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CHARGED PARTICLES AS PROBES TO STUDY ENTRANCE CHANNEL EFFECTS IN THE COMPOSITE SYSTEM ^{164}Yb[1]

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ABSTRACT

We present preliminary results in a study of entrance channel effects by comparing measured charged particles and γ-ray multiplicities in coincidence with residue nuclei (identified by discrete transitions), from both mass symmetric and asymmetric reactions. The systems studied are ^{64}Ni + ^{100}Mo and ^{16}O + ^{148}Sm , both of which would produce the ^{164}Yb compound nucleus with 52 MeV of excitation energy. In the (α2n) exit channel, the center of mass α-particle angular distribution is symmetric around 90° in the Ni-induced reaction, indicating emission from a fully equilibrated system. Furthemore, the extracted anisotropies show no evidence for an enhancement of α-particle emission in the low energy region, which indicates emission from a nearly spherical system. However, the corresponding angular distribution of the ^{16}O-induced reaction shows a strong forward component, which is a clear signature of a non-statistical contribution to the residue cross-section. This non-statistical component has to be taken into account when comparing decay modes of a compound nucleus formed in different entrance channels.

1. Introduction

The experimental observation[1-7] that the decay modes of excited compound nuclei appear to depend on their mode of formation is one of the most unexpected findings of heavy ion fusion reactions near the Coulomb barrier. Entrance channel effects were observed[1-3] by comparing ratios of xn and/or αxn evaporation cross sections as a function of the compound nucleus spin distribution, formed in different HI reactions. Specifically, large differences were observed in the exit-channel cross sections at high spin. In additional experiments, large differences were also found in

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in the region of the GDR for compound nuclei formed in symmetric and asymmetric entrance channels.

Trapping in a superdeformed minimum for the mass symmetric entrance channel was proposed[1,2,8] as an explanation for these observed effects. If this is correct, one would expect an enhanced emission of low energy α-particles for this entrance channel. However, this is contrary to the observation[3] of a larger α-particle emission cross section, in the ^{164}Yb$\longrightarrow$^{158}Er(α2n) evaporation channel at $E^* = 49$ MeV, for the ^{16}O + ^{148}Sm case, when compared to that from the ^{64}Ni + ^{100}Mo reaction. It can also be argued that an incomplete fusion contribution might be responsible for the larger α-particle cross section observed in the ^{16}O induced reaction. Clearly, a satisfactory understanding of these effects is still lacking, and the full understanding of the origin of these entrance channel effects needs more theoretical and experimental work.

In order to shed some light on this subject, we have studied the charged particles emitted in coincidence with the identified residual nucleus (corresponding to the α2n channel) formed in the ^{64}Ni + ^{100}Mo and ^{16}O + ^{148}Sm reactions. γ-ray multiplicities were also obtained for each of the residue channels, for both reactions. The shapes of the charged particle spectra, and their angular distributions, should be a sensitive probe for the entrance channel effects observed in this system.

2. Reactions and Experimental Setup

The experiment was performed at the HHIRF of the Oak Ridge National Laboratory. Isotopically enriched ^{100}Mo($\approx$ 306 μg/cm^2) and ^{148}Sm($\approx$ 968 μg/cm^2) targets were bombarded with ^{64}Ni (E_{lab} = 242 MeV) and ^{16}O (E_{lab} = 87 MeV) projectiles, respectively. Light charged particles were detected and identified with the Dwarf Ball, a CsI(Tl) scintillator array[9], which consists of 64 detectors in a nearly 4π geometry, covering laboratory angles from 24.4° to 155.6° in 14 rings of different θ_{lab}. Energy calibrations for protons were performed by ^{12}C(p,p) and ^{12}C(p,p$'$) reactions. For α-particles, the energy calibration was obtained from the proton energy calibration using an empirical relationship given in Ref.[9], corrected at low energies by α-source calibrations. In order to stop elastically scattered projectiles, appropriate sets of absorbers were used in these experiments. This resulted in maximum thresholds (at the forward angles) of 8 MeV for alphas and 2 MeV for protons, in the ^{64}Ni induced reaction, and 10 MeV and 3 MeV, respectively, for the ^{16}O beam. At backward angles, the thresholds are 2 MeV for alphas and 1 MeV for protons, for both systems. Residue nuclei were identified by discrete transitions, detected in a array of 18 Compton-suppressed Ge detectors inserted in the Oak Ridge Spin Spectrometer array. The γ-ray multiplicity was measured by 54 NaI(Tl) detectors of the Spin Spectrometer. Good separation between γ-rays and neutrons was achieved by time-of-flight techniques, using the average "t_0" procedure discussed in Ref.[10,11]. Energy calibrations and efficiencies were obtained by using standard procedures with calibrated γ-ray sources.

3. Results

Energy spectra for the ^{158}Er(α2n) exit channel are shown in figure 1 for both Ni and O reactions, at three selected angles. These spectra were obtained by summing the individual spectra for all detectors in the same ring. For both reactions, α particle center of mass energies were measured from below the exit channel Coulomb barrier, which is around 19 MeV, up to 30 MeV.

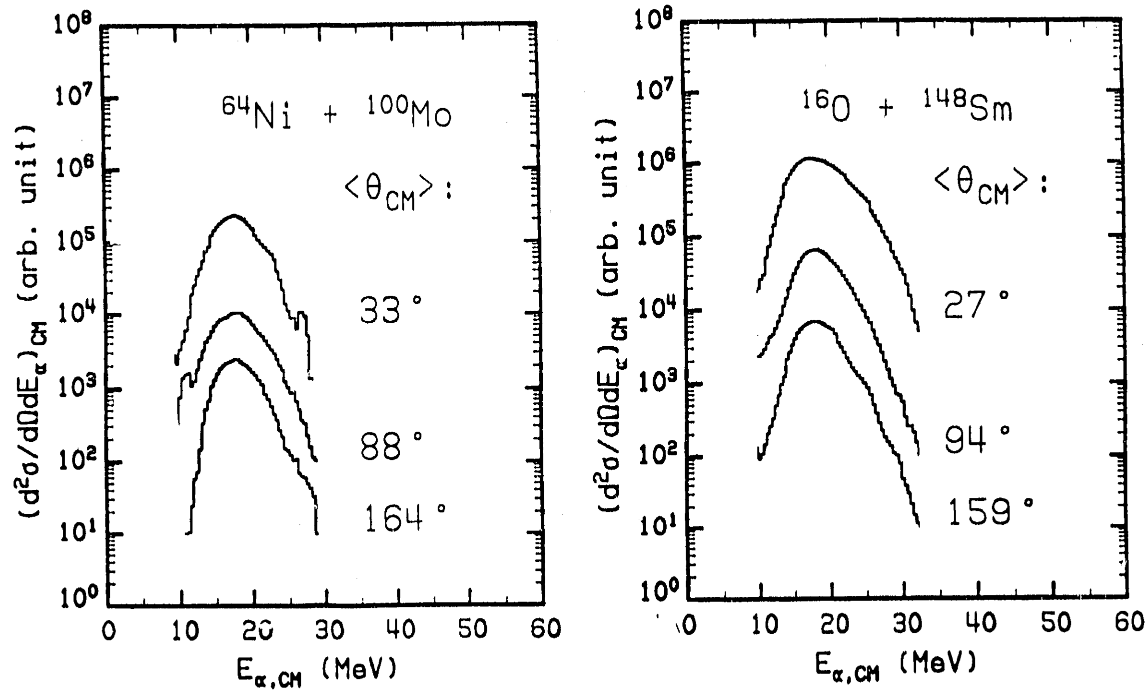

Fig. 1: Alpha particle double differential cross sections $(d^2\sigma/d\Omega dE_\alpha)_{CM}$ for the (α2n) exit channel as a function of $E_{\alpha,CM}$, at the indicated CM angles, for ^{64}Ni + ^{100}Mo and for ^{16}O + ^{148}Sm.

Figure 2 shows the center of mass angular distributions, obtained by integrating in energy the spectra displayed in figure 1, for both reactions. In the ^{64}Ni + ^{100}Mo system, the angular distribution shows a pattern that is symmetric around θ_{CM}=90° which characterizes emission from a fully equilibrated compound nucleus. However, for the ^{16}O + ^{148}Sm system, the angular distribution presents a rather different pattern, with an extra forward component. This indicates that non-statistical mechanisms are contributing to the ^{158}Er(α2n) exit channel cross section.

Needless to say, this invalidates direct comparison of cross sections as an indicator of entrance channel effects on *the decay* of compound nuclei.

The importance of these non-statistical α-particles in the O reaction can be better understood by plotting the angular distribution of the α-particles for different center of mass energy bins. This is shown in figure 3a. The forward contribution in the angular distribution is clearly associated with high energy α-particles. Furthermore, these high energy α-particles are associated with the lowest γ-ray multiplicities (Fig. 3b), consistent with the idea that an incomplete fusion mechanism produces these events. These results are consistent with the higher cross section observed[3] at low γ-ray multiplicity, for the ^{16}O + ^{148}Sm system, when compared to the ^{64}Ni + ^{100}Mo.

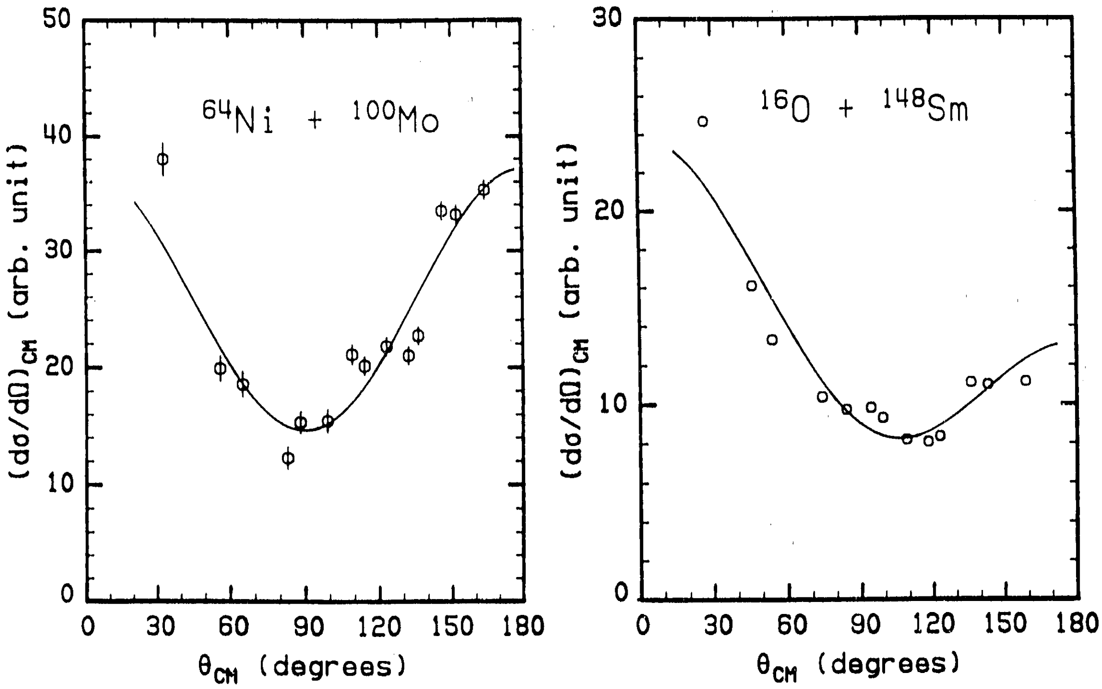

Fig. 2: Center of mass angular distributions of α-particles in the ^{158}Er(α2n) exit channel in the ^{64}Ni + ^{100}Mo and ^{16}O + ^{148}Sm reactions. The solid curves are least-squares fits to $A_0[1 + A_2P_2(\cos\theta_{CM})]$ and $A_0[1 + P_1(\cos\theta_{CM}) + P_2(\cos\theta_{CM})]$, respectively.

The formation of long lived superderformed configurations at high spin, in the symmetric mass system, has been suggested[1,2,5,7] as a possible explanation for the effects observed in these previous experiments. If this shape configuration exists in the ^{64}Ni + ^{100}Mo channel, an enhacement of the subbarier α-particle emission should be observed in this system, with the angular distribution showing a large anisotropy at subbarrier energies. Figure 4a shows α-particle angular distributions for the ^{158}Er(α2n) channel formed in the ^{64}Ni+ ^{100}Mo reaction, for 3 different α-particle center of mass low energy bins. These angular distributions were fit with a Legendre polynomial, and the A_2 coefficients are shown in figure 4b. The variation of the experimental anisotropy with the α-particle energy, in the subbarrier region, shows a pattern that is characteristic of emission from a spherical system. No evidence for large shape deformation is found for the ^{64}Ni+ ^{100}Mo system.

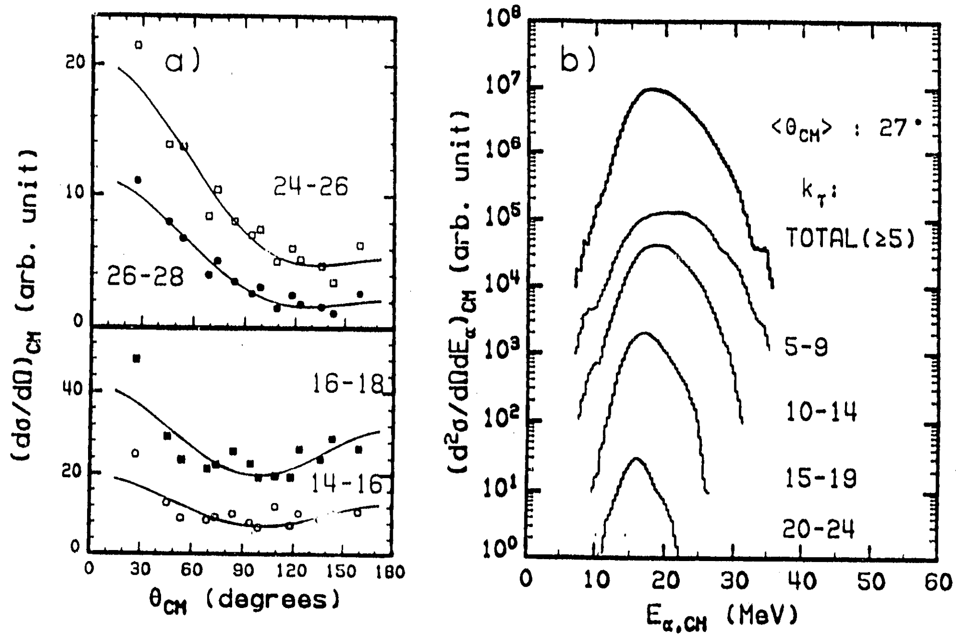

Fig. 3: a) Center of mass angular distributions of α-particles in the ^{158}Er(α2n) exit channel of the ^{16}O + ^{148}Sm reaction, gated at the indicated α-energy bins. See fig. 2 caption for the meaning of the solid lines. b) α-particle spectra measured in the most forward ring for the same reaction, and its decomposition using the indicated γ-ray coincidence gates.

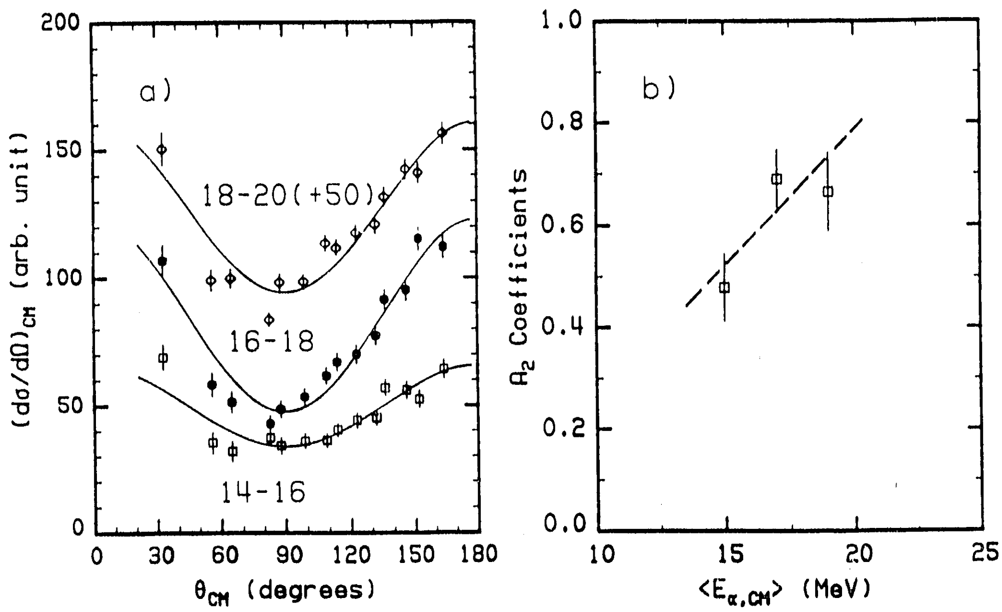

Fig. 4: a) Center of mass angular distributions for the ^{158}Er(α2n) exit channel in the case of the ^{64}Ni + ^{100}Mo reaction, gated by various α-particle subbarrier energy bins. See fig. 2 caption for the meaning of the solid lines. b) Extracted A_2 coefficients as a function of the corresponding average α-particle energy.

4. Conclusions

The study of entrance channel effects using light charged particles as probes in HI reactions seems to provide a powerful tool for investigating these effects, since it allows a clear experimental observation of a non-statistical mechanism present in some of these low energy HI reactions, for instance, in the $^{16}O + ^{148}Sm$ system. This non-statistical component, which gives rise to a different compound nucleus, must be taken into account if any comparison is to be made between systems in a effort to look for entrance channel effects in the *decay* of compound nuclei. Also, the variation of the anisotropy, below the exit channel Coulomb barrier, for the $^{64}Ni + ^{100}Mo$ system agrees with what is expected for α-particle evaporation from a spherical system. This rules out an important shape deformation[1,2,8] entrance channel effect.

Additional experiments have been done in the ^{160}Er compound nucleus, using the systems $^{64}Ni + ^{96}Zr$ and $^{16}O + ^{144}Nd$ as entrance channel reactions. These results should give further valuable information on this subject.

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