APH N.S., Heavy Ion Physics **11** (2000) 000–000

HEAVY ION PHYSICS
©Akadémiai Kiadó

Quasi-Elastic Scattering Measurements in the Systems ^{12,13}C+^{105,106}Pd

O.A. Capurro,[a] J.E. Testoni, D. Abriola, E. Achterberg, D.E. DiGregorio, G.V. Martí, A.J. Pacheco and M.R. Spinella

Laboratorio TANDAR, Departamento de Física, Comisión Nacional de Energía Atómica, Av. del Libertador 8250, 1429 Buenos Aires, Argentina,

Received 13 October 1999

Abstract. Quasi-elastic scattering excitation functions at backward angles and near barrier energies for the systems ^{12,13}C+^{105,106}Pd have been measured. The first derivative of the cross sections respect to the energy was determined. The purpose of this work is to evaluate if such derivative is a good representation of the barrier distribution involved in the fusion process. The results are analyzed considering that the characteristics of the barrier distribution depends on the effective Q-values.

Keywords: nuclear reactions, ^{105,106}Pd(^{12,13}C,X) E = 30–52 MeV, measured quasi-elastic $\sigma(\theta)/\sigma_R$ at $\theta \simeq 164°$, subbarrier fusion, deduced fusion barrier distribution
PACS: 25.70.Bc, 25.70.Hi, 25.70.Jj

1. Introduction

We have measured quasi-elastic excitation functions for the ^{12,13}C + ^{105,106}Pd systems at near barrier energies. The irradiations were performed using the facility of the TANDAR Laboratory in Buenos Aires. The scope is to obtain a representation of the barrier distribution in the fusion process. This barrier distribution is usually obtained calculating the second derivative of the fusion excitation function. A few years ago, it was suggested [1] that such representation could be extracted from quasi-elastic reaction cross sections measured at backward angles. The principal advantage of this method compared with that based in the fusion excitation function [2] is to lead to smaller experimental uncertainties because only the first derivative of the excitation function is required. Our purpose is to study systems where the coupling to the transfer channels is more significant than the coupling

1219-7580/00/ $ 5.00

to the inelastic ones. A way to reach this aim is to work with systems for which the transfer channels are energetically favored, while the product of the atomic numbers of the reactants are low enough to reduce the effect of the coupling to the vibrational degrees of freedom. The results are compared with systems whose transfer channels are not favored. We have chosen palladium isotopes which have vibrational characteristics as targets and, as projectiles with low atomic number, two isotopes of carbon.

The setup for these experiments is shown in the Fig. 1.

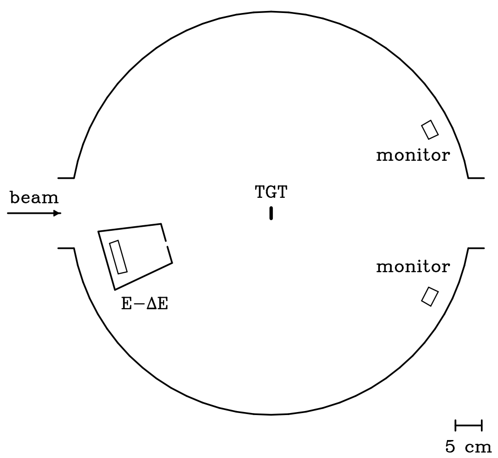

Fig. 1. Experimental setup used for our quasi-elastic scattering measurements. The monitors and the ionization chamber were placed at ∼30° and ∼164°, respectively.

Two conventional surface barrier detectors were placed at forward angles for normalization purposes. An ionization chamber was put at a backward angle to allow the measurement of differential cross sections on a range of about 2.6 degrees around 164 degrees. Gas P-10 at pressures of 100 torr has been used in this gas ionization chamber. A silicon surface barrier detector was placed in the chamber to measure the residual energy of the reaction products.

The target thickness was around of 100 μg/cm^2. Some of these targets were prepared by evaporation and others using an electrodeposition technique.

The bombarding energy range was typically from 30 MeV to 52 MeV and the energy step was 0.5 MeV in almost the overall range. Irradiation time of 30 minutes for beam currents of 100 nA were sufficient to obtain good statistic at the lowest energy (i.e. 20000 counts for the quasi-elastic channel peak in E vs. ΔE spectrum). But, at the highest energy, it was necessary to bombard the target during two hours at beam current of 400 nA. In this way, the number of events for the quasi-elastic peak in the two-dimensional spectrum was of about one thousand.

A typical statistical error of the cross section was 1%. On the other hand, the uncertainty in the bombarding energy was around of 0.3%. The four excitation functions obtained in this work are plotted in the Fig. 2. As can be seen in this figure, the measured ratio of quasi-elastic to Rutherford scattering falls from 0.9 to

0.1 over an energy range of about 7 MeV in the different systems. This fast fall is expected for a short range of barriers.

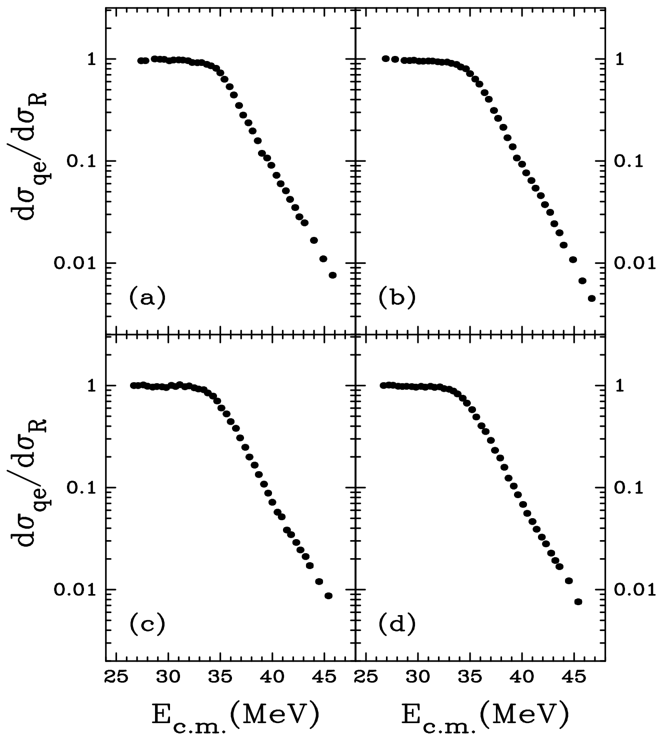

Fig. 2. Quasi-elastic scattering excitation functions for the studied systems: ^{12}C+^{105}Pd (a), ^{12}C+^{106}Pd (b), ^{13}C+^{105}Pd ((c), and ^{13}C+^{106}Pd (d). The scattering angle of these quasi-elastic data was around 164° in the laboratory system. The statistical error of the cross sections was about 1%.

2. First Derivative of the Quasi-Elastic Data

The next step in this study was to obtain the first derivative respect to the energy of the ratio between quasi-elastic scattering and Rutherford cross section. This derivative was determined from a straight line fit to each set of three adjacent points. The slope obtained from this fit was assumed to give a good estimate of the first derivative around the middle point of each interval.

Table 1 shows the effective Q-values for transfer channels of up to two nucleons for the systems under study. We will assume that for negative $Q_{\rm eff}$-values one would expect a second barrier of energy higher than the corresponding to the principal barrier and that, on the other hand, positive Q_{eff}-values would be reflected in the presence of barriers of lower energy.

Table 1. Effective ground-state Q_{eff}-values for transfer channels of up to two nucleons (in MeV). The minus sign (−) indicates pickup reaction and the plus sign (+) indicates stripping reaction.

Transfer reactions	$^{12}C+^{105}Pd$	$^{12}C+^{106}Pd$	$^{13}C+^{105}Pd$	$^{13}C+^{106}Pd$
−2p	−19.0	−19.6	−10.6	−11.2
−1n −1p	−8.1	−10.6	−2.2	−4.7
−2n	−4.0	−3.5	−7.7	−7.3
−1n +1p	−9.1	−10.7	−9.2	−10.8
+2p	−2.9	−2.2	−7.4	−6.7
+1n +1p	−6.9	−9.2	−0.4	−2.7
+2n	−15.7	−16.1	−7.6	−7.9
+1n −1p	−23.3	−26.2	−8.1	−11.1
−1p	−11.9	−12.5	−6.2	−6.8
−1n	−2.2	−4.6	1.1	−1.4
+1p	−4.8	−4.8	−6.4	−6.4
+1n	−9.2	−12.2	4.6	1.6

As a result of the first differentiation of the quasi-elastic excitation function for the $^{12}C+^{105}Pd$ system, one obtains a function with a gaussian-like shape centered around 35.5 MeV (Fig. 3a). The dotted line is drawn only to guide the eye and corresponds to the arithmetic average between two consecutive experimental points. One can observe in this barrier distribution, a little bump around 38.5 MeV which, might be originated in the one neutron pick-up reaction. The effective Q_{eff}-value for this reaction is −2.2 MeV. Other channels are very unfavored from the energetic point of view.

The principal barrier of the $^{12}C+^{106}Pd$ system is localized at approximately 36 MeV (see Fig. 3b). We cannot see clearly any extra barrier. The effective Q_{eff}-values are very negative in this system. The only exception corresponds to the stripping reaction of two protons.

Figure 3c shows the first derivative of the ratio between the quasi-elastic reaction and the Rutherford cross section for the $^{13}C+^{105}Pd$. The most prominent barrier seems to be centered at about 34.8 MeV. The negative Q_{eff}-values of the one neutron plus one proton stripping and pickup channels could be responsible of the bump observed at the right of the principal barrier. In this system, there are one neutron stripping and pickup channels with positive Q_{eff}-values. Their presences might be reflected in the kink placed at the left of the principal barrier.

The $^{13}C+^{106}Pd$ system has the one neutron pickup reaction with a negative Q_{eff}-value of 1.4 MeV and this transfer could be present through the bump observed at 2 or 3 MeV above the principal barrier in Fig. 3d. On the other hand, this system

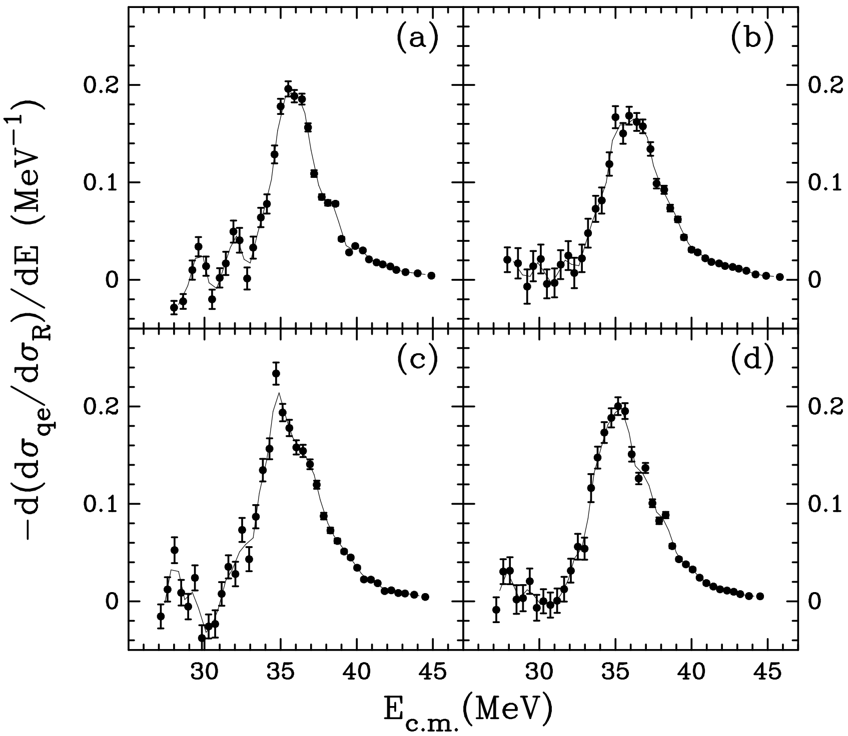

Fig. 3. Representations of the barrier distribution obtained from our quasi-elastic data: $^{12}C+^{105}Pd$ (a), $^{12}C+^{106}Pd$ (b), $^{13}C+^{105}Pd$ (c), and $^{13}C+^{106}Pd$ (d). The solid line is drawn to guide the eye.

has the one neutron stripping transfer channel energetically favored with a positive Q_{eff}-value of 1.6 MeV. However, its presence below the prominent barrier is not clear.

The analysis of the systems which we have performed allow us to investigate the sensibility of the method used to obtain a representation of the barrier distribution and to point out the following remarks.

It is quite clear the difference in the position of the principal barriers corresponding to systems which have the same target but different projectile when one compares the Fig. 3a with the Fig. 3c and the Fig. 3b with the Fig. 3d.

Besides, it can be observed that the representations of the barrier distribution for the systems with ^{13}C as projectile are wider than those corresponding to ^{12}C. This is clear for both targets. This observation has to be related with the number of transfer channels energetically favored in each system; this number is always greater when the incident particle is carbon thirteen (see Table 1).

Finally, we must consider the first derivative of the relative quasi-elastic cross sections in the low energy region where some peaks, lower than the principal one, are present. Perhaps, these scattered experimental points are associated to statistical fluctuations. However, comparing all plots of the Fig. 3, the scatter points in the systems with ^{105}Pd as target is "stronger". Up to now, we have not explain the true origin of these fluctuations.

3. Conclusions

We have measured the quasi-elastic excitation functions for four systems with a high degree of precision and a fine energy step.

The errors of the first derivative respect to the energy of the quasi-elastic excitation functions are quite small if they are compared with those usually got from the second derivative of fusion excitation functions.

The representations of the barrier distributions obtained in this work might reveal the presence of transfer channels in some of the systems. The shift observed in the principal barrier position for systems with same target but different projectiles, allow us to evaluate the resolution of the technique.

Our next step will be to carry out coupled channel calculations in order to improve the analysis of our data.

Finally, we point out that it would be interesting to measure fusion data for the studied systems in order to have an experimental comparison between the two procedures for obtaining representations of the barrier distributions.

Acknowledgement

Some of us (J.E.T., D.E.D.G., A.J.P. and M.R.S.) acknowledge the financial support of the Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina.

Note

a. Permanent address: Laboratorio Tandar, Departamento de Física, Comisión Nacional de Energía Atómica, Av. del Libertador 8250, 1429 Buenos Aires, Argentina; E-mail: capurro@tandar.cnea.gov.ar

References

1. H. Timmers, J.R. Leigh, M. Dasgupta, D.H. Hinde, R.C. Lemmon, J.C. Mein, C.R. Morton, J.O. Newton and N. Rowley, *Nuc. Phys.* **A584** (1995) 190.
2. N. Rowley, G.R. Satchler and P.H. Stelson, *Phys. Lett.* **B254** (1991) 21.