Transfer measurements for the Ti + Ni systems at near barrier energies

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Abstract. Large enhancements have been observed in the sub-barrier fusion cross sections for Ti + Ni systems in our previous studies. Coupled channel calculations incorporating couplings to 2^+ and 3^- states failed to explain these enhancements completely. A possibilty of transfer channels contributing to the residual enhancements had been suggested. In order to investigate the role of relevant transfer channels, measurements of one- and two-nucleon transfer were carried out for ^{46,48}Ti + ^{64}Ni systems. The present paper gives the results of these studies.

Keywords. Transfer; sub-barrier fusion; kinematic coincidence.

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1. Introduction

Fusion and transfer are two important modes of interaction of heavy ions at energies near the Coulomb barrier. The fusion process at sub-barrier energies has usually been explained on the basis of the one dimensional barrier penetration model. However, in the early 80's, large enhancements in the fusion cross sections were observed by Beckerman and others [1] in the fusion of heavy ions at below barrier energies. This effect has been attributed to the coupling of the fusion channel to various other degrees of freedom. These include inelastic excitations, deformation of the projectile and the target, nucleon transfer etc. Coupled channel calculations including the contributions from the above channels have shown good agreement with the observed fusion enhancements [2]. A number of review articles have been published to date on the subject [3].

Few nucleon transfer reactions in the near and sub-barrier heavy ion collisions constitute a significant part of the reaction cross section. A full quantum mechanical description of the process becomes very tedious and involved. However, semiclassical methods are expected to be applicable. Also, efforts have been made to utilize the experimental transfer data along with the semiclassical approach for a reliable extraction of the transfer form factors. The form factors provide a quantitative input for taking into account the possible role of the transfer channels in the coupled channels approach for understanding the observed enhancements in the sub-barrier fusion observables like cross section, average spin etc.

The transfer measurements at the above barrier energies utilize the data forward of the grazing angle in order to extract the transfer probability as a function of the closest distance of approach. However, the transfer probabilities derived were found to be in disagreement with the theoretically derived values using the semiclassical approach. This is the so called slope anomaly [4]. An interpretation of this has been possible based on the interference of the Coulomb and nuclear branches of the deflection function [4]. In contrast to the above barrier data, the semiclassical methods have been found to describe the sub-barrier measurements quite successfully as contributions to the observed scattering process arise from the trajectories with impact parameters corresponding to the Coulomb branch only. Thus the sub-barrier measurements offer a completely unambiguous and reliable way of extracting the transfer form factors. Besides, the extraction of the transfer form factors from detailed experimental data for the multi-neutron and proton transfer data in the sub-barrier region should provide a simple and stringent test of the semiclassical concepts while describing the transfer process at large inter nuclear distances.

At the Nuclear Science Centre, New Delhi, we had carried out a few measurements [5,6] on the sub-barrier fusion of some Ti + Ni systems using the Pelletron accelerator and the Recoil Mass Separator HIRA installed there. These studies revolve around the quantitative test of the importance of the transfer channel coupling (especially the positive Q-value two neutron pick up for the reactions involving ^{64}Ni target, which are 2.58 MeV and 4.01 MeV respectively for ^{48}Ti and ^{46}Ti projectiles) which has been invoked in an empirical explanation of the observed isotopic dependence of the fusion enhancement [5,6]. To complement the fusion measurements, we have carried out transfer measurements also on the two systems ^{46,48}Ti + ^{64}Ni. In these measurements we have resorted to a kinematic coincidence technique for detecting the transfer products in order to overcome the problems associated with the M/q ambiguity at the focal plane of the HIRA. Such a technique was earlier seen to be helpful in this aspect [7]. In the following sections the details of these measurements and the important results obtained are given.

2. Experimental details

Experiments have been carried out using ^{46,48}Ti beams with energies ranging from 120 MeV to 142 MeV, obtained from the 16 MV Pelletron accelerator at the Nuclear Science Centre, New Delhi. Self-supporting ^{64}Ni targets with thickness of 240 μg/cm^2 were used. The recoiling target like nuclei at 20° enter the Recoil Mass Separator HIRA. These have been detected at the focal plane of the HIRA by a gas detector system [8] consisting of a front end multiwire proportional counter, position sensitive in two directions, backed by a $\Delta E - E$ gas ionization chamber. These are counted in coincidence with the corresponding low energy back scattered projectile-like particles detected in a Si surface barrier detector placed inside the scattering chamber at 91.5° and 94.2° respectively for ^{48}Ti and ^{46}Ti reactions. Impurity concentrations of neighbouring isotopes were estimated using the lowest beam energies.

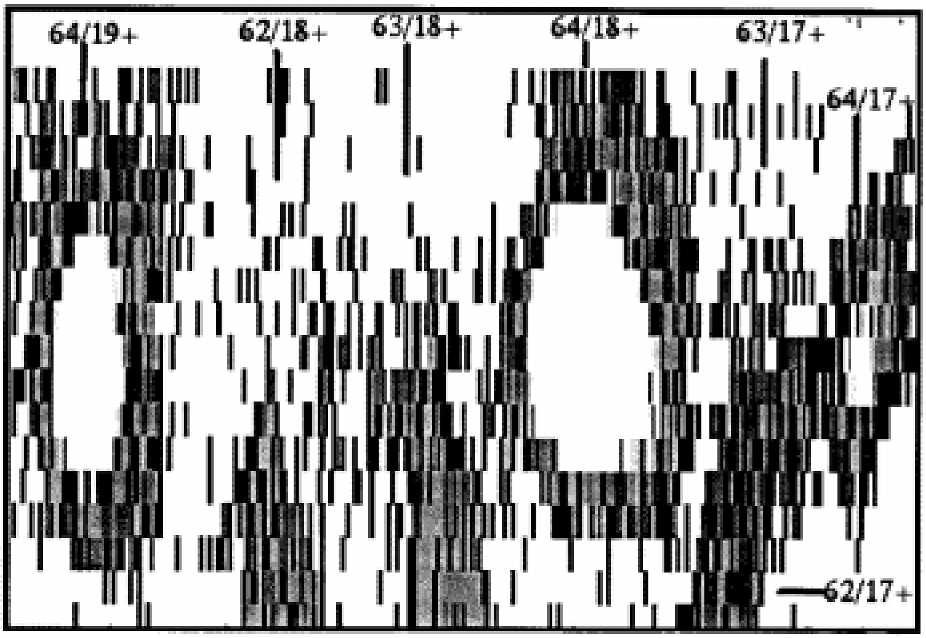

Figure 1. Two dimensional spectrum of HIRA focal plane position vs. time of flight.

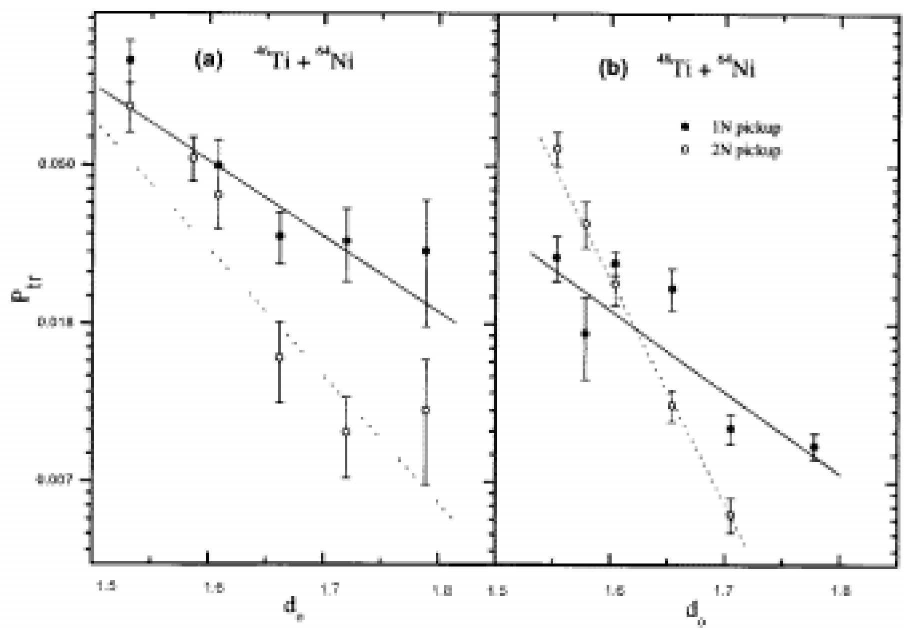

Figure 2. Transfer probability as function of reduced distance of closest approach.

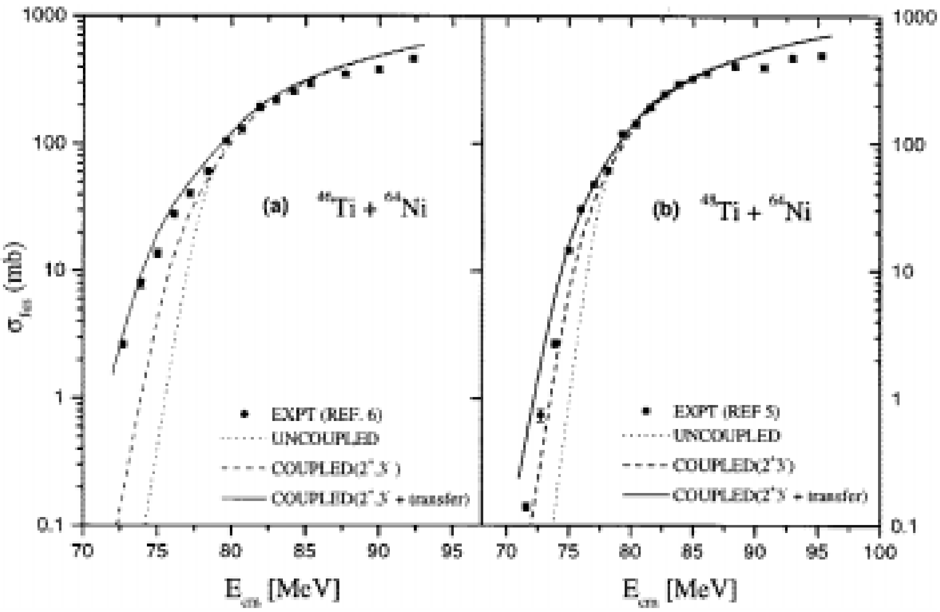

Figure 3. Experimental fusion excitation functions vis-a-vis coupled channels calculations.

The capability of the kinematic coincidence technique used in resolving the M/q ambiguity is demonstrated in figure 1 which shows a two dimensional plot of focal plane position vs. the flight time of the transfer products. The various M/q peaks are reasonably well separated in this plot.

Transfer probabilities for the one and two neutron transfer for both pick up and stripping have been extracted by taking the ratio of the cross section of a particular transfer channel to the sum of the cross sections for the transfer channels and the elastic channel. These have been plotted as function of the reduced distance of closest approach of the heavy ions in figure 2.

3. Results

The slope parameter was determined to be 0.34 and 0.93 respectively for the 1N and 2N channels of ^{48}Ti and 0.31 and 0.53 for the lighter Ti projectile from the plots in figure 2. The values of the slopes so obtained were used to extract the relevant transfer form factors and used in a coupled channel calculation. The results are shown in figure 3. Reasonable agreement was obtained with the experimental fusion excitation functions at near and sub-barrier energies.

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