5. RESEARCH ACTIVITIES

3.1.5.1 5.1 NUCLEAR PHYSICS

S.K. Datta and R.K. Bhowmik

The series of experiments carried out with the eight clover INGA setup at NSC has come to an end. These detectors are currently in the process of being shifted for using with the Cyclotron beam at VECC, Kolkata. A total of sixteen experiments were carried out with this setup with the majority used in coincidence with the Charged Particle Array and Neutron array. Some of the experiments were done with thin targets with recoils detected in the recoil separator HIRA.

Preliminary results from some of these experiments are reported here. The level scheme of ^{123}Cs has been investigated for identifying the various multi-quasiparticle bands. Magnetic Rotation phenomena have been studied in the nucleus ^{137}Pr. High spin structure of the N=28 nucleus ^{52}Cr was established. The properties of the s-d nuclei ^{31}P, ^{33}S and ^{37}Cl were established through γ–γ recoil correlation. Lifetime of the levels in ^{79}Rb and ^{139}Pr were investigated through DSAM and delayed n-γ coincidence technique respectively.

The RIB facility at NSC has been extensively used for studying reaction cross sections near barrier energies. The cross-section for elastic and transfer reactions in the reactions ^{7}Be + ^{27}Al and ^{7}Be + ^{9}Be have been studied.

The anomalous behaviour of quasi-fission reaction below barrier energies have been investigated through angular and mass distribution measurements on ^{19}F+^{232}Tn system. The results indicate a change in reaction mechanism below barrier for the above system.

The reaction mechanism for ^{16}O + ^{169}Tm incomplete fusion reaction below 7MeV/nucleon has been reinvestigated through measurement of angular distribution of residues. In-beam $\alpha-\gamma$ coincidence measurements are planned to investigate the spin distribution of the residual nuclei populated through Incomplete Fusion reaction.

5.1.1 Rotational Structures in ^{123}Cs

Kuljeet Singh[1], J. Goswami[1], D. Mehta[1], N. Singh[1], K. P. Singh[1], R. P. Singh[2], S. Muralithar[2], N. Madhavan[2], J.J. Das[2], S. Nath[2], A. Jhingan[2], P. Sugathan[2] and R.K. Bhowmik[2]

[1]Department of Physics, Panjab University, Chandigarh - 160 014
[2]Nuclear Science Centre, New Delhi- 110 067

In the present work, excited states in the ^{123}Cs nucleus were populated utilising the ^{100}Mo(^{28}Si,p4n) reaction at a beam energy of 130 MeV. The ^{28}Si beam was provided by the 15 UD Pelletron accelerator at Nuclear Science Centre (NSC), New Delhi. The target consisted of 3 mg/cm^2 ^{100}Mo rolled onto a Pb backing of 15 mg/cm^2. The γ-γ coincidence data were obtained using INGA spectrometer consisting of 8 sets of Compton-suppressed clover detectors. A total of 5×10^8 γ-γ events with coincidence condition of at least two of the eight Clover detectors were collected. About 14 % of the total cross-section constituted the *p4n* reaction leading to ^{123}Cs. The coincidence events were sorted into E_γ-E_γ matrices using INGASORT which were used to construct the level scheme of ^{123}Cs and DCO analysis for characterising the dipole/quadrupole nature of the transitions.

The partial level scheme of ^{123}Cs established from the present work is shown in Fig.1. The earlier observed structures [1-2] based on $\pi h_{11/2}$, $\pi g_{9/2}^{-1}$ and $\pi g_{7/2}$ configuration

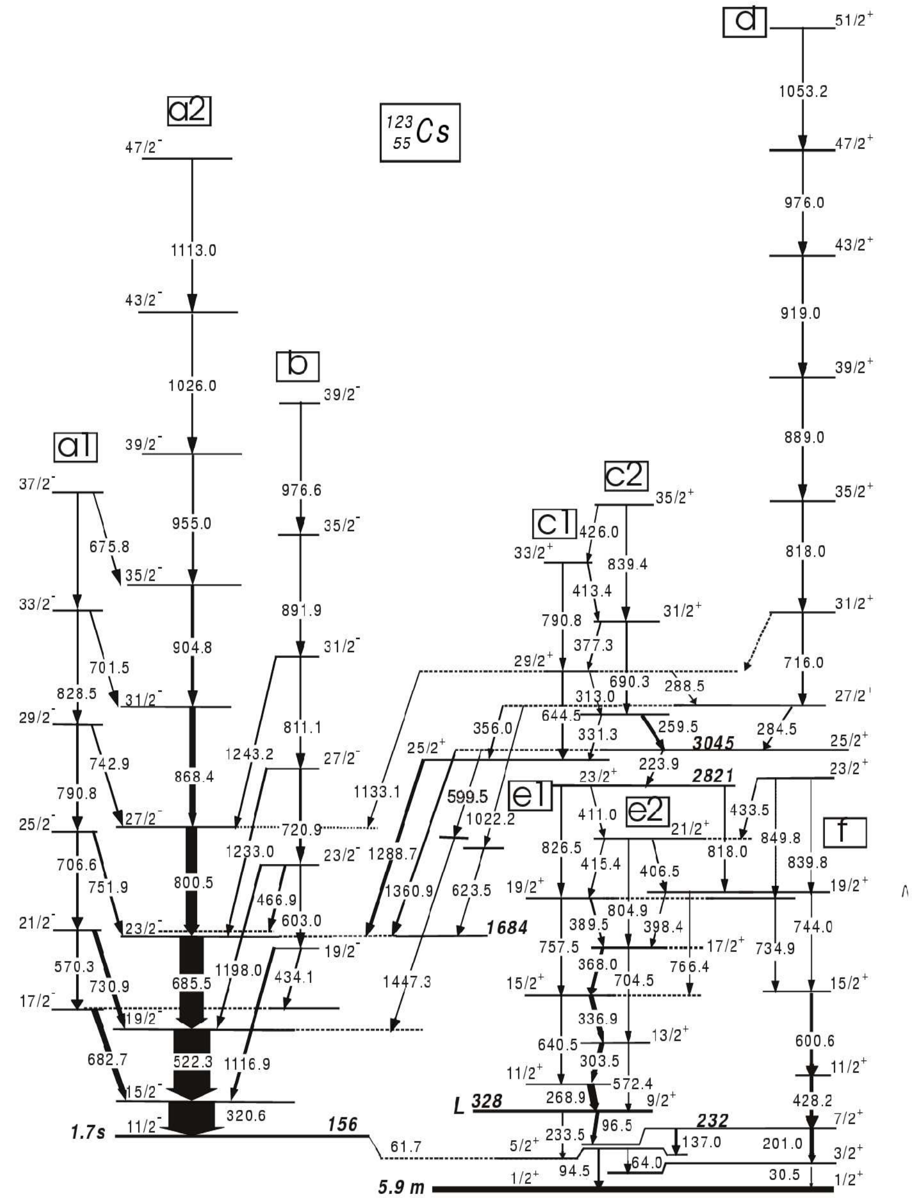

Fig. 1: The level scheme of ^{123}Cs

labelled as A1-A2, E1-E2 and F respectively, have been extended. Two newly identified bands are labelled as band C and D. The positions of these bands have been established with the help of inter-band transitions and connections to the low-energy levels established from the ^{123}Ba decay [3]. The band heads of $\pi g_{7/2}$ and $\pi g_{9/2}^{-1}$ bands have been established based on the observed linking transitions and intensity balance from the present data and the recent low-energy level scheme from the β^+/EC ^{123}Ba decay ($T_{1/2}$=2.7 min) [3]. An isomer with $T_{1/2}$=114 ns was proposed at 232 keV by Gizon et al and assigned I^{π}=9/2$^+$ as band-head of the $\pi g_{9/2}$ band. It is worth mentioning that the intensity of the 96.5 keV (M1) transition, after internal conversion correction, is well balanced by the

137.0 keV (M1) and 201.0 (E2) transitions in the gated spectra of higher lying transitions (time window chosen for the present coincidence data ~100 ns), which indicates that the level at 232 keV ($I_\pi = 7/2^+$) is not an isomer with $T_{1/2}$=114 ns. A loss in intensity (~ 50 %) has been observed at the 328 keV state ($9/2^+$) in the gated spectra of higher lying transitions indicating possibility of life time at this level. The γ-vibrational band (band- B) built on the Yrast $\pi h_{11/2}$ rotational band was also observed.

Both the $\pi(h_{11/2})^2$ and $\nu(h_{11/2})^2$ alignments are identified in the $\pi g_{7/2}$ and $\pi(g_{9/2})^{-1}$ bands respectively. The corresponding multi-quasiparticle bands are labelled C1-C2 and D.

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5.1.2 Magnetic Rotation in ^{137}Pr

Priyanka Agarwal[1], Suresh Kumar[1], Monika[2], Rishi Kumar Sinha[3], Anukul Dhal[3], S. Murlithar[5], R.P. Singh[5], N. Madhavan[5], Rakesh Kumar[5], R.K. Bhowmik[5], S.S. Malik[2], K.S. Thind[2], S.C. Pancholi[4], L. Chaturvedi[3] and A.K. Jain[1]

[1]Department of Physics, I.I.T.Roorkee, Roorkee-247667
[2]Department of Physics,G.N.D.U, Amritsar-143005
[3]Department of Physics, B.H.U, Varanasi-221005
[4]Department of Physics, Delhi University, Delhi –110007
[5]Nuclear Science Centre, New Delhi-110067

The A=130 mass region is expected to support magnetic rotation phenomenon in many nuclei. However a confirmed existence of MR is known only in few cases [1]. In an effort to study the structure properties of MR in A =130 mass region, we have initiated a series of studies. This is the first result in this series.

An experiment has been performed in order to investigate in detail the existence of Magnetic Rotation phenomenon in ^{137}Pr. The reaction used was ^{122}Sn(^{19}F, 4n)^{137}Pr at 80 MeV. The ^{19}F beam was delivered by the 15-UD Pelletron accelerator at NSC. Self supporting enriched ^{122}Sn target of thickness 1.2 mg/cm^2 was used. The gamma rays were detected using the 8 CS-clover detector INGA facility. The data has been sorted using the INGASORT program.

In the offline analysis, the data was sorted into $E_\gamma - E_\gamma$ (4K × 4K) matrices. To establish the coincidence relationships, and to identify the various γ-rays belonging to ^{137}Pr a 4K × 4K final matrix has been used. A magnetic Rotational M1 band with Δ I=1 transitions, tentatively proposed earlier upto spin $41/2^-$, has been extended to higher spins with additions of some new transitions. On the basis of earlier studies and a comparison with neighboring nuclei, we may assign the observed band a configuration $\pi h_{11/2}$ $\nu(h_{11/2})^2$. The detailed calculation based on Tilted Axis Cranking Model has been done. Pairing energy is taken from mass data Δ_p=1.048 MeV, Δ_n= 0.65 MeV. The minimization in energy using the Nilsson- Struntinsky Method yields a local minimum at β_2 = 0.135, β_4 = 0.009 , $\gamma = 58^\circ$ and average tilt angle $\delta = 20^\circ$. The calculations are able to reproduce the band very well [2]. The intensity balance, spin and parity calculation for the placement of observed new transitions for constructing the level scheme of ^{137}Pr is in progress. Detailed analysis is also in progress.

The Figures below exhibit a typical gated sum spectrum and partial level scheme with some new transitions for the proposed Magnetic Rotational Band [3,4].

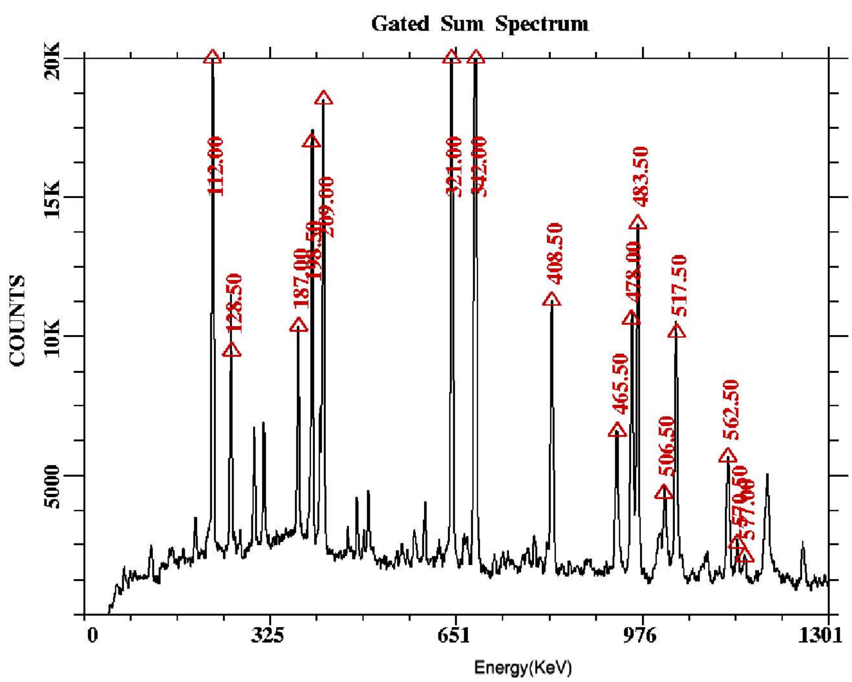

Fig 1: Gated Sum Spectrum of MR band

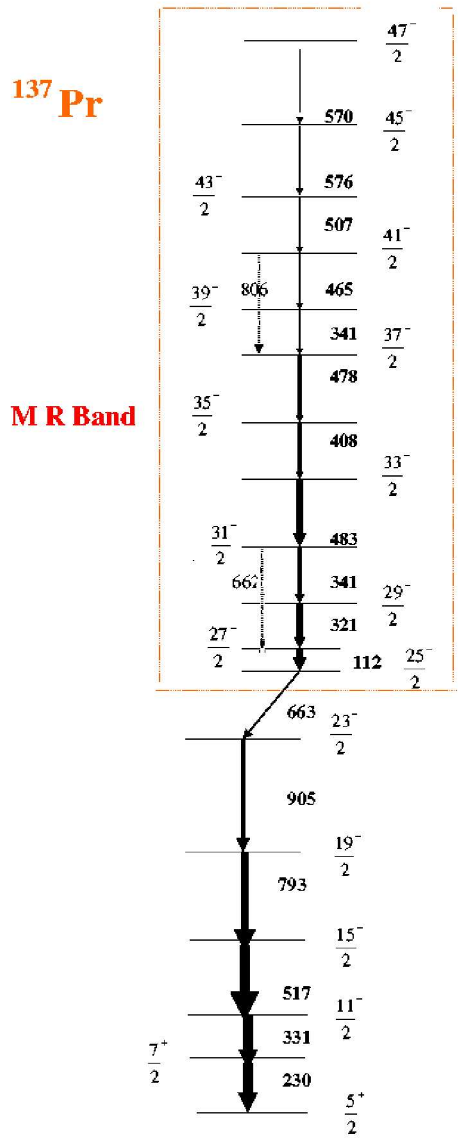

Fig. 2: Partial level Scheme showing three new transitions at the top of MR band in the box

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5.1.3 Shape effects in ^{79}Rb

Rishi Kumar Sinha[1], Anukul Dhal[1], Priyanka Agarwal[2], Suresh Kumar[2], Monika[3], Bir Bikram Singh[4], Rajesh Kumar[4], P. Bringel[5], A. Neusser[5], Rakesh Kumar[8], K. S. Golda[8], R. P. Singh[8], S. Muralithar[8], J. J. Das[8], N. Madhavan[8], K. S. Thind[3], A. K.Sinha[7], I. M.Govil[4], R. K.Bhowmik[8], A.K.Jain[2], S.C.Pancholi[6] and L.Chaturvedi[1].

[1]Department of Physics, Banaras Hindu University, Varanasi-221 005
[2]Indian Institute of Technology, Roorkee-247 668
[3]Department of Physics, Guru Nanak Dev University, Amritsar-143 005
[4]Department of Physics, Panjab University, Chandigarh-160 014
[5]HISKP, University of Bonn, Germany
[6]Department of Physics and Astrophysics, Delhi University, Delhi-110 007
[7]IUC-DAEF, Kolkata Centre, Bidhannagar, Kolkata-700098
[8]Nuclear Science Centre, New Delhi-110067

The nuclei in mass region ≈ 80 are characterized by low density of single particle levels and large shell gaps of ≈ 2MeV at oblate ($\beta_2 \approx 0.3$, N or Z=34, 36) and prolate ($\beta_2 \approx 0.4$, N or Z=38, 40) shapes. The result is that the nuclear shapes in this mass region vary with particle number, excitation energy and spin and are strongly configuration dependent.

An experiment was performed to investigate the nuclear shape changes with rotational frequency in the $\pi g_{9/2}$ +ve parity and the $\pi p_{3/2}$ –ve parity bands in ^{79}Rb [1-3] through the measurement of lifetime of excited states by the Doppler Shift Attenuation Method (DSAM). The high spin states in ^{79}Rb were populated using the ^{63}Cu (^{19}F, p2n) ^{79}Rb reaction at beam energy of 60 MeV. At this beam energy, ^{78}Kr was also populated substantially through the reaction channel ^{63}Cu (^{19}F, 2p2n) ^{78}Kr. The target used was enriched ^{63}Cu of thickness 700 μg/cm^2 with a backing of Ta of thickness 8 mg/cm^2. The target and the backing were fused together by evaporating In of thickness 70 μg/cm^2 in between the two. The γ-rays were detected with INGA facility consisting of 8 CS – Clover detectors at the Nuclear Science Centre, New Delhi. A total of 8.4×10^8 two-fold coincidence events were collected in the experiment. Four neutron detectors (two at an angle of ~ 49^0 and the other two at an angle of ~ 45^0 with respect to the beam direction) were also used for the neutron gating. The data has been sorted off-line using the INGASORT program and a number of 4K × 4K matrices have been made with all possible detector pairs with a dispersion of 0.5 keV/channel. For the lifetime measurements, a coincidence matrix was formed with all detectors versus the four clover detectors at backward angle of 141^0. Figs. 1 and 2 show the sum gated spectra for the Yrast +ve parity band in ^{78}Kr and the $\pi g_{9/2}$ +ve parity band in ^{79}Rb respectively. Fig. 3 shows the lineshape fitting for the 1142 keV transition in the +ve parity band in ^{79}Rb by gating on the 501 keV gamma-ray which is below the transition of interest.

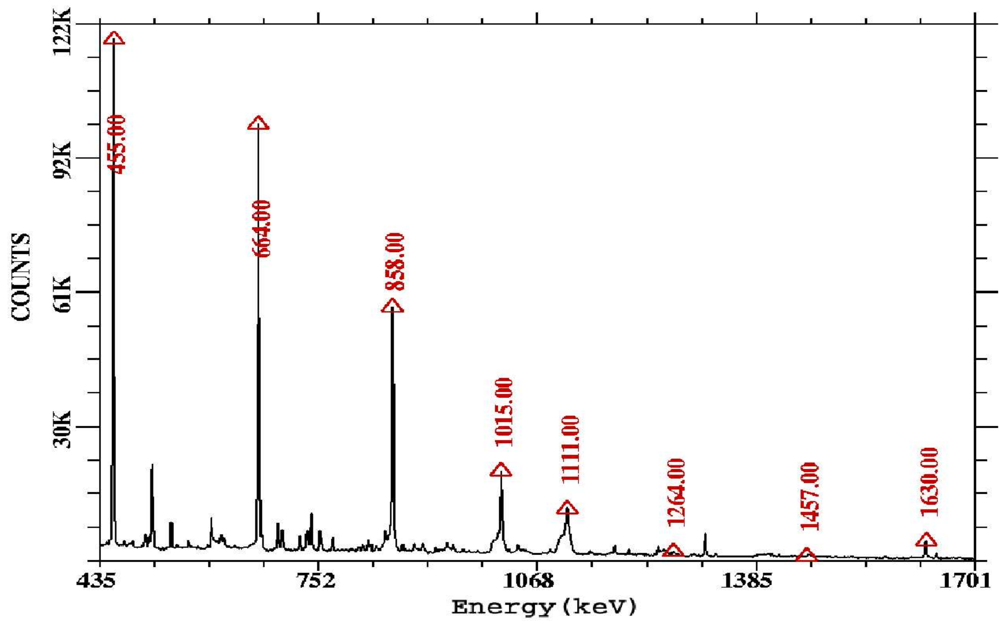

Fig. 1: The added gated spectra of 455+ 664+858+1015+1112 keV peaks in ^{78}Kr

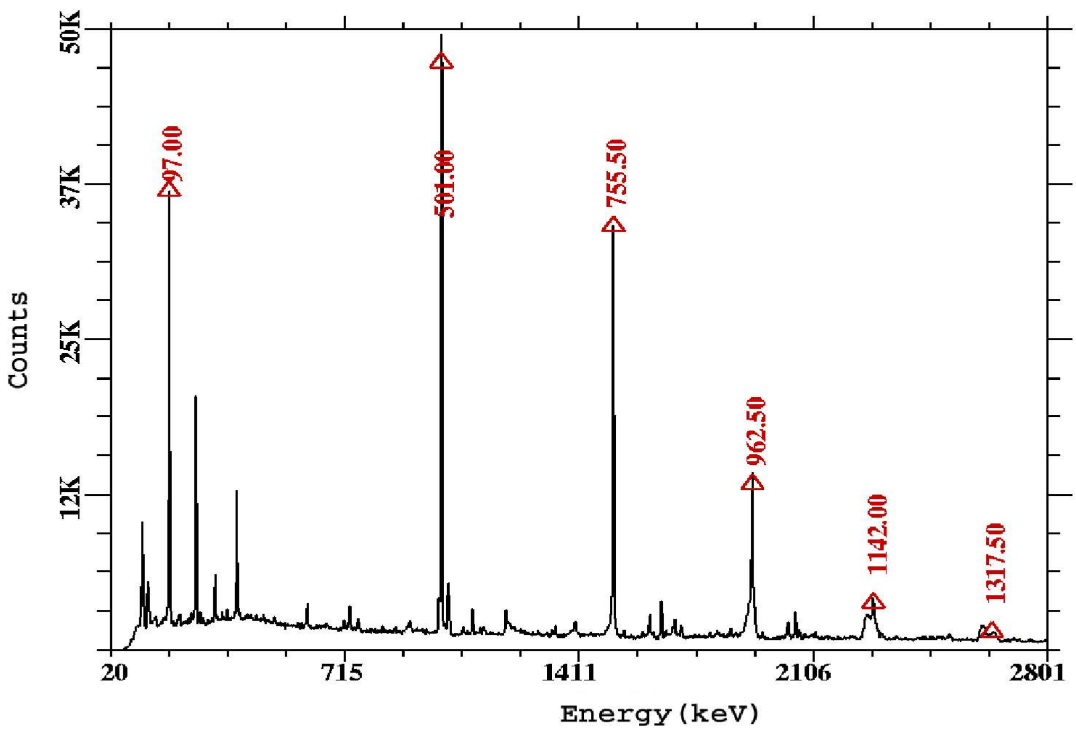

Fig. 2 : The added gated spectra of 97+ 501+756+963 +1142 keV peaks in ^{79}Rb

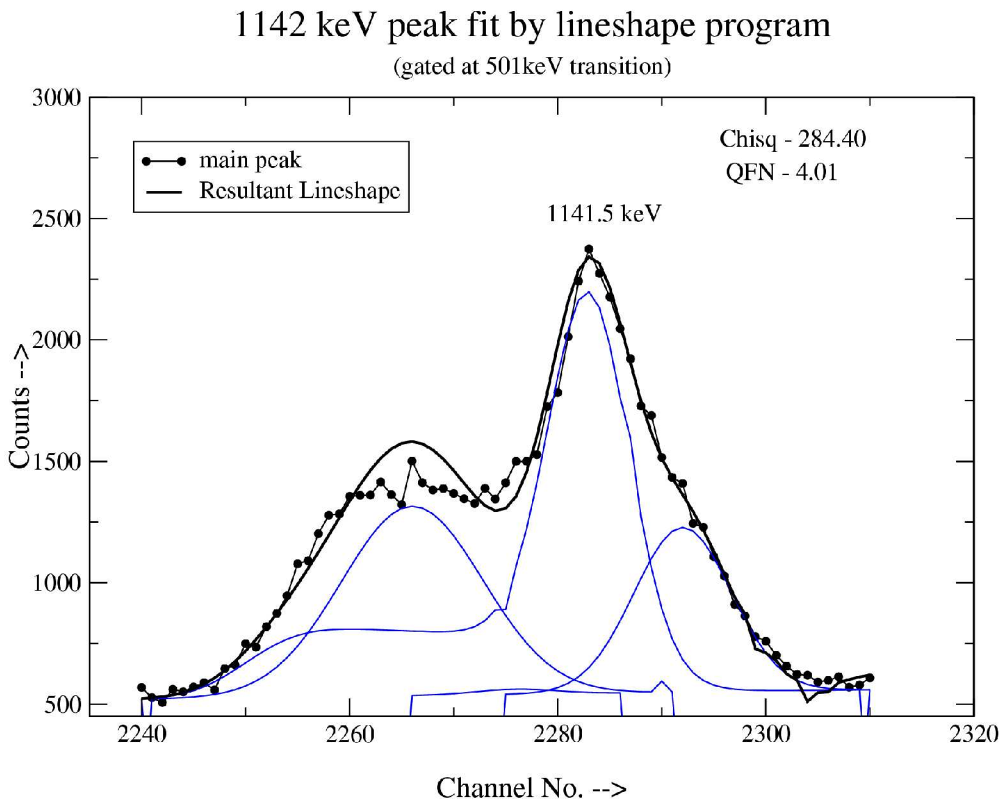

Fig. 3: Lineshape analysis of the 1142 keV peak in ^{79}Rb

Further analysis of the data for the lifetime measurements is in progress. Theoretical model calculations will be done for the interpretation of the experimental results.

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5.1.4 Nuclear Spectroscopy of ^{52}Cr

Rajesh Kumar[1], A. Kumar[1], Bir Bikram Singh[1] S. K. Chamoli[1], S. Muralithar[3], R. P. Singh[3], N. Madhavan[3], P. Sugathan[3], J. J. Das[3], R. K. Bhowmik[3], L. Chaturvedi[2], I. M. Govil[1]

[1]Department of Physics, Panjab University Chandigarh-160014
[2]BanarasHinduUniversity,Varanasi [3]Nuclear Science Centre, New Delhi-110067

Studies of the fp-shell nuclei at or near the neutron shell closure with N=28 are of special interest since these nuclei are ideal for description in the framework of the shell model. The properties of ^{52}Cr have been extensively investigated in the frame work of the shell model. The high spin yrast states are expected to be rather pure in the shell model sense and hence they can provide valuable information on the residual interactions in the $1f_{7/2}$ shell. The excited states of these nuclei have been interpreted in terms of shell model configurations [1-2]. The ^{52}Cr nucleus has been studied earlier [3] and many of the observed properties have been reasonably well explained in the light of model calculations but the band structure has not been properly identified. The high spin states of the nucleus ^{52}Cr were populated through the reaction $^{28}Si(^{27}Al, 3p)^{52}Cr$ at beam energy of 70 MeV delivered by the 15UD Pelletron at Nuclear Science Centre (NSC), New Delhi. A self-supporting target of ^{27}Al of 500 μg/cm^2 thickness was used. Measurements were made using the HIRA-INGA setup consisting of eight Compton suppressed Clover detectors, four neutron detectors and a 4π charged particle ball along with Heavy Ion Reaction Analyzer for selecting the residues. A total of 600 million events were collected with M ≥ 2 fold γ-multiplicity during the course of the experiment. The preliminary level scheme of ^{52}Cr nucleus is shown in Fig.1.

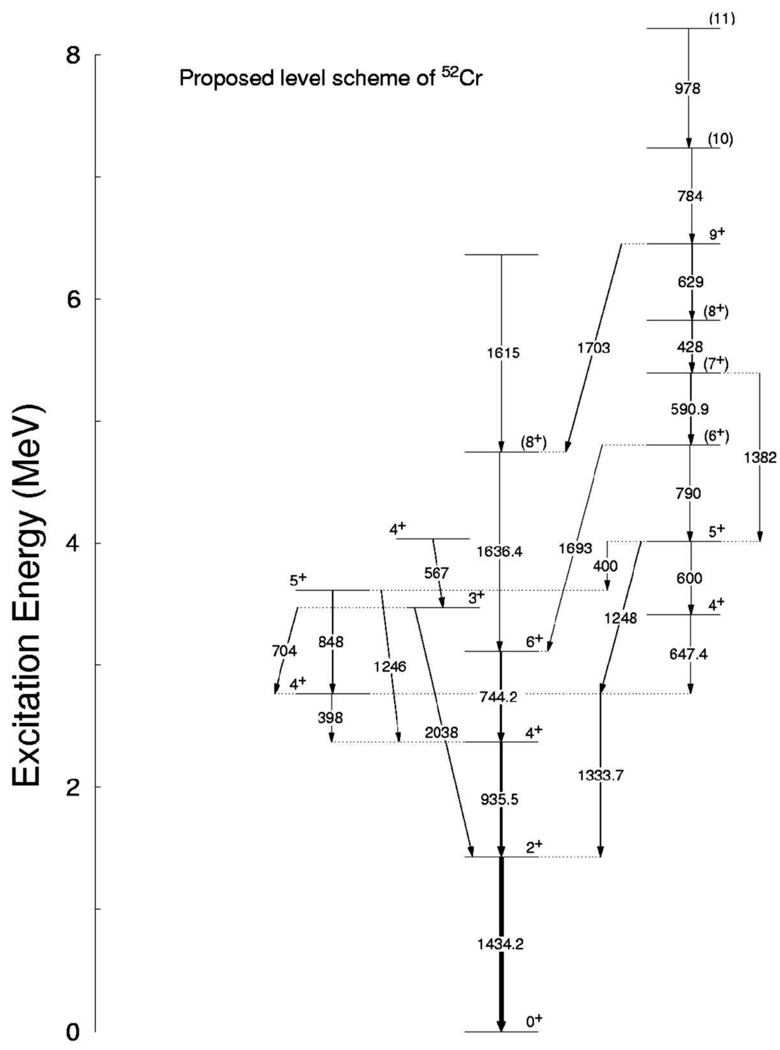

Fig . 1: Level scheme of ^{52}Cr

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5.1.5 Study of high spin states in sd shell nuclei

R. P. Singh[2], P.V. M. Rao[2] , S. Muralithar[2], R. Kumar[2], N. Madhavan[2], J.J. Das[2], P. Sugathan[2], S. Nath[2], A. Jhinghan[2], K.S. Golda[2], G. Ganguly[1] and R.K. Bhowmik[2]

[1]Calcutta University, Kolkata.
[2]Nuclear Science Centre, New Delhi-110067

The high spin properties of sd shell nuclei provide ideal ground for testing predictions of various models based on the deformed mean field and the spherical shell model. A number of recent calculations based on the mean field models also predict the existence of stable superdeformed bands in a number of nuclei around ^{32}S /1-3/. This prompted us to investigate the high spin properties of the sd shell nuclei with the INGA setup coupled to HIRA and other ancillary detectors /4/ at NSC.

We chose the fusion evaporation reaction ^{27}Al(^{12}C,xp,ya,zn) at 60 MeV to populate some of these nuclei. ^{31}P, ^{33}S and ^{36}Cl nuclei were predominantly populated in the above reaction and small amounts of ^{34}S, ^{35}Cl were also populated. Earlier work on ^{36}Cl, ^{33}S and ^{31}P can be found in refs /5,6,7/ respectively.

γ–γ measurements were carried out with a thin self-supporting Al target (~ 500 μg/cm^2) with the recoil products emitted in forward angles detected in the recoil separator HIRA. The absolute detection efficiency of the mass-identified recoil products is ~ 0.2%. Fig 1 shows the gamma spectra with mass-gates on A=33 and A=36 nuclei. The prominent γ-transitions belonging to these masses are marked. The observed lines are strongly Doppler-broadened due to the velocity and angular spread of the recoil products.

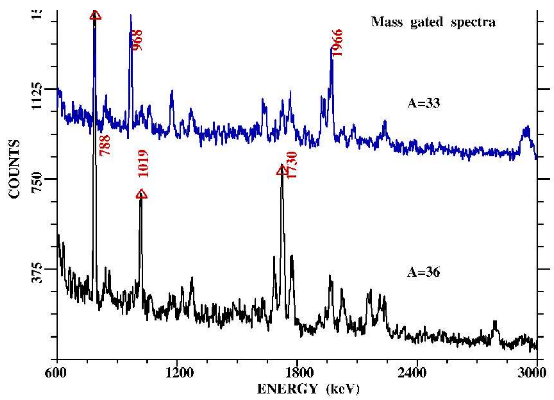

Fig. 1: Recoil gated γ- spectra with gates on A=33 and A=36 respectively

The γ–γ energy and angular correlation measurements were carried out in a separate experiment using a gold-backed target of Al (thickness ≈ 500μg/cm^2). Level schemes were derived from the E_γ-$E_\gamma$correlation matrix by gating with known transitions.

Tentative level schemes from the present work for ^{31}P, ^{33}S and ^{36}Cl are shown in adjoining figures 2 to 4. For ^{31}P and ^{33}S there is no published report on the level structure based on gamma-gamma coincidence data. From the present level of analysis we can not confirm the existence of any superdeformed band in ^{36}Cl, ^{33}S and ^{31}P nuclei. The detailed data analysis is in progress.

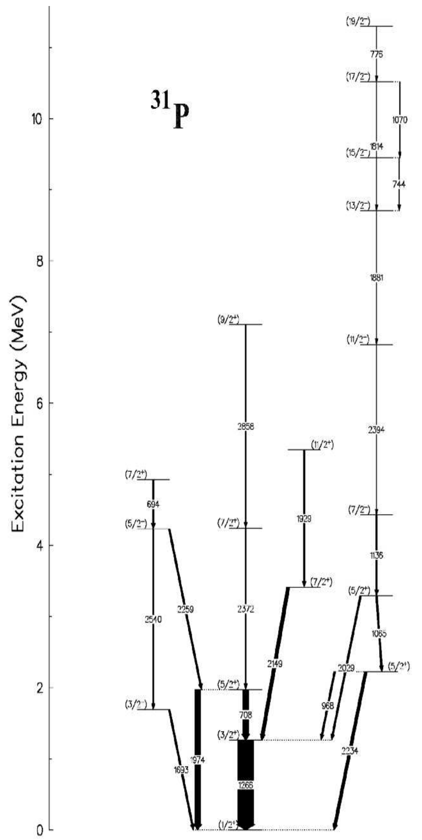

Fig 2: Tentative level scheme of ^{31}P

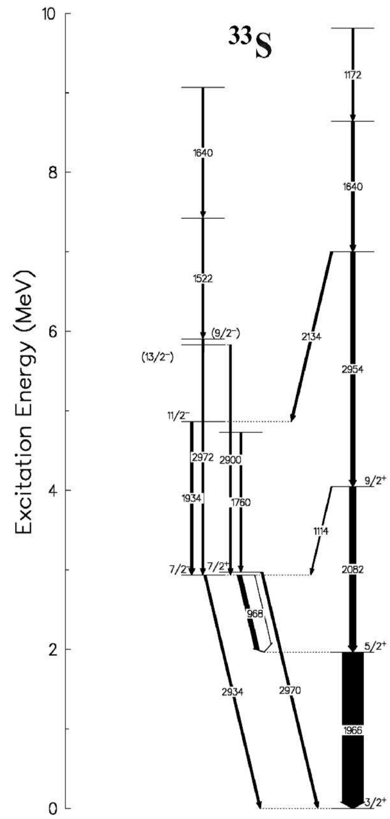

Fig 3: Tentative level scheme of ^{33}S

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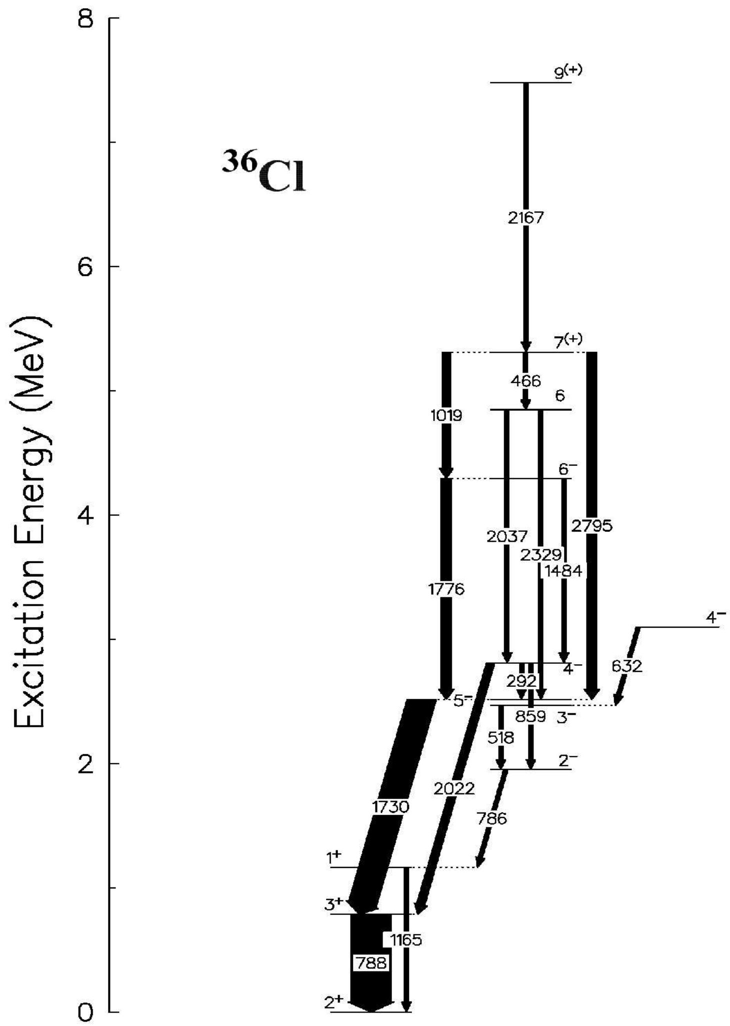

Fig. 4: Tentative level scheme of ^{36}Cl

5.1.6 Prompt and Delayed Spectroscopy of ^{139}Pr

Somen Chanda[1], Sarmishtha Bhattacharyya[2], Tumpa Bhattacharjee[2], Anjali Mukherjee[2], Swapan Kumar Basu[2], S. S. Ghugre[3], R. P. Singh[4], Rakesh Kumar[4] and R. K. Bhowmik[4]

[1]Fakir Chand College, Diamond Harbour, West Bengal
[2]Variable Energy Cyclotron Centre, Kolkata
[3]Inter University Consortium for DAE Facilities, Kolkata
[4]Nuclear Science Centre, New Delhi-110067

High spin states in ^{139}Pr were re-investigated via the reaction ^{130}Te (^{14}N, 5n) ^{139}Pr using a dc beam of E_{beam}= 75 MeV. The target was made of specpure (99.9%) 2.2mg/cm^2 thick metallic ^{130}Te evaporated on 2mg/cm^2 Au backing with a 50μg/cm^2 Au film cover on front. A clover array, consisting of 8 HPGe Clover detectors (with ACS) along with four NE213 neutron detectors placed at forward angles, was used to collect γ-γ doubles and higher fold coincidence events as well as n-γ timing information. Typical beam current was ~ 1-2nA, and typical count rate was ~ 10 kcps for single fold and ~ 1.2k for γ–γ doubles or higher fold. Mainly conventional electronics was used for pulse processing, but for two clovers (at position #7 & 8) NSC made high-density modules were used. With this, around 300 million coincidence events were collected in this experiment.

The coincidence data have been sorted into a 4K×4K E_γ - E_γ matrix after proper gain matching. From the symmetrized matrix, spectra against different gates of interest have been projected. Another 4K×4K E_γ - T_γ matrix is made in which the x-axis contains the coincidence energies and the y-axis contains the corresponding n-γ time spectrum. Several n-γ TAC spectra corresponding to different E_γ gates have been projected from this matrix which clearly enable us to measure the life-times of a few levels in ^{139}Pr. Preliminary analysis indicate that the level scheme for ^{139}Pr, as observed in our earlier studies using GDA [1], is well corroborated. Different cascades of γ–transitions are being tested and confirmed with the help of a γγγ cube analysis. From this data we are able to extract DCO Ratio and Polarization values for different transitions as compared to the earlier experiment. For this purpose, a 4K×4K DCO matrix and two 4K×4K polarization matrices (one for parallel and other for perpendicular scattering) have been made. The construction of a revised level scheme is under progress based on the additional information obtained from this experiment.

REFERENCE

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5.1.7 fp shell proton drip line nuclei at high excitations

Mamta Aggarwal[1]

[1]Nuclear Science Centre, New Delhi-110067

We investigate extremely proton rich fp shell nuclei in highly excited state. In view of the very high excitations possible in the nuclei formed in collisions, the effects of thermal and rotational excitations on the particle stability are studied through the variations in the proton separation energy. Knowledge of the separation energies and precise location of proton drip line near fp shell region is an important input for understanding rp processes and the interesting nuclear structure found in fp shell region. Spin orbit splitting gives rise to a sizeable energy gap in the fp shell between $f_{7/2}$ orbit and other orbits ($p_{3/2}$ $p_{1/2}$ $f_{5/2}$ producing semi magic no. N(or Z)=28. Excitations across this gap are however, important for ground and excited state properties of fp shell nuclei around N, Z=28.

We explore the hot rotating fp shell proton rich isotopes of Ni, Fe and Cr, in a theoretical framework and calculate their proton separation energy as a function of temperature and spin using statistical theory of hot rotating nuclei [1,2] combined with the macroscopic-microscopic approach for the ground state. We find that the shell effects and shape transition due to rotation alter the boundary of the drip line at low temperatures and with increasing temperature the proton drip line is pushed to higher neutron number whereas the neutron drip line is lowered to less neutron rich nuclei [3].

We found that the fp shell nuclei exhibit shell effects at proton drip. Magnitude of the nuclear level density parameter 'a' is minimum at magic no. drip line nucleus ^{46}Fe(N=20) and at ^{54}Fe(N=28) (Fig.1). With increasing excitation, shell effects are washed out. Entropy of these drip line nuclear systems is computed which shows fluctuations with spin (Fig.2). Thermal and rotational excitation changes the separation energy and alter the drip line. The unstable drip line nuclei ^{42}Cr, ^{46}Fe, ^{50}Ni have ground

Fig.1. Fig. 2.

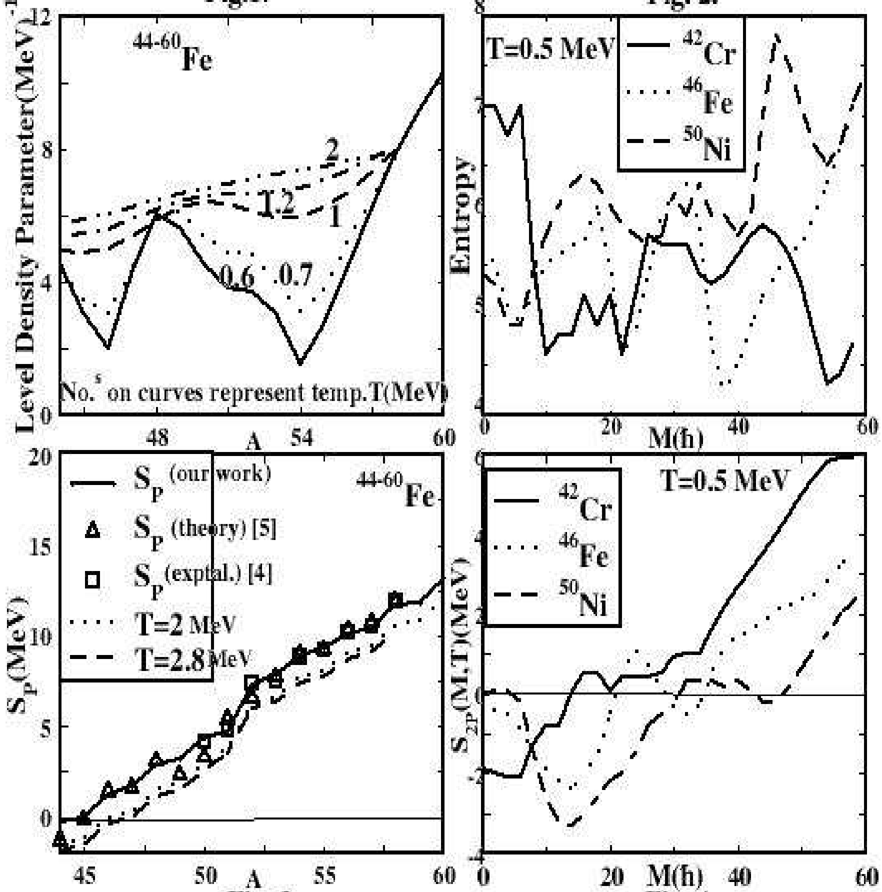

Fig. 3. Fig. 4.

state proton separation energy $S_{2P} < 0$, but surprisingly, these nuclei are stable with positive separation energy at high spins (see Fig. 4). Thus nuclear rotation makes it possible to get these unstable drip line nuclei stable with positive separation energy at certain excitations. As thermal excitation increases, proton separation energy decreases and eventually reduces to zero and the nuclei which were stable in ground state become unstable against proton decay e.g. ^{46,47}Fe [1] are stable nuclei in ground state with $S_p > 0$, but decay by proton emission at thermal excitation corresponding to T ~ 2 MeV (Fig.3). Thus by this method, we also come to know the exact excitation energy at which a particular stable nucleus will become unstable against proton emission. Ground state separation energies (solid line) agree very well with experimental [4] and theoretical [5] predictions (see Fig. 3).

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5.1.8 Simultaneous measurement of elastic, transfer and fusion cross - sections for the $^{7}Be + ^{27}Al$ system

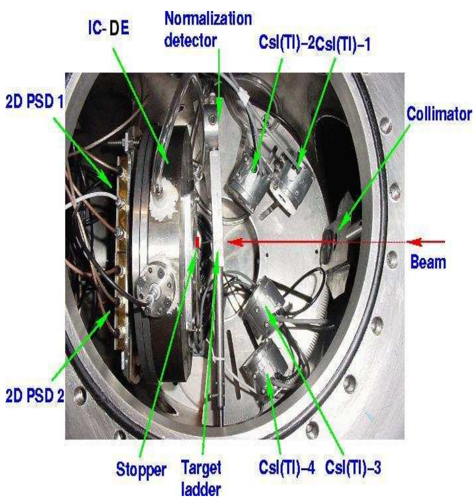
K.Kalita[1], J.J.Das[7], S. Barua[3], S.Verma[1], S.Nath[7], N.Madhavan[7], P. Sugathan[7], A.Jhingan[7], T.Varughese[7], R. Singh[1], K.Ramachandran[4], K.Mahata[4], A.Navin[4], A.Chatterjee[4], S.Kailas[4], P.Basu[5], M.Sinha[5], H.Majumdar[5], S.Bhattacharya[5], R.Bhattacharya[6], A.K.Sinha[2]

[1]Department of Physics & Astrophysics, Delhi University, Delhi –110007
[2]IUC-DAEF, Kolkata-98
[3]Physics Department, Gauhati University, Guwahati-14
[4]NPD, BARC, Mumbai-85
[5]Saha Institute of Nuclear Physics, Kolkata-64
[6]Gurudas College, Kolkata
[7]Nuclear Science Centre, New Delhi-110067

Reactions induced by radioactive ion beams are of considerable interest in Nuclear Physics. These nuclei, being rather loosely bound, are susceptible to break-up and also can substantially populate transfer channels when used for inducing nuclear reactions. Reactions involving such nuclei usually have significantly positive Q-values that enable the measurements on transfer reactions to be done without too much difficulty from the point of view of energies. The break-up threshold for ^{7}Be (into $^{4}He + ^{3}He$) is 1.6 MeV which is much lower than the corresponding value of 2.5 MeV for ^{7}Li (into $^{4}He + ^{3}H$). In fact, the former is similar to the ones for ^{6}Li and ^{9}Be. The sizes of ^{6}Li, ^{7}Li and ^{7}Be are very similar. The reactions induced by low energy beams of $^{6,7}Li$ have been studied for a number of target nuclei. However, it is not so for ^{7}Be projectiles. With the availability of high purity low energy ^{7}Be-beam at NSC [1], we decided to study elastic scattering, transfer and fusion for $^{7}Be + ^{27}Al$ system. The resulting data should provide useful information about the shape, size and other nuclear structure related degrees of freedom influencing the above mentioned processes.

The intensity of the beam being low (~ 10 kHz) a very efficient detection system was conceived to do the simultaneous measurement for all the three processes. A large area telescopic detector setup (ΔE-E) has been developed for elastic scattering and transfer reaction measurements [2]. In this ΔE is a gas ionization chamber with an axial field geometry and E- two position sensitive silicon detectors placed side by side (50 mm x 50 mm each) (PSSD) for the residual-energy measurement. CSI (Tl) detectors were used at back angles for the detection of light particles emitted in fusion-evaporation reaction. Efforts were made to place these detectors at the closest distance to the target. The experimental set-up is shown is Fig.1. Special care was taken to have a high purity (> 99.99%) ^{27}Al target rolled down to a thickness of 1.0 mg/cm^2. The collimator was kept wide open and a thick Au plated Ta stopper was used in order to avoid contamination to fusion from impurities in Ta.

We intended to separate the projectile like particles resulting from ^{7}Be + ^{27}Al elastic scattering from the ones arising from the various possible transfer channels according to their Z-values ($^{6,7}Li$, ^{7}Be etc.). The IC was operated at pressures up to 50 mbar of isobutane. The typical ΔE-E spectrum at 21 MeV beam energy is shown in Fig. 2. The ^{6}Li and ^{7}Be groups of particles can be seen to be well separated. Also, Figs. 3 and 4 show typical spectra for elastic scattering / transfer (one proton stripping, Q= + 6 MeV) at 21 MeV. Spectra with blank are also shown for the same incident flux. The data were taken at 17, 19 and 21 MeV. The data analysis is in progress.



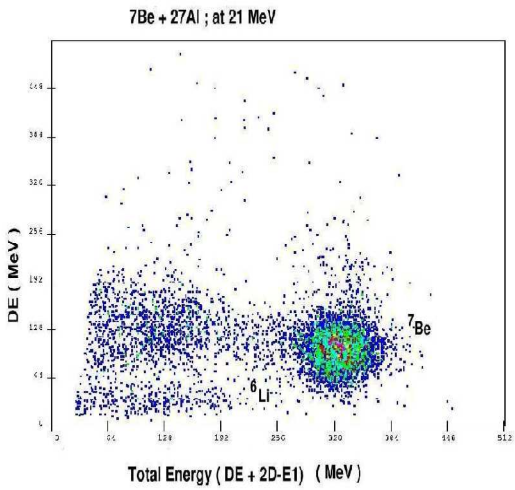


Fig. 1: Experimental setup for measuring elastic/transfer & fusion for ^{7}Be+ ^{27}Al system

Fig. 2: ΔE-E spectrum

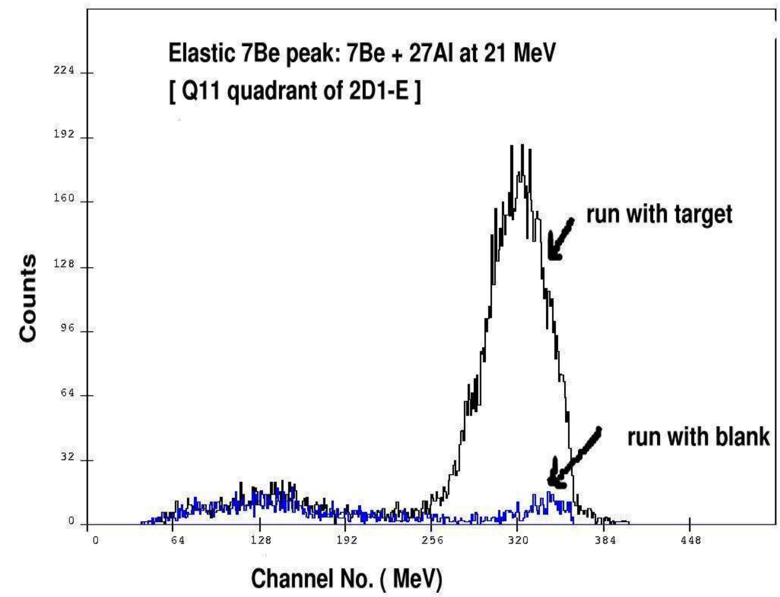


Fig. 3: Elastic ^{7}Be spectrum

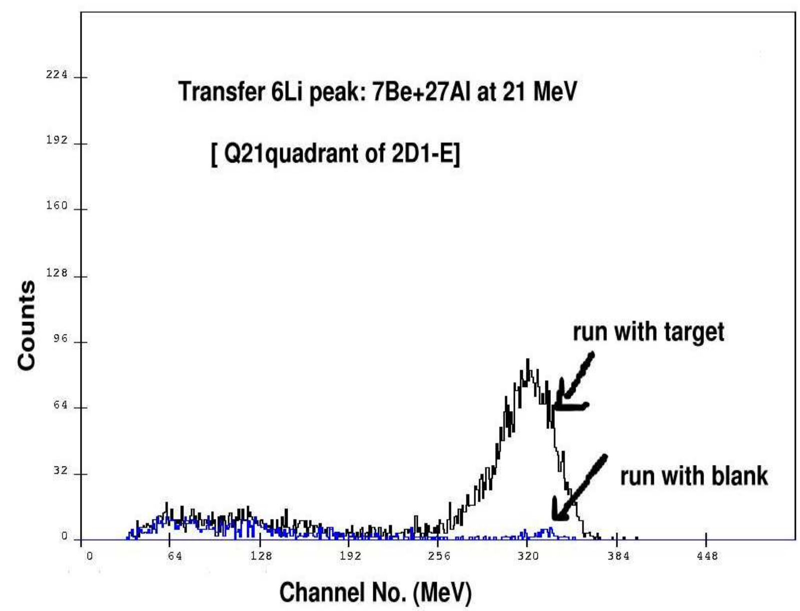


Fig. 4: One proton stripping ^{6}Li spectrum

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5.1.9 Study of elastic scattering of ^{7}Be + ^{9}Be system

S. Verma[1], J. J. Das[5], A. Jhingan[5], K. Kalita[1] , S. Barua[3], N. Madhavan[5], P. Sugathan[5], S. Nath[5], T. Varughese[5], R. Singh[1] , R. K. Chaudhary[4] and his group[2]

[1]Department of Physics and Astrophysics, Delhi University, Delhi - 110007
[2]Nuclear Physics Division, BARC, Mumbai – 400085
[3]Department of Physics, Gauhati University, Guwahati – 781014
[4]Institue of Physics, Bhubaneswar – 751005
[5]Nuclear Science Centre, New Delhi-110067

The effect of breakup of weakly bound projectile on fusion has been extensively investigated in recent years both experimentally [1] and theoretically [2,3], but there is not yet a definite conclusion. There is a special interest on this subject due to the recently available radioactive ion beams. Reactions with these nuclei are important in processes of astrophysical interest and also in search of the mechanisms that produce superheavy elements. These nuclei are bigger than stable ones, implying a considerably lower Coulomb barrier and hence an increase in sub barrier fusion cross section as it depends more or less exponentially on barrier height. These nuclei also have low breakup thresholds. This means that breakup related processes should be more prominent. Thus fusion cross section around the barrier can be enhanced or hindered. Another approach to study of the influence of break-up on fusion cross section is through the analysis of the behavior of the energy dependence of the real and imaginary parts of the optical potentials at near barrier energies.

In view of the above facts, we have undertaken an experiment to measure the elastic scattering cross section for ^{7}Be on ^{9}Be system.

Experimental details :

The experiment was done at energies of ^{7}Be as E_{lab} = 17, 19 and 21 MeV, covering an angular range of 11° to 34° in lab frame. The ^{7}Li beam from 15UD Pelletron was bombarded on polyethylene foil to produce ^{7}Be beam through inverse kinematic reaction $p(^7\mathrm{Li},^7\mathrm{Be})n$. A pair of ΔE-E (Si surface barrier) detectors were mounted to measure recoil protons in the production chamber. The ^{9}Be target used in the experiment was of thickness 1.368 mg/cm^2. In order to compensate for low beam intensity an efficient detector system was used to measure the scattering events [4]. The detector assembly consisted of a ΔE (gas) - E (Si) telescopic system. The gas Ionisation chamber (IC) consisted of three parallel grid electrodes seperated by 10 mm and was placed perpendicular to the beam direction. Two position sensitive large area Si detectors (50mm x 50 mm each), placed side by side, were used as E detectors providing both energy and postion signals as shown in Fig. 1.

A 10 mm Ta stopper was placed before the detector assembly to avoid the beam from falling directly on detectors. The fields of HIRA were tuned to make ^{7}Be beam centered on the Ta stopper. This was verified by ensuring equal number of counts being detected in both PSSDs. The pressure of P10 (90% Ar + 10% methane) gas used in Ionisation Chamber was maintained at 74 ± 0.5 mbar. A Si-SSB detector, used for normalisation, was mounted on one end of target ladder in the scattering chamber. It was periodically introduced along the beam axis to count the incident ^{7}Be particles. The ratio of recoil protons recorded in the monitor detector of production chamber to ^{7}Be counts in normalisation detector were found to be more or less constant. Thus the incident ^{7}Be flux was determined.

An IC(ΔE)-E(tot) spectrum with target (^{9}Be) at 19 MeV is shown in Fig. 2. At each energy a blank run (no target) with sufficient statistics was taken to reject the unwanted events from the genuine elastic scattering events measured with ^{9}Be target. It was ensured that the beam path remains undisturbed through out the experiment. The analysis of data is in progress.

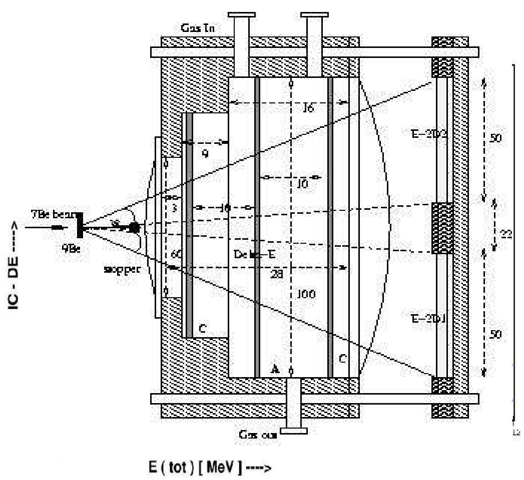

Fig 1 : Schematic of detector assembly

Fig 2 : ΔE vs E(tot) for E1-PSSD

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5.1.10 Fragment mass distribution as a direct probe of quasi-fission reaction in below barrier energies

T.K. Ghosh[2], S. Pal[2], N. Majumdar[2], S. Chattopadhyay[2], T.Sinha[2], A.Saxena[1], P.K. Sahu[1], K.S.Golda[3], S. K. Datta[3] and P. Bhattacharya[2]

[1]Bhabha Atomic Research Centre, Mumbai-400085
[2]Saha Institute of Nuclear Physics, Kolkata-700064
[3]Nuclear Science Centre, New Delhi-110067

In near barrier or sub-barrier light heavy ion induced fission on heavy targets, the formation of the compound nucleus critically depends on the direction of mass flow. For entrance channel mass asymmetry lower than the Businaro-Gallone ridge (as in the present case), the experimentally observed anomalous angular distribution [1,2] were postulated to be due to orientation dependent quasi-fission phenomena in which the system passes over a mass asymmetric saddle point before a statistical equilibrium is reached in all coordinates of motion. Hence, the width of fragment mass distribution should be a direct probe to investigate the onset of the postulated quasi-fission phenomena. However, no unambiguous and clear signals of quasi-fission in mass distributions have been observed [3]. We have made precise measurement of the mass distribution in $^{19}F + ^{232}Th$ in a long TOF spectrometer for complimentary fragments with improved mass resolution to investigate how good is mass distribution as a direct probe of quasi-fission.

The experiment was carried out at Nuclear Science Centre Pelletron, New Delhi, using pulsed ^{19}F beam (pulse width ~1.5 ns) over an energy range (lab) 88 MeV to 107 MeV. The target was a self supporting ^{232}Th of thickness 1.8 mg/cm^2 .Two MWPCs (24 cm x 10 cm), developed in our laboratory at SINP, were kept at the folding angle, 52.6 and 33.2 cm away from the target (shown in Fig. 1), to catch the complementary fission fragments (FF). Timing w.r.t. pulsed beam, X-Y positions and energy loss of the FF on the detectors were collected . Two Si surface barrier detectors were kept at ±10° for flux normalization.

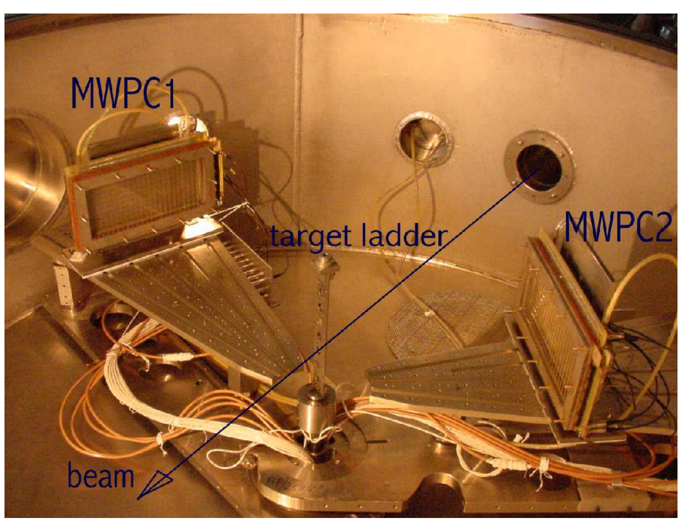

Fig. 1: Detectors placed inside GPSC

Separation of the fission fragments (FF) form the transfer fission (TF) were done using folding angle technique in θ and φ. The fragment masses were determined from the time difference between the MWPC signals [4]. The mass resolution of the set-up was found typically 3 amu. All the measured mass distributions are symmetric in shape, peaking around A_{CN} / 2 contrary to the basic assumption of Hinde et al. [3]. Fig.2 shows the variance of the mass distributions (σ_A^2). At above barrier energies, σ_A^2 falls monotonically with decrease in excitation energy as expected. But just below barrier it increases with decrease in energy and well below the barrier it again starts to fall with decrease in energy. It is exactly a replica of the behavior of anisotropy [2] with energy for this system.

The present result shows a definite correspondence of the variation of the width of the mass distribution with that of the anomalous angular anisotropy in the sub-barrier region where the increasingly dominant role of quasi-fission mechanism with lowering of energy was postulated. Our findings for the first time clearly establishes that the system indeed goes over a different mass asymmetric saddle point in sub-barrier energies which produces a sudden jump of the width of the mass distribution. It shows a clear picture of the system undergoing a different reaction mechanism other than the normal statistically equilibrated saddle point in the fission path.

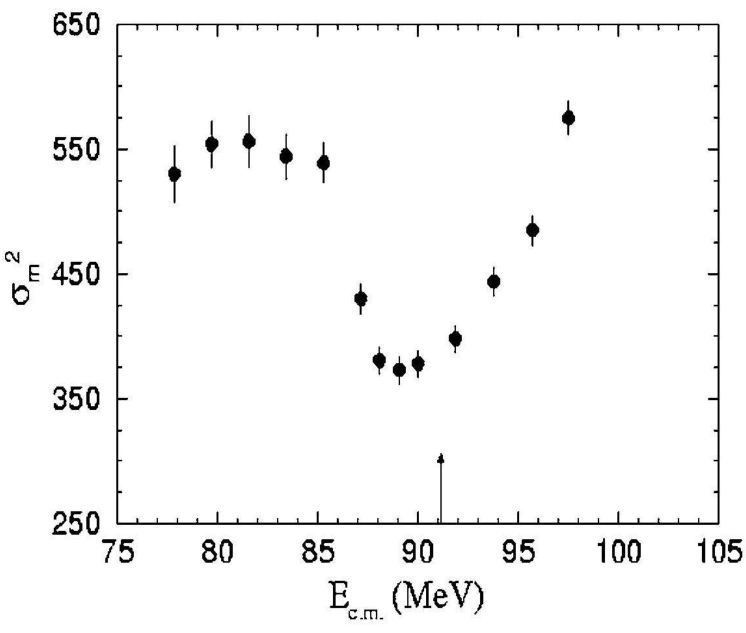

Fig. 2: Variance of the mass distributions as a function of energy (Arrow indicate the Coulomb barrier)

This provides a challenging input to the microscopic theoretical explanations of the fission mass distribution and firmly establishes the postulations of the orientation dependent quasi-fission reactions in addition to the demonstration of the reaction channel through evaporation residue measurement [5].

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5.1.11 Study of Incomplete Fusion in $^{16}O+^{169}Tm$ Systems below 7 MeV/nucleon

Unnati[1], Manoj Kumar Sharma[1], B. P. Singh[1], H.D. Bhardwaj[2], Sunita Gupta[3], Rakesh Kumar[4] and R. Prasad[1]

[1]Department of Physics, Aligarh Muslim University, Aligarh-202002
[2]Department of Physics, DSN College, Unnao-2098021
[3]Department of Physics, Agra College, Agra
[4]Nuclear Science Centre, New Delhi-110067

During the last couple of years there has been a renewed interest in the study of incomplete fusion (ICF) in heavy ion (HI) reactions particularly with heavier target nuclei. It has been observed that at energies just above the Coulomb barrier, both the complete fusion (CF) and the incomplete fusion (ICF) are the dominant reaction mechanisms. Recent measurements [1,2] of excitation functions (EFs) for the production of large number of residues in HI reactions have further confirmed their important role in reaction mechanism. It is possible to separate out the relative contributions of various ICF channels from the measurement of EFs, the Recoil range distribution (RRD) and angular distribution of evaporation residues. With a view to study CF and ICF in several projectile-target combinations, a program of precise measurement and analysis of EFs, RRD and angular distribution of the residues have been undertaken. Earlier, the EFs for some reactions in the system $^{16}O+^{169}Tm$, in the energy range ≈71-95 MeV and RRD of the residues in the Al-foils at ≈87 MeV beam energy have been measured using the activation technique. In order to confirm earlier findings, the experiments have been carried out to measure the RRD for the residues in the same system for which EFs and RRDs have already been measured at two more energies i.e., ≈81 and 85 MeV to see energy dependence of relative contribution of CF and ICF components. Further, in order to get complimentary information regarding CF and ICF fusion, the angular distribution for the residues have also been measured at ≈81 MeV. The analysis of the present experimental data has indicated substantial contribution from the ICF of the oxygen ions and the measured data of angular distribution of cross-sections for residues agree well with our earlier results i.e., measurement of EFs and RRDs. As a representative case, the distribution of cross-section as a function of lab. angles for reactions $^{169}Tm(^{16}O,4n)^{181}Ir$ and $^{169}Tm(^{16}O,3\alpha n)^{172}Lu$ are shown in Figs. 1(a) and 1(b). It may be observed from these figures and in general, that the residues produced by CF channels have forward distribution, while the residues produced by ICF channels have distributions peaking at higher angles as expected.

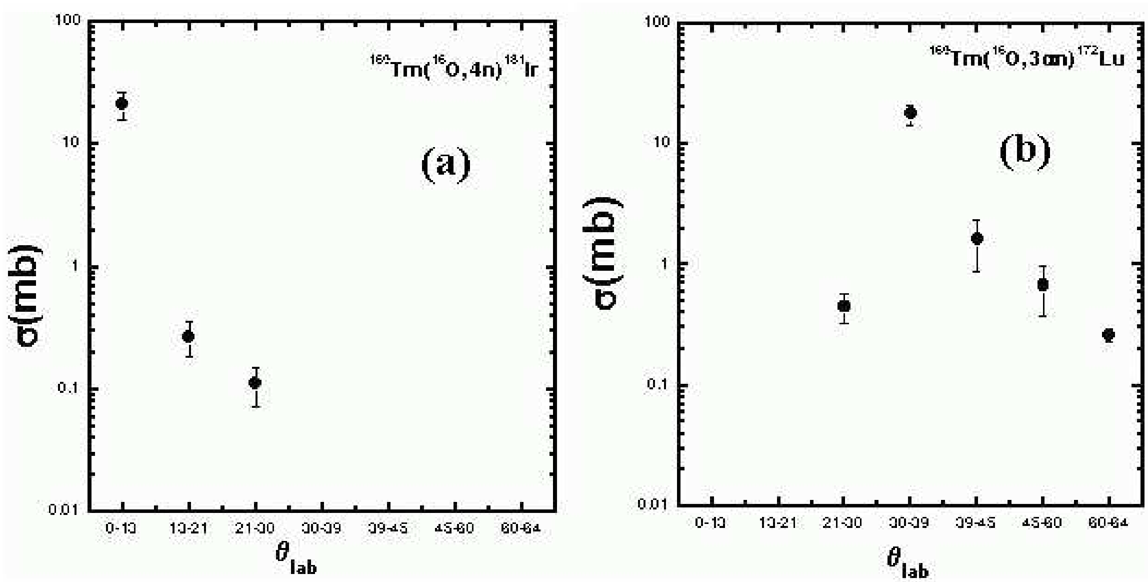

Fig. 1: Angular Distribution of residues produced in the reaction ^{16}O + ^{169}Tm at 81 MeV by (a) complete fusion and (b) incomplete fusion

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