CHAPTER I
INTRODUCTION

The nuclear spectroscopy has undergone considerable progress in the last decade with the availability of heavy ion beams, and the development of detection techniques as well as nuclear theories. This has enabled detailed investigation of the nuclear level schemes and development of new theories in a systematic way for nuclei in different mass regions. The fast rotation of a nucleus indeed induces significant modifications of nucleonic motions and of nuclear stability, changes in the nuclear shape and in the deformation. The large amount of energy and angular momentum transferred in nuclear reactions are not only converted to external excitations (i.e. rotation of the nucleus as a whole) but also to intrinsic degrees of freedom.

A systematic survey of the collective properties of nuclei in the $Z>50$ transition region shows several interesting features. The spectroscopy of these medium-mass transitional nuclei is characterised by the occurrence of low-lying collective states. However, the intrinsic nature of these states appears to change from nucleus to nucleus. Some spectra resemble those of anharmonic vibrators, others resemble those of axially symmetric rotors, and still others resemble those of triaxial or \(\gamma\)-unstable rotors.

A characteristic feature of transitional nuclei is the softness of the nuclear surface: Thus, by adding an extra particle to a doubly even system one can expect that the core shape is influenced by the odd-particle. In general an effective core shape of an odd-mass nucleus may arise which deviates from that of the neighbouring doubly even nuclei.

Collective features of the odd-mass nuclei in the $Z>50$ transition
region have generated considerable theoretical interest. The traditional theoretical approaches used for the interpretation of the collective properties of these nuclei are based on models of deformed rotors [1] or anharmonic vibrators [2]. Recently microscopic theory [3] and the interacting boson-fermion model [4] have been applied for a more detailed understanding of the collectivity of transitional nuclei.

Iodine nuclei with Z=53 form an important link in the systematics of the transitional region between the primarily spherical Sn nuclei and the well deformed La and Ce nuclei. The odd-mass iodine nuclei $^{121,123}$I with 68 and 70 neutrons, respectively, lie near the middle of the N=50-82 neutron shell. The structure of these nuclei is important in the systematics of the odd-mass iodine isotopes. They are expected to show several features that are characteristic of a soft rotor. Theoretical calculations in $^{121,123}$I [5,6] predict the prolate oblate energy difference $V_{PO}$ to be small, and hence these nuclei should be sensitive to the shape polarizing effects of the valence quasiparticles. As a consequence of these effects and the softness of the nuclear cores, shape-coexistence phenomena are expected to occur. Thus one may expect collective bands based on intrinsic states with different shapes and deformations in these nuclei. A spectroscopic investigation and interpretation of the various collective features in $^{121,123}$I nuclei are presented and discussed in this dissertation.

In both $^{121,123}$I, $\Delta I=2$ bands built on $11/2^-$, $7/2^+$, and $5/2^+$ states, and $\Delta I=1$ bands built on low-lying $9/2^+$ states have been reported [7,8]. The $\Delta I=2$ bands have been interpreted as "decoupled bands" resulting from the coupling of the odd particle in the $d_{5/2}$, $g_{7/2}$ or $h_{11/2}$ orbital, with the collective motion of the core. This interpretation is based on the observation that the transition energies in these bands are comparable to the energy level separations in the
corresponding even-even Te cores. The decoupled structures, however, are expected to be achieved best only with the odd particle in a high j orbital such as \( h_{11/2} \), with its angular momentum aligned with that of the core. The \( \Delta I = 1 \) bands have been interpreted as rotational structures built on prolate deformed \( 9/2^+ \) proton hole states. Similar low-lying \( 9/2^+ \) states are also observed in neighbouring odd proton odd mass nuclei, and they are believed to result from the excitation of a \( g_9/2 \) proton across the \( Z = 50 \) shell gap, leaving a hole in the \( g_9/2 \) subshell.

In the neighbouring nucleus \( ^{119}\text{In} \), coexisting collective structures built on prolate as well as oblate \( 11/2^- \) band heads have been reported recently [9]. In a recent work on \( ^{121}\text{I} \), also similar shape coexistence has been reported [5]. Also it has been suggested that the \( 5/2^+ \) ground states in the odd-mass iodine nuclei with neutron number \( N > 66 \) are likely to have oblate deformation. The previously reported experimental information in \( ^{123}\text{I} \), however, is not exhaustive, and several levels in this nucleus have been reported as uncertain [7]. The motivation of the present work is to search for new levels and transitions as well as higher spin members of various bands, and to investigate the shape coexistence phenomena in these nuclei.

The spectroscopic study of the \( ^{121,123}\text{I} \) nuclei has been carried out by in-beam gamma-ray spectroscopy in the fusion-evaporation reactions \( ^{121}\text{Sb} \left( \alpha, 2\gamma \right) ^{123}\text{I} \) and \( ^{121}\text{Sb} \left( \alpha, 4\gamma \right) ^{121}\text{I} \) at projectile energies of 30 and 55 MeV, respectively.

Enriched \( ^{121}\text{Sb} \) targets of \( \sim 3 \text{ mg/cm}^2 \) thickness were used in the experiments. The experiments were carried out at the Variable Energy Cyclotron Centre, Calcutta. Experiments involved measurements of \( \gamma \)-ray singles, \( \gamma\gamma \) coincidence, \( \gamma \)-ray angular distributions and DCO ratios, using HPGe detectors. In some of the experiments BGO Compton suppression shields were used to suppress the Compton background in HPGe detectors.
Measurements of γ-ray energies, relative intensities, coincidence relations, transition multipolarities and multipole mixing ratios in these experiments yielded several new results. These experiments reveal various features of the collective structures and provide evidence of shape coexistence in these nuclei \([6]\).

The \(\Delta l=1\) band based on the \(9/2^+\) state in \(^{121}\)I is confirmed up to the \(23/2^+\) state. In \(^{123}\)I, this band previously reported up to the \(17/2^+\) state, has been extended to the \(19/2^+\) state with the observation of new cascade and cross-over transitions from this state. The \(\Delta l=1\) transitions in this band show positive \(E2/M1\) mixing ratios implying prolate deformation for this band. The \(B(E2)\) ratios for the cascade and cross-over transitions have been deduced from the measured transition intensities and the multipole mixing ratios. The \(\Delta l=2\) negative parity bands based on yrast \(11/2^-\) states, connected by stretched \(E2\) transitions are observed up to \(27/2^-\) states in both nuclei, confirming the previous results. In \(^{123}\)I several side transitions are observed to feed different states of this band. This includes three new transitions which are now placed in the revised level scheme of \(^{123}\)I. The \(5/2^+\) g.s. bands show \(\Delta l=1\) character with close similarity in the two nuclei. In \(^{123}\)I new transitions connecting the \(17/2^+\), \(15/2^+\) and \(13/2^+\) states are observed besides other new levels and transitions. In \(^{123}\)I, another positive parity band with \(\Delta l=1\) character, beginning with the second \(7/2^+\) state is observed. New gamma-ray transitions observed in this band are 357.3, 409, 766.4, 845, and 856.3 keV. This band in \(^{123}\)I shows features similar to those of the g.s. band. In \(^{121}\)I the g.s. band is observed up to the \(25/2^+\) state confirming the results of a recent report [5]. The band based on the second \(7/2^+\) state in \(^{121}\)I, however, shows only one signature component, which is observed up to the \(19/2^+\) state. The \(E2/M1\) mixing ratios of the \(\Delta l=1\) transitions in the ground state bands show
negative signs indicating oblate deformation for these bands. A negative
parity band based on an oblate deformed 11/2⁻ state in ¹²¹¹ is observed
upto the 21/2⁻ state in agreement with the recent report [5]. In ¹²³¹,
however, this band is not observed in the experiments. Isomeric states
with probable spin parity (21/2⁺) have been reported [8,7] in both
¹²¹¹,¹²³¹. In ¹²³¹, the decay chain from this isomer proceeding through
different levels via various transitions finally feeding the levels of
the 9/2⁺ band is confirmed in the present work. In addition, the present
work shows a new transition of 423.8 keV which populates the 2016.0 keV
level, which in turn decays to the above mentioned band. In ¹²¹¹ there
is considerable ambiguity regarding the energy of the isomeric
transition from the isomer. Isomeric transition energies of 134.8 and
158.7 keV in ¹²¹¹ have been reported in the literature [8,5]. The
present work shows the transition energy to be 134.6 keV in agreement
with the former value.

Theoretical calculations have been carried out using a
quasi-particle-plus-rotor model with a rotation-dependent interaction
between the core and the quasiparticle. The strength of this interaction
is adjusted by a single parameter which determines simultaneously the
Coriolis attenuation as well as the reduction in the recoil term. An
axially symmetric Nilsson potential has been used in the calculations.
Calculations have been done with both prolate and oblate deformations,
and it is found that the observed band structures in these nuclei are
explained as being associated with different deformations.

The calculations show [10] the odd parity ΔI=2 bands as being
associated with prolate deformation (β = + 0.20) and arising from
configuration comprising mainly the [550] 1/2⁻ orbital with admixtures
from the [541] 3/2⁻ and [532] 5/2⁻ orbitals. The even parity ΔI=1 bands
based on 9/2⁺ states in ¹²¹¹,¹²³¹ are also reproduced with prolate
deformation ($\beta = +0.20$) and with almost pure configuration involving the [404] $9/2^+$ orbital. Calculations with oblate deformation ($\beta = -0.15$) reproduce the even parity $5/2^+$ bands in $^{121,123}$I. New $\Delta I=1$ band beginning with the second $7/2^+$ state observed in the experiments in $^{123}$I in this work, is also reproduced with oblate deformation ($\beta = -0.15$). In $^{121}$I also, the calculations predict a similar $\Delta I=1$ band based on the second $7/2^+$ state. Experimentally, however, only one signature partner is observed in $^{121}$I, with $\Delta I=2$ sequence of levels. Nevertheless, the levels of the observed signature agree quite well with the corresponding theoretical levels. Calculations show these bands based on the $5/2^+$ and $7/2^+$ states as arising from configurations involving the [413] $5/2^+$ and [404] $7/2^+$ orbitals, with oblate deformation ($\beta = -0.15$). Calculations with oblate deformation ($\beta = -0.15$) also give odd-parity $\Delta I=1$ bands based on the high $\Omega$ [505] $11/2^+$ orbital. The calculated band agrees quite well with the experimentally observed band in $^{121}$I. Calculations predict the existence of this band in $^{123}$I also. Experimentally, this band has not been observed in $^{123}$I so far.