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NUCLEAR TEMPERATURES, BARRIERS AND LEVEL DENSITIES AT EXCITATION ENERGIES 400 MeV

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Résumé - La dépendance des températures, des barrières et des paramètres des densités de niveaux sur l'énergie d'excitation a été déterminée pour les noyaux de masse $A \approx 160$ en utilisant des mesures de coïncidence entre résidus lourds, particules légères et rayons gammas. L'accroissement de température entre 140 et 400 MeV est consistant avec un changement du paramètre de densité de niveaux de $a = A/8$ aux basses énergies jusqu'à $a = A/13$ pour les hautes énergies.

Abstract - From coincidence measurements between heavy residues, light particles, and γ-rays, the excitation energy dependence of the temperatures, barriers, and nuclear level density parameters for nuclei with $A \approx 160$ have been determined. The temperature increase with excitation energy in the range of 140 to 400 MeV is consistent with a nuclear level density parameter a which ranges from essentially $a = A/8$ at the lower excitation energies to $a = 1/13$ at the higher excitation energies.

I - INTRODUCTION

A widely used method for characterizing the composite system formed in intermediate energy nuclear reactions is the determination of linear momentum transfer /1,2/. We report here the results of experiments in which combined measurements of linear momentum transfer and angular momentum transfer, together with observations of the spectra of emitted α particles in the reactions of 19 and 35 MeV/u ^{14}N with ^{154}Sm, have been used to isolate and study the properties of nuclei with mass $\approx$ 160 a.m.u. at high excitation energy.

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II - EXPERIMENTAL METHOD

The experimental method consisted of measurements of the velocity distributions of heavy recoiling residues observed at 12° in coincidence with γ-rays and or light particles emitted in the backward direction. The residue velocities were determined using a time of flight telescope consisting of a micro-channel plate start detector (carbon foil of 20 μg/cm^2) and a Si stop detector (100 μm thickness). The γ-rays were detected in four to eight 7.5 cm by 7.5 cm cylindrical NaI detectors. Light particles were detected in back angle Si detector telescopes consisting of detectors of 15 μm backed by 1000 μm. The targets were self supporting ^{154}Sm foils 200 μg/cm^2 in thickness.

III - RESULTS

The measured residue velocity distributions, $(1/v^2/(d^2\sigma/dvd\Omega))$ observed at the two different bombarding energies are characterized by most probable velocities less than that resulting from total momentum transfer and a skewing towards the lower velocities (smaller momentum transfers). We have measured the spectra of coincident α-particles at laboratory angles of 135° to 145° relative to the detection angle of the residue. In Fig. 1 we present the spectra observed in coincidence with residues of selected velocities. These spectra have been transformed to the frame of the moving residue using the average velocity of the detected residue to effect this transformation. At the very backward angles, the spectra are well characterized by the function $(\varepsilon-B_c)\,e^{-(\varepsilon-B_c)/T}$ representing Maxwellian surface emission from a hot source where ε is the channel energy, B_c is the emission barrier, and T is the nuclear temperature. Examples of the fits of this function to the observed spectra are shown as the solid curves in the figure. The apparent temperature increases with increasing residue velocity. In contrast, the barrier remains essentially constant.

The additional yield of particles at lower energies suggests that either the simple sharp cut off in transmission coefficients implied by this function is inadequate or that the barrier varies somewhat extending to even lower energies than the derived barrier.

Increasing residue velocity implies increasing momentum transfer and increasing excitation energy of the composite system. Assuming that the missing momentum is carried away in the forward direction by particles or clusters having the beam velocity leads to simple relationships for the most probable fractional momentum transfer and excitation energy /3/

$$\rho = \frac{A_T}{A_P}\frac{v_R}{v_P - v_R} \quad \text{and} \quad E_X = E_P\,\frac{A_T}{A_P}\left(1 + \frac{A_T}{\rho\,A_P}\right)^{-1}$$

where A_P and A_T are the projectile and target masses, v_P and v_R are the projectile and residue velocities and E_P is the projectile energy.

Using these excitation energies together with the observed temperatures it is possible to derive the excitation energy dependence of a, the Fermi gas nuclear level density parameter appropriate to the expression $E_X = aT^2$. However, such a derivation implicitly assumes first chance emission of the α-particles. The apparent temperatures extracted from the experimental data are actually weighted sums of contributions coming from α-particles emitted at different stages of the de-excitation cascade. We measured the relative differential multiplicities, $dM_a/dE^*_{th}(E^*)$, for α-particles at different excitation energies and derived the initial temperatures from the experimental data using $dM_a/dE^*_{th}(E^*)$ as the weight function. The results from such an analysis are shown in Fig. 2 which is a plot of the temperature vs the square root of the excitation energy plus the temperature. The dependencies expected for A/8 and A/13 are also plotted. Included in this figure are some temperatures derived for nuclei of similar mass by determinations of the average energy of the

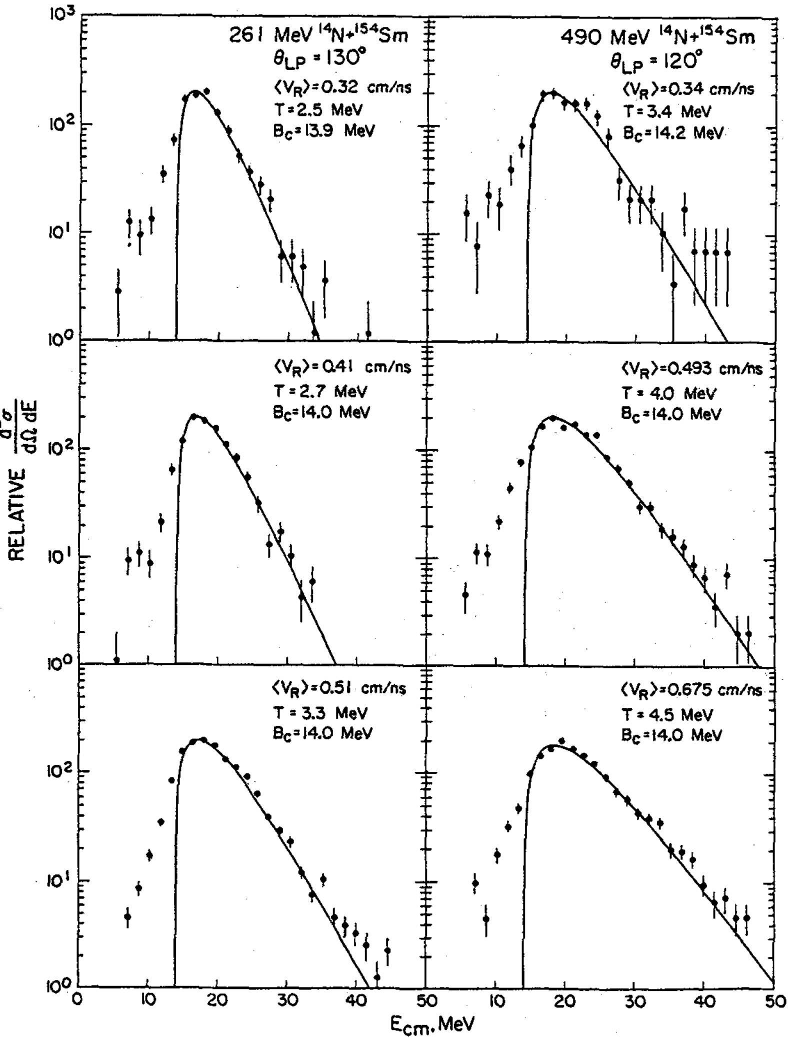

Fig. 1

first emitted neutron from residue angular distribution measurements /4/. From those data, the level density parameter determined is close to a = A/8 which agrees with our data for the lower excitation energies.

This decrease in a (or alternatively, the change from $E_X = aT^2$ to $E_X = aT^Y$ with $Y<2$) is similar to that predicted on the basis of the finiteness of the single particle space in the nucleus /5/.

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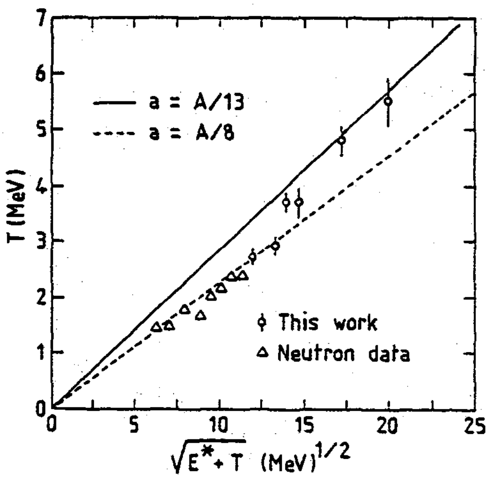

Fig. 2

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