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FUSION AND ELASTIC SCATTERING

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ABSTRACT

Excitation functions for the fusion of ^{16}O with $^{64,65}Zn$ in the energy range of 0.8-1.7 times the coulomb barrier were measured. Reduced fusion excitation functions, scaled to remove the geometrical effects show an isotopic effect in the excitation functions for sub-barrier energies. Furthermore, angular distributions for the elastic scattering were measured for the ^{16}O + $^{64,68}Zn$ systems in the energy range of 43 MeV to 56 MeV. An anomalous back-angle elastic scattering was observed for the ^{16}O + ^{64}Zn system for energies around the coulomb barrier.

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Experimental set-up and procedure

The ^{16}O beam was obtained from the 8UD Pelletron accelerator of the São Paulo University. Thick targets ($\approx 800 \mu g/cm^2$) of $^{64,66}Zn$ for the fusion cross section determination were made rolling some pellets of Zn isotopically enriched (99,4% and 98,6% respectively). Thin targets ($\approx 70 \mu g/cm^2$) of $^{64,68}Zn$ for the elastic scattering measurements were made evaporating the Zn isotopes (99,3% enriched for ^{68}Zn), on a $5 \mu g/cm^2$ carbon backing.

The fusion cross sections were obtained from the gamma rays of the compound nucleus (CN) evaporation residues detected with a $88.8 cm^3$, Ge(HP) detector. For each energy, on line spectra were measured with the detector at 55° and 90°. Further, several off-line decay spectra were taken after each irradiation. The Zn targets were placed on a thick Ta backing. The unambiguous identification of each evaporation residue was made from the available $70 \leq A \leq 82$ spectroscopic information[1] and the decay characteristics, when possible.

The elastic scattering measurements were performed with an array of four surface barrier Si detectors and two additional Si detectors placed at ±25° to the beam for monitoring the beam intensity. A maximum angular uncertainty of $\Delta\theta_{LAB} \approx \pm 0.3$ has been estimated. The angular distributions were taken between $\theta_{LAB} \approx 20°$ and $\theta_{LAB} \approx 170°$.

Analysis - Fusion excitation functions for the $^{16}O + ^{64,66}Zn$ systems were measured from ≈0.8 to ≈1.7 times the coulomb barrier. The analysis of data have shown a strong enhancement[2] of the sub-barrier fusion cross sections compared to the predictions of a one dimensional barrier penetration model (BPM) using a nuclear potential based on a liquid drop model such as proximity[3] and Krappe-Nix-Sierk potential[4].

Figure (1) shows the reduced fusion excitation functions for the systems (scaled to remove the geometrical effects), where the characteristic parameters as barrier height, radius and curvatures (Table 1), were obtained from a fit of the excitation functions for values of $\sigma_{FUS} > 100mb$. For these values, the fusion cross sections have a linear dependence with $1/E_{CM}$.

This figure shows an interesting isotopic dependence of the cross sections for these systems: $\sigma_{FUS}^{66} > \sigma_{FUS}^{64}$ for sub-barrier energies. Such a behaviour has been observed in some systems[5] and they are completely absent in others[6].

A clear interpretation of this behaviour especially viewed as an influence of the nuclear structure in the fusion and spin distributions for energies around the coulomb barrier is not yet available.

Figure (2) shows a Q_{value} analysis of the most important transfer channels, that could have some influence on fusion, showing two positive Q_{value} channels but with a value far from optimum Q_{value} in the energy range studied. An a priori identification of one or more transfer channels which can be coupled to fusion channel for these systems with consequent principal responsibility for the sub-coulomb fusion enhancement is not obvious.

Another interesting feature of the ^{16}O + ^{64}Zn fusion data analysis, taken with the time-of-flight technique[2], is the presence of fission-like products with mass around one-half of compound nucleus, A_{CN} = 80, and for energies around 15% above the coulomb barrier. Figure (3) shows a biparametric (Energy-time), spectrum taken with the detector placed at 5° and at 64 MeV of ^{16}O. This figure shows the mass projection and calibration of this spectrum. These products can be due to a lower fission barrier than predicted from the liquid drop model[7]. This decay channel of CN can be very relevant, specially due to the existence of a large deformation valley in the A = 80 mass region (as has been shown for $^{77-80}Sr$ by C.J. Lister and collaborators[8]). Thus for most of evaporation residues there will exist a delicate balance in N, Z that could permit rapid fluctuations of the nuclear shapes and deformations with the proton and/or neutron number. We are studying now these fission like residues.

Finally, figure (4) shows the elastic scattering angular distributions for the ^{16}O + ^{64}Zn system and for the coulomb barrier. As can be seen, there is an enhancement of the backward angle elastic cross sections for energies closer to the coulomb barrier: such an enhancement has been found for the ^{16}O + ^{63}Cu collision[9] and is yet to find a satisfactory theoretical explanation and its possible connection with reactions channels. Figure (5) shows the data obtained for the ^{16}O + ^{68}Zn system. The solid lines represent the best global fit obtained with the optical model using the PTOLEMY code[10] and with fixed geometry. We are making a careful study of these effects for other target-projectile combinations to obtain the spin and structure influence on this "anomalous" behaviour.

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Table 1. Barrier parameters extracted from the data and from de proximity potential (PRT)

System	Vb(MeV)	Rb(fm)	$\hbar$(MeV)
$^{16}O + ^{64}Zn$	32.7 ± 3.1	10.3 ± 0.3	3.48 ± 0.21
PRT	32.02	9.98	3.93
$^{16}O + ^{66}Zn$	34.5 ± 3.0	9.6 ± 0.3	4.15 ± 0.33
PRT	33.42	9.53	3.89

Figure Captions:

Figure 1. Reduced fusion excitation functions for the $^{16}O + ^{64,66}Zn$ (scaled to remove the geometrical effects) the solid lines are visual guides.

Figure 2. This is a diagram showing the resumed Q_{value} analysis for the most important transfer channels. (The sign +(-) indicate pick-up (stripping) transfer reaction).

Figure 3. Time-of-flight biparametric (Energy-time) spectrum and mass projection for the $^{16}O + ^{64}Zn$ reaction, at 64 MeV and the detector placed at 5°, showing the fission-like residues.

Figure 4. Elastic scattering angular distribution for $^{16}O + ^{64}Zn$ systems. The solid line represent the best globar fit obtained from the optical model analysis.

Figure 5. Ídem of figure 4 but for the $^{16}O + ^{68}Zn$ system.

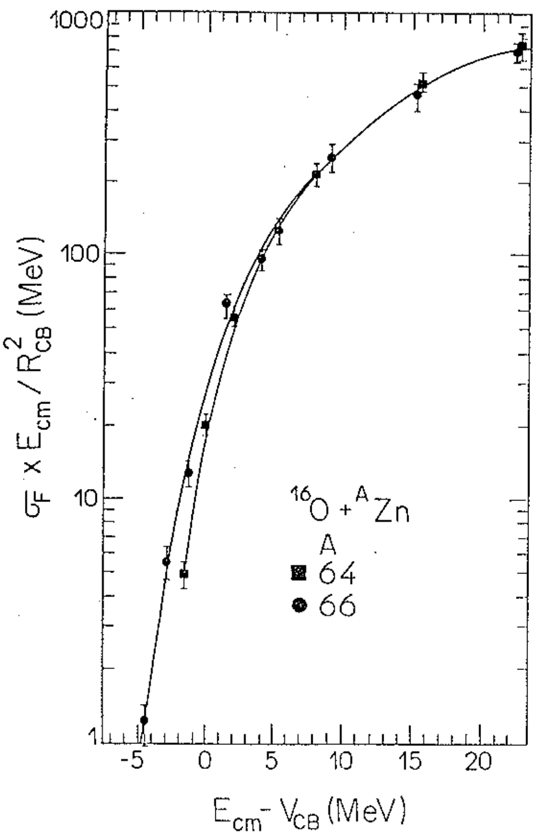

Fig. 1

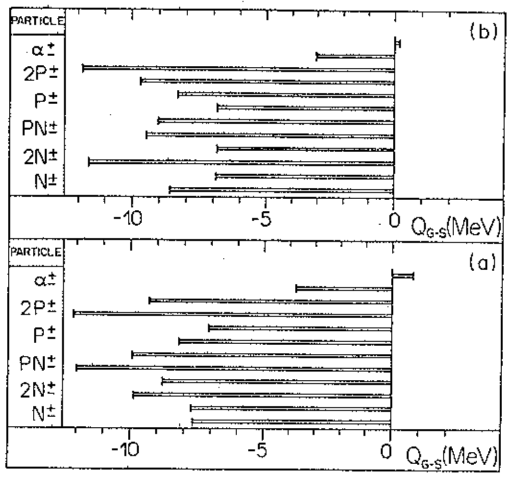

Fig. 2

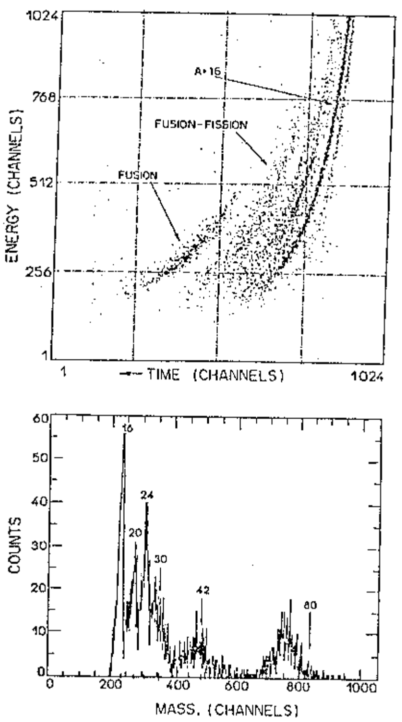

Fig. 3

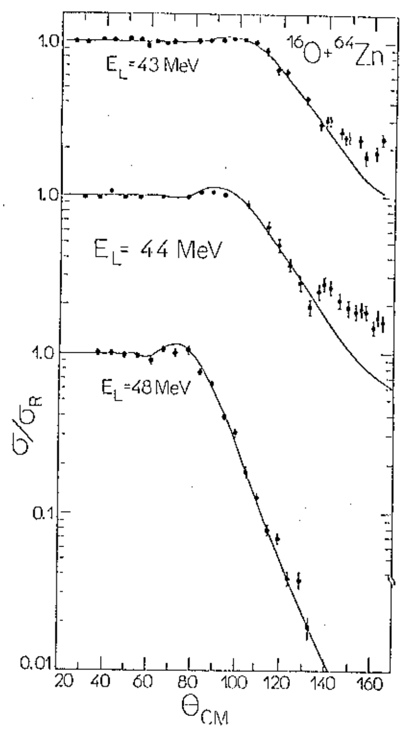

Fig. 4

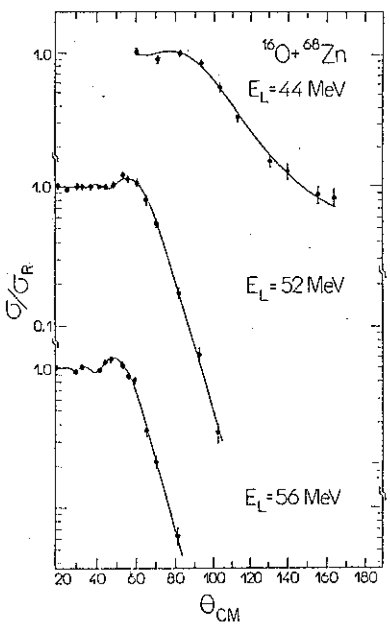

Fig. 5