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Transfer probability measurements in the superfluid ^{116}Sn+^{60}Ni system

D. Montanari[1,a], L. Corradi[2], S. Szilner[3], G. Pollarolo[4], E. Fioretto[2], A.M. Stefanini[2], E. Farnea[1,5], C. Michelagnoli[1,5], G. Montagnoli[1,5], F. Scarlassara[1,5], C.A. Ur[1,5], S. Courtin[6], A. Goasduff[6], F. Haas[6], T. Mijatović[3], and N. Soić[3]

[1]*Istituto Nazionale di Fisica Nucleare, Sezione di Padova, I-35131 Padova, Italy*
[2]*Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy*
[3]*Ruđer Bošković Institute, HR-10 002 Zagreb, Croatia*
[4]*Dipartimento di Fisica Teorica, Università degli Studi di Torino, and Istituto Nazionale di Fisica Nucleare, I-10125 Torino, Italy*
[5]*Dipartimento di Fisica e Astronomia, Università degli Studi di Padova, I-35131 Padova, Italy*
[6]*Institut Pluridisciplinaire Hubert Curien, CNRS-IN2P3, Université de Strasbourg, F-67037 Strasbourg, France*

Abstract. We measured excitation functions for the main transfer channels in the ^{116}Sn+^{60}Ni reaction from above to well below the Coulomb barrier. The experiment has been performed in inverse kinematics, detecting the lighter (target-like) ions with the magnetic spectrometer PRISMA at very forward angles. The comparison between the data and microscopic calculations for the present case and for the previously measured ^{96}Zr+^{40}Ca system, namely superfluid and near closed shells nuclei, should significantly improve our understanding of nucleon-nucleon correlation properties in multinucleon transfer processes.

1 Introduction

At bombarding energies below the Coulomb barrier and at large internuclear distance, nuclei interact through the tail of their density distribution and are only slightly influenced by the nuclear potential. Under these conditions, reaction products are excited in a limited energy region (few MeV) and therefore the complexity of coupled channel calculations diminishes, since few populated excited states have to be taken into account, and more quantitative information may be extracted on particle correlations [2]. In most of the previous works transfer probabilities P_{tr} have been derived from angular distributions at energies above the Coulomb barrier, where processes other than the direct one may contribute to the cross section, causing slope anomalies [3–6]. Excitation functions at energies below the barrier have been performed in only a few cases [7–10], due to experimental difficulties and to limitation in detection efficiency. Since a few years, using large acceptance magnetic spectrometers, it is possible to study multinucleon transfer reactions at energies far below the Coulomb barrier with good mass and atomic number resolution, especially in inverse kinematics conditions where the

[a]e-mail: daniele.montanari@pd.infn.it

lighter target-like recoils have high kinetic energy. The efficient use of the large solid angle spectrometer PRISMA to perform such studies has already been demonstrated in the study of the ^{96}Zr+^{40}Ca system [11]. Making use of inverse kinematics, excitation functions for the most intense transfer channels have been obtained by detecting target-like recoils and varying the bombarding energies in several steps from above to well below the barrier, corresponding to a broad range of distances of closest approach. The data have been compared with microscopic calculations performed within a semi-classical theory [12, 13], where the two-nucleon transfer included the 0^+ ground states of both projectile and target and the first excited 0^+ state of the light reaction partner. From the comparison, the role played by the $f_{7/2}$ and $p_{3/2}$ single particle states has been identified. The former dominates the ground state wave function of ^{42}Ca and the latter dominates the wave function of the 0^+ state at 5.76 MeV. Such a state for the +2*n* channel has a good match with the optimum Q-value, being Q_{gs}=+5.6 MeV. The importance of states with different spin and parity has been also evidenced. As a further step we found it interesting to investigate another system whose ground to ground state Q-value is close to zero for neutron transfers, matching their optimum Q-value (∼ 0 MeV). The ^{60}Ni+^{116}Sn system is very suitable in this sense, since it has $Q_{gs}^{+1n} = -1.7$ MeV and $Q_{gs}^{+2n} = +1.3$ MeV. One then expects to have a main population close to the ground to ground state transitions and, in particular for the +2n channel, it is interesting to see how calculations including only transfer to the 0^+_{gs} states compare with the experimental data. We present below some preliminary results of a reaction involving the ^{60}Ni+^{116}Sn system in inverse kinematics performed using the magnetic spectrometer PRISMA [14–16].

2 The experiment and experimental results

Similar to the ^{96}Zr+^{40}Ca case [11, 17], we detected the light target-like ions setting the magnetic spectrometer at a very forward angle. The detected reaction products had at the same time enough kinetic energy, resulting in a good mass resolution, and a forward focused angular distribution which allowed a high detection efficiency. The ^{116}Sn beam was delivered by the heavy ion PIAVE injector and the ALPI superconducting booster of the Laboratori Nazionali di Legnaro with an average current of ∼ 2 pnA onto a 100 μg/cm^2 ^{60}Ni target with a C-backing of 15 μg/cm^2. Ni-like recoils have been detected by PRISMA at θ_{lab}=20°, corresponding to $\theta_{c.m.}$=140°. The beam energy was varied in steps of ≃ 10 MeV from 500 to 395 MeV. Some furhter points have been measured making use of an 85 μg/cm^2 thick C-foil placed in front of the Ni targets. This was done to optimize the time loss due to the change of energy with ALPI and allowed to degrade the ^{116}Sn beam by about 7 MeV. Two energies, E_{lab}= 220 and 280 MeV, have been used with the Tandem only, to have a precise energy reference. The obtained excitation function, from above to ≃ 25% below the Coulomb barrier, ranged from ≃ 12 to ≃ 16 fm of distance of closest approach. The identification of the reaction products in PRISMA is based upon an event-by-event reconstruction of the trajectories of the ions [15, 16] inside the spectrometer. We use positional information provided by the start [18] and focal plane [19] detectors of PRISMA and the equation of motion of a charged particle in the quadrupole and dipole magnetic fields to reconstruct the trajectories of the ions inside PRISMA. Trajectories are considered to be planar and the effects of the fringing fields of the magnets are taken into account by assigning an effective length to the optical elements of the spectrometer. This is done in order to have a fast off-line algorithm to be used for data analysis. Under these assumptions the trajectories are uniquely defined by only one parameter, the bending radius ρ in the dipole.

Assuming a binary reaction and imposing the conservation of linear momentum, we could reconstruct the total kinetic energy loss (TKEL) for the different reaction channels. In Fig. 1 we display the TKEL spectra for the elastic, the one (+1*n*) and the two (+2*n*) neutron pick-up channels at the bombarding

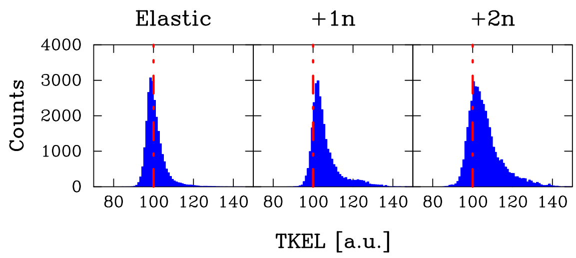

Figure 1. TKEL loss spectra for the elastic and +1n, +2n transfer channels at the bombarding energy E_{lab} = 475 MeV. See text for details.

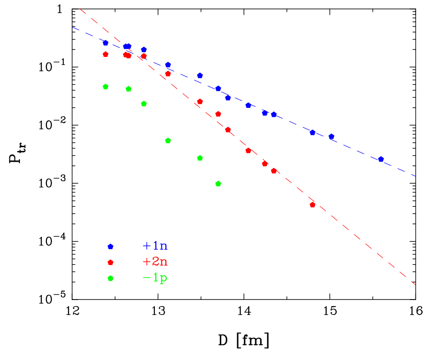

Figure 2. Transfer probabilities for +1n (blue), +2n (red) and -1p (green) reaction channels plotted as a function of the distance of closest approach D. Neutron data extend down to ≃15 fm, while for proton stripping further analysis is needed (see text for details).

energy of E_{lab} = 475 MeV, close to the Coulomb barrier. The elastic(+inelastic) peak has a width of ~ 2 MeV, close to the expected experimental energy resolution. The vertical dashed lines indicate the position of the Q-value for the elastic, Q_{el}=0 (channel 100 in the figure), which is taken as a reference for all the other isotopes. TKEL distributions for neutron transfers are peaked around Q=0, as it is expected by considering that their ground to ground state Q-values are $Q_{gs}^{+1n} = -1.7$ MeV and $Q_{gs}^{+2n} = +1.3$ MeV, respectively. At the same time one sees a tail toward larger TKEL, more marked for the $+2n$ channel, typical of the energy regime close to the barrier. These energy loss components tend to disappear far below the barrier.

At present data are being analyzed with the main aim to extract the transfer cross sections for the one and two neutron pick-up channels and for channels involving proton stripping. Transfer probabilities have been obtained as the ratio of differential cross sections of the transfer channels to the elastic and plotted versus the distance of closest approach, Preliminary results for the transfer probabilities of one-neutron, two-neutron and one-proton transfer channels are plotted in Fig. 2 with blue, red and green symbols, respectively. Data are well described by an exponential functions, dashed lines for +1n and +2n channels, at large distances where the experimental elastic yield is almost completely due to pure Rutherford events. At higher energies (smaller distances) the slope of experimental data deviates from the exponential trend due to the presence of mechanisms other than the direct one. The

$-1p$ and the $+1n$ channels are the basic building blocks for the understanding of the more complex multiple particle transfer. The comparison of their behaviour as a function of the bombarding energy will tell about the shape of the form factors [20].

3 Conclusions

We measured in inverse kinematics the nucleon transfer excitation functions for the ^{116}Sn+^{60}Ni system. Light target-like ions have been detected with the magnetic spectrometer PRISMA with a good mass and atomic number resolution in the whole energy range. Data analysis is in progress to deduce the cross sections and transfer probabilities for neutron pick-up channels as well as for channels involving proton stripping. The comparison between data and theory for the present case and for the previously measured ^{96}Zr+^{40}Ca system, namely superfluid and near closed shells nuclei, will significantly improve our understanding of nucleon-nucleon correlations in the transfer process.

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