Search for diabolic pair transfer at higher angular momentum states by using heavy-ion induced reaction

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Abstract

We will study the multi-nucleon transfer between two medium-heavy nuclei to find the dynamical aspects of pairing correlations in nuclei, in particular for the cases of nuclear superfluidity. To understand the enhancement of pair transfer probability due to the superfluidity nature of the nuclei which could lead to the nuclear Josephson effect, diabolic pair transfer, a manifestation of Berry phase in nuclei which involves pair transfer across a bend crossing and spin dependence of pairing correlations in two nucleon transfer reactions, we propose to study the transfer processes for ^{206}Pb *on* $^{172,174}Yb$ *and* $^{174,176}Hf$ *systems, at and above the Coulomb barrier energies. The experiment will be performed at X7 using the ion beam from UNILAC facility. Final reaction products will be measured by using an annular proportional counter in coincidence with gamma–rays.*

Introduction:

The study of heavy-ion collisions around the Coulomb barrier offer an excellent opportunity to explore several spectacular effects which lead to a better understanding of reaction mechanisms as well as the sub-lime effects of nuclear structure. Effects such as the enhancement in the sub-barrier fusion cross-section, energy dependent optical model potential, slope anomaly of the one and two nucleon transfer channel etc. are needed to be understood fully in terms of channel coupling mechanism, in and near barrier region.

The multi nucleon transfer processes provide valuable information on nucleon-nucleon correlations in nuclei, specifically on the pairing correlations that enhance the transfer of nucleon pairs during heavy-ion collision. The enhanced transfer of nucleon pairs between two superfluid heavy nuclei in a cold reaction, corresponding to a super-current is related to the Josephson effect (JE). The direct enhanced super current (dc) JEs or the occurrence of alternating current (ac) can be favoured or hindered with the choice of different Q-value and mass partitions. The quenching of the pairing field at high angular momenta is due to the Coriolis force, acts in opposite directions on the two nucleons of each time-reversal pair. This implies a weakening of the pair correlation with increasing angular momentum which lead to a reduced probability of two nucleon transfer effects.

Such effects are particularly important for those nuclei which have many particles outside the close shells (viz **A** near and above 100). Maximum pairing enhancement is expected in such cases where both partners can be chosen to be in a superfluid state and the superfluid flow of pair will lead to an increased flow of nucleons which will enhance reactions with a large change in mass asymmetry. Because of heavier mass and large Z, reactions offer special possibilities in the interpretation of the results semi-classically without going to complicated quantum mechanical calculations. In addition, due to large Z, the strong Coulomb field will lead to a strong excitation of low-lying states. Consequently, the reaction mechanism will involve a strong coupling between inelastic excitation and transfer processes. Hence a full understanding of the different reaction channels near barrier region are needed to extract the information of the enhanced two-nucleon transfer probability.

Previous Investigations and Present Status:

Two nucleon transfer reactions induced by heavy-ions offer a number of possibilities and specific features which have allowed significant progress in the study of dynamical pairing correlations with respect to more traditional transfer reactions induced by light projectiles [1]. For example, only heavy projectiles can provide the reservoir of nucleon pairs that is a necessary ingredient for the occurrence of a multi-pair transfer process. And only heavy projectiles (and targets) provide us the opportunity to see the effect of shell closing phenomenon (or of open shell) on transfer of pairs of nucleons.

Multi-nucleon transfer process in ^{40}Ca+ ^{208}Pb system for pairing correlation have been done extensively at L.N.L., Italy [2] to see the effect of shell closing on pair transfer. A similar work was done for ^{58}Ni + ^{208}Pb [3,4]. An interesting experiment was done on multi-nucleon transfer reaction for ^{40}Ca + ^{124}Sn . In this work, evidence for complex degrees of freedom was found. The experimental isotope yield for the -2p and +2p channels could not be reproduced by calculations that incorporate only independent single nucleon transfer mode [5,6].

Transfer reactions at high angular momentum have not been investigated as yet in great details. Due to experimental difficulties, very little experimental work has been done so far on this aspect of transfer reactions. Nucleon transfer accompanied by Coulomb excitation was studied in various systems around Coulomb barrier energy at GSI, Darmstadt using UNILAC accelerator beams. First benchmark experiment [7] was performed to study few nucleon transfers in the system ^{232}Th on ^{206}Pb near Coulomb barrier. Particle-particle gamma coincidence techniques were used to identify excited states of reaction products populated through inelastic scattering and nucleon transfer reaction. The reaction products were detected with five position-sensitive parallel-plate avalanche counters and kinematics correlations technique was used to identify them. Eight germanium detectors were used to measure the γ-radiation. Four were placed at forward directions and four at backward directions. The mean excitation energy was measured by means of six NaI(Tl) detectors. Large cross sections for one and two neutron pick-up from ^{232}Th have been observed. Observed result is in accordance with the assumption of a cold transfer to states near the yrast line. In the above experiment the collective excitation of ^{230}Th was observed up to high spin state of 16ħ, which was produced by two-neutron transfer and electromagnetic excitation.

In another recent experiment of few neutron transfers, a very asymmetric system ^{206}Pb on ^{118}Sn was used where both semi-magic nuclei showed super-fluid properties[8]. Particle gamma coincidence techniques was used with five Euroball cluster detectors (EB) combined with the Heidelberg-Darmstadt 164 element NaI(Tl) Crystal Ball (CB) for gamma measurements and large area position-sensitive detectors for reaction product measurements. The fragments are identified via the known gamma decays of the lowest excited states using the high resolution of EB. The transfer to well defined final channels with known quantum numbers is selected using the high efficiency multiplicity filter of CB. The enhancement is observed for the two-neutron transfer channels populating the low-lying super fluid 2^+ states in ^{120}Sn and ^{116}Sn. This is the first observation of neutron pair transfer enhancement for a heavy nuclei binary system with super-fluid properties with levels separated experimentally. An experiment has been performed at the linear accelerator UNILAC of GSI, Darmstadt, Germany for ^{162}Dy + ^{116}Sn in inverse kinematics [9] and the authors observed an unusual transfer slope for two neutron transfer.

Till date only one experiment has been reported to investigate the effects of proximity to a diabolic point on nucleon transfer using the reaction ^{206}Pb on ^{154,156}Gd [10]. The experiment was performed with Spin spectrometer which consisted of 15 Compton-suppressed Ge and 55 NaI detectors at Oak Ridge National Laboratory. ***No clear evidence for diabolical pair transfer was observed within the sensitivity range of the experiment performed***.

In the present proposal we would like to investigate multi-nucleon transfer mechanism at low and higher angular momentum states for two nuclei at energies above the Coulomb barrier. The diabolic pair transfer from the rotational states of the superfluid nuclei viz., the isotopes of ^{172,174}Yb and ^{174,176}Hf nuclei will be studied. Several theoretical calculations show the possible positions of the diabolical points in the superfulid nuclei. They also indicate the isotopes for which one can expect diabolical pair transfer (fig 1) [11]. The calculations show a strong prosibility of diabolic pair transfer for Yb and Hf nuclei.

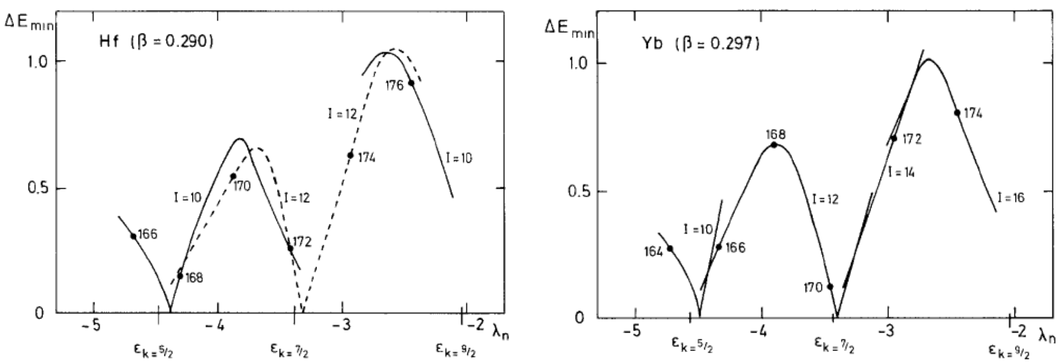

Fig. 1. The Hf and Yb-chain : The interaction strength in the level crossing between the ground state band and the s-band characterized by the minimal distance between the yrast band and the first excited band $\Delta E_{min.}$ Connected lines correspond to minimal distances for the angular momenta I= 10-16ħ. Full dot symbols indicate the even mass Yb-isotopes. The position of the deformed single-particle energies of the $\nu\ i_{13/2}$ levels for the nucleus ^{166}Yb and ^{170}Hf [11] are given on the abscissa.

The above mentioned reaction mechanism can be explored with the existing facility at GSI using a highly efficient gamma detector array (composed of cluster detectors and segmented super clover detectors) and particle identification set-up. The nearly doubly magic ^{206}Pb will be used as projectile to avoid complicated structural effects in the reaction mechanism

Expeirmental Plan and Beam time requirement:

In the present proposal we would like to investigate the diabolical pair transfer for ^{206}Pb on ^{172,174}Yb and ^{174,176}Hf systems. The experimet will be performed at X7 beam Hall of GSI using UNILAC beams. We plan to use the γ-detector array consisting of four cluster germanium detectors from EUROBALL and segmented super clover of GSI for identifying the high spin states of the transfer products. An annular proportional counter will be used to identify the reaction products in coincidence with γ–detectors. A beam of around 5-8 MeV/nucleon from the UNILAC accelerator will be made to impinge on the heavy mass target nuclei (^{206}Pb). Target thickness will be around 300-500 μg/cm^2.

Standard VMI based data acquisition system (Multi Branch System, MBS) and root based online software package will be used to analyse the data from reactions.

We considered the total gamma ray photo peak detection efficiency of the said system to be around 4%. Cross-section of the transfer channel of interest is around few micro barns. The count rate calculations have been performed based on the above parameters and 50% duty cycle of the accelerator. The beam time required for each isotope will be around 14 shifts. Two shifts will be required for the set-up of detector and particle gamma coincidence. The experiments has been performed in two part. In first part we will investigare ^{172,174}Yb isotopes and next part ^{174,176}Hf systems ***Total shifts required will be 30 for each part (two nuclei).***

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Summary

- Diabolic pair transfer for ^{172,174}Yb and ^{174,176}Hf on ^{206}Pb will be performed
- UNILAC beam will be used. Ernery will be in between 5-8 A.MeV.
- Target thickness will be 300-500 $\mu g/cm^2$

- Cluster Ge –detector from EUROBALL and Segmented Super Clover will be used for gamma ray detection
- The experiment will be split up in two part
- **Total beam time requeted for each part: 30 Shifts**
- **Total beam time requeted : 60 Shifts.**