# Annax-I

# Investigation of multi-nucleon transfer reactions in $^{40}Ca$ on $^{68,70}Zn$ at and near the Coulomb barrier.

***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 disentangle the enhancement of pair transfer probability due to the effects of coupling and due to the superfluidity nature of the nuclei, we propose to study the reaction mechanism in detail which include elastic, inelastic, fusion and transfer processes for* $^{40}Ca$ *on* $^{68,70}Zn$ *system, at and near the Coulomb barrier. The experiment will be performed at HIRA (GPSC, if required). Final reaction products will be measured in coincidence with gamma–rays. A new time-of-flight set-up will be installed at HIRA target chamber- area to measure the mass and Z for the reaction products for the above mentioned barrier energies.*

**Motivation:**

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 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 due to the Coriolis force which will act in opposite direction 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 effect.

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 a 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.

In the present proposal we would like to study multi-nucleon transfer in $^{40}$Ca on $^{68,70}$Zn reaction around the Coulomb barrier energy. The excited states and ground state transfer probability will be extracted by measuring the de-excited gamma-rays in coincidence with transfer products. The doubly magic $^{40}$Ca will be used as projectile to avoid complicated structural effect in the reaction mechanism. Also the heavier nature of the beam can play an important role in the enhancement of the pair transfer. Medium heavy $^{68,70}$Zn has large number of neutron pairs out side the closed shell. Effects of sub-shell closer on the multi-neutron transfer can also be studied. A full understanding of the reaction mechanism and effects of channel coupling on the transfer cross-section can be extracted from elastic, inelastic and fusion reaction.

Therefore, in the present proposal we are also interested in studying elastic, inelastic, fusion reaction along with multi-nucleon transfer reaction for the above systems.

**Experimental Plan:**

The experiment will be performed at HIRA. We have a plan for three different beam times to address the above problem. In our first beam time we would like to measure the transfer reaction products below the Coulomb barrier energies. We will use gamma detectors to identify the ground state and excited states (sum of all excited states) transfer. In our 2$^{nd}$ beam time we would like to measure the fusion cross-section at and around the Coulomb barrier energy and also the efficiency of HIRA using gamma detectors. In our 3$^{rd}$ beam time we will measure the transfer product at the above barrier energies and also the elastic scattering cross-section. The following detectors will be used in our different beam times.

1. Standard HIRA detectors will be use to detect the reaction products at focal plane.
2. Two large area gamma –detector (Clover/NaI) will be placed close to HIRA reaction chamber.
3. Two DE - E silicon detectors will be placed inside the chamber to identify the different Z of the reaction products.
4. Two monitor detectors will be placed at very close angle to the beam axis in the chamber for monitoring and normalisation purpose.
5. For Elastic scattering measurement we need to place two position sensitive large area silicon detectors inside the chamber.
6. A Time-of –Flight set-up will be placed one of the flanges of the reaction chamber for the detection of the above barrier transfer products in coincidence with gamma detectors. Time-of-flight set-up will be designed and fabricated at NSC. It will consist of two multi-wire proportional counter and ΔE-E detectors to identify the different reaction products (mass and Z).
7. Standard electronics will be used.

$^{68,70}$Zn targets of different thicknesses (100μg/cm2, 500μg/cm2) will be required for the experiments. The targets will be prepared at the target lab. of IUAC.

The cross-sections for elastic, inelastic, transfer, fusion will be extracted through a detailed off-line analysis of the data collected during the experiments.

**Beam Requirement:**

1. Beam : $^{40}$Ca
2. Energy : 100 – 145 MeV
3. Intensity : 2pnA to maximum possible.

**Beam Time Request and justification :**

**Number of Run** : 3 (Three) with 4-5 months gap

***Total beam time :*** 54 shifts (15 shifts + 18 shifts + 21 shifts )

*1$^{st}$ beam time :* HIRA set-up time + transfer product measurement time = 15 shifts

*2$^{nd}$ beam time* : HIRA set-up time + fusion measurement + HIRA efficiency measurement = 15 shift

*3$^{rd}$ beam time :* Transfer measurement above barrier + elastic, inelastic measurements

We have asked for 2 separate beam time for transfer reactions. For above barrier energies we will use ToF setup which will be constructed at IUAC. We will measure the transfer cross-section in coincidence with emitted gamma rays. In order to get meaningful statistics for selected excited states of the transfer channels we need 21 shifts for above barrier energies (due to the low detection efficiency (around 0.5 %) of gamma detector).

**IMPORTANCE OF THE PROPOSED EXPERIMENT IN THE CONTEXT OF THE INTERNATIONAL STATUS :**

Transfer reactions close to the Coulomb barrier energies are complex in their nature and the important degrees of freedom acting in the reaction mechanism as well as their proper identification are still poorly understood. In different investigated systems [1] the main degrees of freedom in the quasi-elastic regime are reported to be single nucleon transfers. Enhancement of two nucleon transfer channels with respect to the estimates based on probabilities for independent particle transfers are discussed in the literature. However, only a few investigations are reported where both experimental, observable and coupled channel calculations [2] are carried out in a consistent way. It is very important to study multi nucleon transfer by comparison of the data with semi-classical models as they improve our knowledge of different degrees of freedom that influence the evolution of reaction, like deformation, single and pair transfer modes etc.

It is indeed obvious that studies of nuclear reactions involving pair transfer mode are very important as these can provide us with information on correlation of nucleons and can be vital in estimation of the role played by pairing effect (in transfer reactions). A study of multi nucleon transfer reactions for the system $^{90}$Zr($^{16}$O, X) and $^{90}$Zr ($^{18}$O, X) was performed at BARC [3]. The enhancement of 2n and 2n correlated transfer cross-section in $^{18}$O case has been explained by interpreting the projectile as a core plus two loosely bound valence neutrons in a di-neutron configuration outside the relatively tightly bound $^{16}$O core. Some other multi nucleon transfer reactions for heavy ions in the mass range 20 to 100 are performed in last few years [4, 5, 6] for different systems and with different purposes.

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 multi-pair transfer process. And only heavy projectile (and target ) provide us the opportunity to see the effect of shell closing effect (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. [7] to see the effect of shell closing on pair transfer. A similar work was done for $^{58}$Ni + $^{208}$Pb [8, 9]. An interesting experiment was done on multi nucleon transfer reaction for $^{40}$Ca + $^{124}$Sn . In this work, evidence for complex degrees of freedom were found. The experimental isotope yield for the -2p and +2p channels cannot be reproduced with calculations that incorporate only independent single nucleon transfer mode [10 , 11].

Now, to the best of our knowledge, no experiment has been reported so far on multi nucleon transfer reaction for the system $^{40}$Ca + $^{68,70}$ Zn at sub barrier and near barrier energy and measure the effect of sub shell closing on pair transfer probabilities.

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