Chapter - 7

Summary and Conclusions

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The present work was motivated to investigate the level structure of nuclei in the vicinity of proton shell closures. In particular we have chosen to investigate the high-spin states of difficult to access odd-odd nuclei ^{36}Cl and ^{54}Mn around the proton shell closures in the vicinity of magic numbers 20, 28 respectively. We have also expected triaxial nuclear deformation for low-spin states in the vicinity of Z ~ 82 proton shell closure. Level structures of odd-odd nuclei ^{36}Cl, ^{54}Mn and yrast level rotational structures in the ^{195}Tl nucleus near the proton shell closure, magic number 82 are studied in the present investigation.

The nuclei in the mass region $30 \leq A \leq 60$ have been studied in the past with increasing interest from both experimentalists and theoreticians. Although the term 'high-spin' in this region applies to spins around $10\hbar$, it is the richness of nuclear phenomena occurring in these nuclei which makes these studies particularly attractive. Spherical shapes are expected for light nuclei having proton number close to 20 and 28. Besides spherical shapes and complex level structures this region witnessed smooth band termination and also some possible shape changes as we go up in the angular momentum. Moreover, the high-spin states are also interesting as one finds the alignments of quasiparticles and resulting shape changes due to such alignment.

The phenomenon of interest in the Z ~ 82 mass region comprises of competition between prolate, oblate and triaxial shapes, competition between the shears bands (involving $\pi h_{9/2} i_{13/2}$ excitations) observed mainly in the Pb, Bi and ^{190}Hg isotopes and the irregular M1 bands (involving $\pi h_{11/2}{}^2$ excitation) observed in $^{191\text{-}196}$Hg nuclei. It is interesting to study the deformation in low spin states and whether it persists at higher angular momenta and how it influences the multi-quasiparticle excitations and alignments in the nuclei. None of the earlier studies on heavier Tl isotopes have been studied at sufficiently higher angular momenta to allow the proton excitations to be observed. From the earlier studies the heavier Tl isotopes (A > 193) are known only up to excitation energy of 4 MeV and spin up to $19\hbar$. Most of the recent investigations on ^{195}Tl were focused on the observed superdeformed states.

In order to explore these nuclei of interest close to shell closures, we have successfully exploited different reaction mechanisms. The heavy-ion reactions were used to populate the high-spin states of these nuclei. The experimental work has been carried

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out at VECC (Variable Energy Cyclotron Centre), Kolkata and Cyclotron facility at iThemba LABS (Laboratory for Accelerator Based Sciences), South Africa. For the spectroscopic studies of these nuclei, the fusion reactions used were:

1. ^{27}Al(^{20}Ne, $x\alpha ypzn$)^{36}Cl at 145 MeV of beam energy.

2. ^{51}V(^{20}Ne, $x\alpha ypzn$)^{54}Mn at 145 MeV of beam energy.
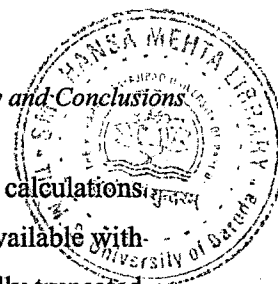
3. ^{181}Ta(^{18}O, xn)^{195}Tl at 83 MeV of beam energy.

For the first experiment we have used a self-supporting ^{27}Al target of thickness ~ 600μg/cm^2. The gamma rays emitted from the residual nuclei were detected using the Indian National Gamma Array (INGA) facility consisting of six Compton-suppressed Clover detectors placed at 40°, 90°, and 125 ° with respect to the beam direction. The coincidence data was then gain matched to 1keV/channel and sorted into a 2-fold γ-γ symmetric and asymmetric (angle dependent) matrix. For the second experiment the INGA facility at VECC has been upgraded to 8 Clover detectors placed two each at 40°, 125° and four at 90°. The target consisted of a self-supporting ^{51}V foil of ~10 mg/cm^2 thickness. The master trigger was generated by a coincidence condition in which three or more Clover detectors had fired. In all about 80 million three- or higher- fold coincidence events were accumulated in the list mode data. For the third and final experiment the target consisted of two metal foils of 500 μg/cm^2 each. The AFRODITE (AFRican Omnipurpose Detector for Innovative Techniques and Experiments) detector system was used which was then consisted of 8 Compton-suppressed Clover Detectors and 6 LEPS (Low Energy Photon Spectrometers) detectors. These detectors were placed at 45°, 90° and 135° respectively. The master trigger was generated by a coincidence condition in which two or more Clover detectors has fired. In all about 10^9 two or higher fold events were accumulated in the list mode data during the experiment.

The data were pre-sorted to correct for any on-line drifts, precise gain-matched, and were sorted into symmetric and angle dependent matrices for detailed offline analysis. The angle-dependent matrices were used to obtain information on the multipolarity of the observed transitions. The use of Clover detector has facilitated the polarization measurements to uniquely assign the electromagnetic nature to the observed transitions.

The level scheme of Z = 17, N = 19 nucleus ^{36}Cl up to $J^{\pi} = 10^{+}$ and $E_x \sim 7.5$ MeV populated following the ^{20}Ne + ^{27}Al reaction has been build. About fifteen new γ-transitions belonging to this nucleus have been identified and placed in the level scheme. These transitions were placed in accordance with the coincidence measurements. For this set of experimental analysis we could only perform the R_{DCO} calculations. Polarization calculations couldn't be performed due to less statistics in coincidence mode. The experimental results were compared with the results of the Oxbash shell model code with ^{40}Ca as the core. The results were in fair agreement with the theoretical ones in the lower excitation energies and vary in the higher side. These nuclei at such low excitation energies have a complex level structure and this warrants further detailed experimental and theoretical investigations. This being an odd-odd nucleus, one expects the dominance of single-particle nature. Indeed, this is exhibited by irregular level spacing and many parallel decay branches and corroborated by the absence of any band-like structure.

Another odd-odd nucleus ^{54}Mn was populated in the reaction - ^{51}V(^{20}Ne, *xαypzn*)^{54}Mn upto $J^{\pi} = 15^{+}$ and $E_x \approx 5$ MeV. In addition to the earlier known transitions, nine new γ-transitions belonging to this nucleus have been placed in the decay scheme based on the coincidence, intensity arguments and the presence of cross-over transitions. The angle dependent E_{γ} - E_{γ} matrices were used to obtain the intensity anisotropy for the observed γ-transitions; which were then used to assign qualitatively the spin of the level de-exciting by the particular transition.

The earlier reported polarization measurements for the 852- and 931-keV transitions had considerable errors, making the spin parity assignments for the level at 1925-keV rather ambiguous. The earlier reported linear polarization for the 852-keV transition was (-0.03 ($\pm$0.05)). Hence, the electromagnetic nature for this level could not be uniquely assigned. Our present measurement indicate that for this transition we obtain a value of $\Delta_{IPDCO} = 0.05$ (0.01). The 156-keV and 852-keV γ-rays are also belonging to ^{64}Zn. Hence Δ_{IPDCO} for the 852-keV transition was obtained from other clean gates such as 212- and 705-keV, to name a few, which yielded a positive value for the Δ_{IPDCO}. Thus a positive value is indicative of an electric nature for the 852-keV transition. The polarization measurement for the 931-keV transition which feeds this level is crucial to confirm the present assignment. Unfortunately the 931-keV transition is in coincidence with the 156-, 212- and 705-keV transitions in other neighbouring nuclei, and the transition is predominantly magnetic in nature in these nuclei.

To interpret the observed level structure of ^{54}Mn, detailed shell-model calculations have also been performed by us using the *fppn* Hamiltonian with ^{40}Ca core, available with the code OXBASH. In the present calculations, the model space was internally truncated to include the following $[\pi(f_{7/2})^{4-5},(p_{3/2})^{0-1},(f_{5/2})^{0-1},(p_{1/2})^{0-1}]\otimes[\nu(f_{7/2})^{7-8},(p_{3/2})^{0-1},(f_{5/2})^{0-1},(p_{1/2})^{0-1}]$ configurations. It is observed that the low-lying levels in the shell-model up to a spin-parity of 9^+ are in good agreement with the experimental ones. The present calculations could not reproduce the observed excitation energies for levels $J > 9^+$. A plausible explanation for this could be the truncation of the model space. The present calculations indicate that 8^+ and 9^+ levels are dominated by 1p3h configurations.

The third experiment was intended to extend the level scheme of ^{195}Tl to higher excitations and angular momenta. In the present investigation the level scheme is studied up to excitation energy of ~ 6 MeV and a tentative spin-parity of $45/2^-$ with the addition of more than 40 new γ transitions. The $9/2^-$ band which is previously known up to $27/2^{(-)}$ has been extended to $45/2^{(-)}$ state. Furthermore the side band built of the $15/2^+$ state which is previously known up to $35/2^{(+)}$ is extended to $45/2^{(+)}$. Two more sidebands were found in the present investigation and are placed in the level scheme of ^{195}Tl. They are placed on above the $29/2^-$ level and the other above the $33/2^+$ level in the level scheme. The issue with the many doublets and multiplets in this nucleus was suitably resolved with the coincidence and multipolarity calculations.

Apart from many doublet and multiplet transitions in this nucleus which made the intensity calculations difficult to perform, we have observed another such doublet at considerably higher spins in the present investigation. The gate on 707.2-keV, we could observe the transition 296.0-keV. The same transition can be observed in all the gates in both the $9/2^-$, $15/2^+$ bands. This indicates that the transition ~ 296-keV is in coincidence in both the $9/2^-$ and $15/2^+$ bands. This is confirmed with the help of gate on a transition in which the transitions of the other band are not in coincidence. Like when we gate on 458.5-keV we could observe only the γ-rays in coincidence with the $9/2^-$ band and in here 296-keV can be clearly observed. And a gate on 175.7-keV transition can have only the transitions coincidence in $15/2^+$ band. Here again we can see the 297-keV transition. This establishes that this transition is a doublet transition. It is reported earlier that the transition 418.6-keV ($15/2^+ \rightarrow 15/2^-$) is a pure dipole basing on the angular distribution coefficients. But the present investigation regarding this transition differs from the earlier ones. The 418.6-keV transition has a multipolarity of 1.27 (0.13); -0.16 (0.04). Based on

the systematic in the present analysis, we may conclude that 418.6-keV transition is a quadrupole and has magnetic nature. Hence the 418.6-keV γ-ray according to the present calculations is an M2 transition.

The existing level scheme and the two bands associated with it were extended to higher spins and excitation energy. As established the band $9/2^-$ is a result of the coupling of $h_{9/2}$ proton to the corresponding core nuclei ^{194,196,198}Hg respectively. And it is assumed that the $15/2^+$ positive parity band arises from the vector coupling of $h_{9/2}$ proton aligned along the symmetry axis, and the broken neutron pair consisting of a rotation-aligned $i_{13/2}$ neutron and a strongly coupled low-j neutron in the $p_{1/2}$, $p_{3/2}$ or $f_{5/2}$ shell.

The above results warrants detailed theoretical calculations which, when coupled with the inputs from precise lifetime measurements, could help us understand the effect of intruder orbitals on the shell structure in the vicinity of magic numbers 20, 28 and also the proton - neutron excitations near the Z ~ 82 proton shell closure. From the present work it can be concluded that the single particle structure is dominating in the odd-odd nucleus ^{36}Cl and ^{54}Mn. This is further established from the shell model results. Whereas in the case of ^{195}Tl the present studies as well as the earlier ones indicate that the collective aspects are predominant in this nucleus.