in this case at $\hbar \omega \approx 0.5$ MeV is a clear indicative that the first band crossing in both the positive and negative parity bands (B1, B2) is due to the alignment of a pair of $g_{9/2}$ neutrons whereas the proton crossing frequency expected above 0.85 MeV supporting the second alignment in negative parity band B2 is being interpreted as due to the alignment of a pair of protons.

4.5.2 Woods-Saxon cranking calculations

The Hartree-Fock-Bogolyubov cranking calculations were performed using Woods-Saxon potential with a short range monopole pairing [30]. The BCS formalism was used to calculate the pairing gap $\Delta$ for both protons and neutrons. The Total Routhian Surface (TRS) calculations were performed in a ($\beta_2$, $\gamma$) plane at different rotational frequencies and the total energy was minimized with respect to hexadecapole deformation ($\beta_4$). For positive parity band the TRS plot is shown in figure 4.12 for a rotational frequency $\hbar \omega = 0.55$ MeV is typical of the surface near the first band crossing which predicts a minimum at quadrupole deformation parameter $\beta_2 = 0.28$, triaxiality parameter $\gamma \approx -22^\circ$ and hexadecapole deformation parameter $\beta_4 = 0.001$. This minimum is indicating that the nucleus becomes more collective triaxial with $\gamma \approx -22^\circ$ near to the prolate axis ($\gamma = 0^\circ$). At higher rotational frequency $\hbar \omega = 0.75$ MeV, the TRS still shows the triaxial minimum at $\gamma \approx -28^\circ$ and similar quadrupole deformation ($\beta_2 = 0.28$) persists.

The TRS for negative parity band B2 shown in figure 4.13 at rotational frequency $\hbar \omega = 0$ MeV predict a collective oblate minimum with a $\beta_2$ of $\approx 0.24$ and $\gamma \approx -60^\circ$. Whereas the TRS at $\hbar \omega = 0.55$ MeV (figure 4.13) depicting the situation near first band crossing in band B2 which predicts a minimum at $\beta_2, \gamma = (0.288, +30)$. At higher rotational frequency $\hbar \omega = 0.75$ MeV which is the situation after second band crossing predicted in negative parity band B2, depicts that the shape of the nucleus stabilizes at the non-collective triaxial same as predicted at $\hbar \omega = 0.55$ MeV with slightly less quadrupole deformation. Thus from the results of total routhian surface calculations in $^{73}$As, it
Figure 4.11: The plot shows the Cranked shell model calculations for quasi-protons (top) and quasi-neutrons (bottom) of $^{73}\text{As}$ using shape parameters $\beta_2 = 0.242$, $\beta_4 = -0.013$ and $\gamma = -63^\circ$. The style of lines indicates the parity and signature of the trajectories following the LUND convention. solid lines $(+, +)$ dotted lines $(+, -)$, dot-dashed lines $(-, +)$ and dashed lines $(-, -)$. 

Z=33, $\beta_2=0.242$, $\beta_4=-0.013$, $\gamma=-63$

N=40, $\beta_2=0.242$, $\beta_4=-0.013$, $\gamma=-63$
can be concluded that there as an evidence for shape coexistence between triaxial prolate and collective oblate shapes at ground state deformation at low rotational frequencies. At higher rotational frequencies afterwards the shape changes to collective and non-collective triaxial corresponds to the configurations in positive and negative parity sequences which perhaps indicating the shape competitions between single particle and collective degrees of freedom. To understand these shape changing effects and the microscopic origin of the observed bands, we have carried out Particle Rotor Model (PRM) calculations. The detailed of the calculations and the results are explained in the following section.
4.5.3 Particle Rotor Model Calculations

Formalism and numerical details

A particle rotor model with a quasiparticle coupled with a triaxially deformed rotor is applied to study the bands observed in $^{73}$As. The PRM adopted here is the same as in Ref. [36]. The model Hamiltonian is expressed as

$$H = H_{\text{coll}} + H_{\text{intr}}. \quad (4.2)$$

The collective Hamiltonian with a triaxial rotor can be written as

$$H_{\text{coll}} = \frac{3}{2} \sum_{i=1}^{3} \frac{\hat{R}_{i}^{2}}{2J_{i}} = \frac{3}{2} \sum_{i=1}^{3} \frac{(\hat{I}_{i} - \hat{j}_{i})^{2}}{2J_{i}}, \quad (4.3)$$

where $\hat{R}_{i}$, $\hat{I}_{i}$, $\hat{j}_{i}$ respectively, denote the angular momentum operators for the core, nucleus and the valence nucleon. The moments of inertia for irrotational flow are given by

$$J_{i} = \frac{4}{3} J_{0} \sin^{2}(\gamma + \frac{2\pi}{3} i) \quad (i = 1, 2, 3), \quad (4.4)$$

where $J_{0}$ depends on the quadrupole deformation $\beta$ and the nuclear mass $A$, while $\gamma$ denotes the degree of triaxiality.

The intrinsic Hamiltonian with pairing is

$$H_{\text{intr}} = H_{sp} + H_{\text{pair}} = \sum_{\nu > 0} \varepsilon'_{\nu}(\alpha_{\nu}^{+}\alpha_{\nu} + \alpha_{\bar{\nu}}^{+}\alpha_{\bar{\nu}}). \quad (4.5)$$

$\alpha_{\nu}^{+}$ is the quasiparticle operator and quasiparticle energies $\varepsilon'_{\nu} = \sqrt{(\varepsilon_{\nu} - \lambda) + \Delta^{2}}$, where $\varepsilon_{\nu}$ is single-particle energy, $\lambda$ denotes the Fermi energy and $\Delta$ the pairing gap parameter. $|\bar{\nu}\rangle$ the time-reversal state of $|\nu\rangle$. The quasiparticle operators $\alpha_{\nu}^{+}$ are given by

$$\begin{pmatrix} \alpha_{\nu}^{+} \\ \alpha_{\bar{\nu}} \end{pmatrix} = \begin{pmatrix} u_{\nu} & -v_{\nu} \\ v_{\nu} & u_{\nu} \end{pmatrix} \begin{pmatrix} a_{\nu}^{+} \\ a_{\bar{\nu}} \end{pmatrix}, \quad (4.6)$$

where $a_{\nu}^{+}$ is the single-particle operator and $u_{\nu}^{2} + v_{\nu}^{2} = 1$. The single-particle states and corresponding energies $\varepsilon_{\nu}$ are obtained by diagonalizing the Nilsson-type Hamiltonian $H_{sp}$ similar to Refs. [37, 38].

To obtain the PRM solutions, the total Hamiltonian (4.2) is diagonalized in the so-called strong coupling basis,

$$|IMK\nu\rangle = \sqrt{\frac{1}{2}} \sqrt{\frac{2l+1}{8}} [D_{M,K}^{I} \alpha_{\nu}^{+}|0\rangle + (-1)^{I-K} D_{M,-K}^{I} \alpha_{\bar{\nu}}^{+}|0\rangle], \quad (4.7)$$

for $K = \ldots, -\frac{3}{2}, +\frac{1}{2}, \ldots$.

More details can be found in Ref. [36].
4.5.4 Potential energy surface

Based on the adiabatic constrained triaxial RMF calculations in PK1 effective interaction [39], the potential energy surface in the $\beta$-$\gamma$ plane ($0 \leq \gamma \leq 60^\circ$) for $^{73}$As is shown in figure 4.14. All energies are normalized with respect to the binding energy of the absolute minimum, and the contours join points on the surface with the same energy (in MeV). The energy separation between contour lines is 0.2 MeV. From figure 4.14, it shows that the ground state of $^{73}$As is oblate deformed, with deformation parameters around $\beta = 0.20$ and $\gamma = 60^\circ$. The corresponding valence proton configuration is $\pi(2p_{3/2}1f_{5/2}2p_{1/2})^5$. The second minimum is located at the area with $\beta \approx 0.35$ and $\gamma \approx 25^\circ$, and the corresponding valence proton configuration is $\pi 1g_{9/2}^1$. The energy difference between these two minima is about 0.4 MeV and corresponding barrier height is about 0.8 MeV. The energy surface around these two minima is $\gamma$ soft and shows the behavior of shape coexistence.

Figure 4.14: Contour plots of potential energy surface in $\beta$-$\gamma$ plane ($0 \leq \gamma \leq 60^\circ$) for $^{73}$As in constrained triaxial RMF calculations based on PK1 [39] effective interactions. All energies are normalized with respect to the binding energy of the absolute minimum (in MeV). The energy separation between contour lines is 0.2 MeV.
4.5.5 **Description of rotational bands**

The observed rotational bands in $^{73}$As are described with the triaxial particle rotor model. In the PRM calculations, the quadrupole deformation parameters $\beta$ are taken from RMF calculation for the corresponding configurations of $^{73}$As, while the triaxiality parameter $\gamma$ is taken as a free parameter to search a favorable triaxiality and investigate the triaxial effect. A variable moment of inertia is used, i.e., $J_0(I) = J_0\sqrt{1 + bI(I + 1)}$ [40]. The Fermi energy $\lambda$ and pairing gap $\Delta$ are obtained by fixing pairing strength $G = 0.315$ MeV.

**Rotational band with positive parity**

Rotational spectra for the band with positive parity calculated by PRM for different triaxiality parameter $\gamma$ are compared with data in figure 4.15. The quadrupole deformation parameter $\beta$ takes a value of 0.35 from RMF calculation in PK1 effective interaction [39] with configuration $\pi 1g_{9/2}$ and $\gamma$ takes $0^\circ$, $20^\circ$, $40^\circ$ and $60^\circ$. It is seen that both the prolate deformation $\gamma = 0^\circ$ and the triaxiality deformation with $\gamma = 20^\circ$ could well reproduce the experimental energy spectra. The large amplitude of signature splitting is obtained in the calculations, thus the observation of only one signature sequence $\Delta I = 2$ band can be understood. The main components of the wave functions in this band are investigated and the dominant component is found to be $\pi 1g_{9/2}$. For the calculations with $\gamma = 40^\circ$ and $60^\circ$, the small amplitude of signature splitting is obtained, which deviates from experimental observation. Therefore the PRM calculation suggests that the triaxial deformation for the positive-parity band is more likely prolate-like deformed, fulfilled by the second minimum of the potential energy surface calculated with the RMF calculation.

**Rotational band with negative parity**

The triaxial PRM calculations have been performed for negative parity states, as well. The quadrupole deformation parameter $\beta$ takes a value of 0.20 according to the RMF calculation in PK1 effective interaction [39] with configuration $\pi(2p_{3/2}1f_{5/2}2p_{1/2})^5$. The proton single-particle energy levels calculated in Nilsson model are plotted for different triaxiality parameter $\gamma$ in figure 4.16, and the proton Fermi surface is found to lie between the $2p_{3/2} 3/2[312]$ and $1f_{5/2} 1/2[310]$ orbits.
Figure 4.15: Rotational spectra for the band with positive parity calculated by PRM for different triaxiality parameter $\gamma$ are compared with data. In the calculations, the parameters $\beta = 0.35$, $J_0 = 8\text{ MeV}^{-1}\hbar^2$ and $b = 0.1$ are adopted.

Figure 4.16: The proton single-particle energy levels calculated in Nilsson model. The red line denotes the Fermi surface.
Rotational spectra with negative parity calculated by PRM with triaxiality parameter $\gamma = 0^\circ$, $30^\circ$ and $60^\circ$ are compared with data in figure 4.17. It is shown that the rotational spectra are reasonably described for these different triaxiality parameters, in particular that $\gamma = 60^\circ$ are the best in agreement with the experimental energy spectra. The strong mixture between single particle components $\pi 2p_{3/2}$ and $\pi 1f_{5/2}$ has been found in this negative-parity band, as suggested in figure 4.16.

To study the spectra more clearly, the signature splitting $S(I)$ for this band by PRM for different triaxiality parameter $\gamma$ are compared with data, in figure 4.18. Here, the signature splitting is characterized by $S(I) = [E(I) - E(I-1)] - \frac{1}{2}[E(I+1) - E(I) + E(I-1) - E(I-2)]$ as in Ref. [36]. It is shown that the triaxiality parameter $\gamma$ has a strong effect on the amplitude of signature splitting in PRM calculation and good agreement with the amplitude of signature splitting is achieved with oblate-like deformation ($\gamma$ is close to $60^\circ$). This is also in agreement with the oblate deformation $\gamma = 60^\circ$ obtained from RMF calculation with the corresponding configuration.

In figure 4.19, the corresponding $B(M1)/B(E2)$ values calculated by PRM for different triaxiality parameter $\gamma$ are compared with experimental data. It is clearly seen that $B(M1)/B(E2)$ staggering is sensitive to the triaxiality parameter $\gamma$ and the experimental $B(M1)/B(E2)$ can be well described by PRM with $\gamma = 60^\circ$. 

Figure 4.17: Rotational spectra for the band with negative parity calculated by PRM for different triaxiality parameter $\gamma$ are compared with data. In the calculations, the parameters $\beta = 0.2$ and $\mathcal{J}_0 = 8\text{ MeV}^{-1}\hbar^2$ and $b = 0.02$ are adopted.
Figure 4.18: The signature splitting $S(I)$ for the band with the negative parity calculated by PRM for different triaxiality parameter $\gamma$ are compared with data.

Figure 4.19: $B(M1)/B(E2)$ values for the band with the negative parity calculated by PRM for different triaxiality parameter $\gamma$ are compared with data.
In summary, the level structure of $^{73}$As obtained in the present study is presented in this chapter. The previously known low spin structure has been verified and provided new information on high spin states by extending the positive and negative parity bands with the addition of 30 new $\gamma$-transitions to the earlier work. We have made an attempt to understand the origin of observed band structures in the framework of Cranked Shell Model (CSM), Hartree-Fock-Bogolyubov, Woods-Saxon cranking calculations and Particle Rotor Model (PRM) calculations. The results of the CSM calculations seem to provide good insight for the observed alignments for the band based on the $g_{9/2}^+$ isomeric state. The shape evolution in $^{73}$As has been discussed in terms of TRS and PES calculations which predicts a prolate-oblate shape coexistence between positive and negative parity bands. The experimentally observed rotational bands in this nucleus are investigated with the triaxial particle rotor model adopting the quadrupole deformation from the RMF calculations. It is found that the positive parity band is likely to be built on the local minimum with configuration $\pi 1g_{9/2}$ of a triaxially deformed shape, while the negative parity one on the global minimum with valence proton configuration $\pi (2p_{3/2}1f_{5/2}2p_{1/2})^5$ of an oblate shape.
Bibliography


