PROPERTIES OF THE INTERMEDIATE MASS FRAGMENT EMISSION SOURCE IN THE 270 MeV ^{3}He + ^{232}Th REACTION

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Intermediate Mass Fragment (IMF) emission is considered to be the sign of decay of highly excited nuclear matter, mainly due to the fact that it appears at relatively high projectile energies. Measurable cross sections for IMF production appear at incident energies E/A = 20-30 MeV, for light ion projectiles[1,2] as well as for intermediate mass and heavy projectiles[3,4]. The fact that IMF yields are observed in reactions induced by light projectiles demonstrates, that target fragmentation is at least partially responsible for IMF yields in heavy ion induced reactions. Various models have been proposed to explain this phenomenon[5-8]. While it is frequently assumed in most calculations that the entire beam energy is available in the excited system at the moment of the IMF emission, inclusive studies of linear momentum transfer suggest that this may not be the case. The purpose of the experiment described here was to determine whether IMF emission occurs predominantly from events in which the full beam energy is available for decay.

To achieve this goal, coincidences between IMF ejectiles and two fission fragments in the 270 MeV ^{3}He + ^{232}Th reactions were measured. Angular correlations between fission fragments allow one to determine whether the observed IMF was accompanied by some other unobserved ejectiles emitted prior to or simultaneously with the IMF emission. In order to make such a determination, one calculates the "missing momentum" $\vec{p}_m$ defined as:

$$\vec{p}_m = \vec{p}_o - \vec{p}_{IMF} - \vec{p}_R$$

where $\vec{p}_o$ is incident momentum, $\vec{p}_{IMF}$ the momentum of the IMF, $\vec{p}_R$ the momentum of the recoiling target residue. If the missing momentum is different than zero, some non-equilibrium emissions must have occurred in addition to IMF emission. Since IMF ejectiles carry away momenta comparable to the beam momentum, the direction of the recoiling target will in general be different from the beam direction. One uses this fact to argue that the missing momentum direction may provide one with a "reaction clock", that will allow one to distinguish between non-equilibrium emission that occurs prior to or following IMF emission. Namely, if particle emission occurs prior to IMF emission, the beam axis should be the anisotropy axis and the missing momentum should point along the beam direction. If particle emission occurs after IMF emission, the relevant anisotropy axis is somewhere between the recoil direction and the direction opposite to the direction in which IMF was emitted; thus, the missing momentum should point somewhere between these two directions.

The experimental arrangement for these studies was designed to allow for identification of the average recoil direction and the magnitude of its velocity. Figure 1a shows the experimental setup. It consisted of two x-y position sensitive wire chambers and six

ΔE-E telescopes for IMF identification, positioned at three LAB angles, ±15°, ±75°, ±160°. Particle telescopes consisted of 3 surface barrier detectors each, with thicknesses 15-30μm for the first element, 300-2000μm for the second and 2000-5000μm for the third one, (serving mainly as a light particle veto). Figure 1b shows the principle behind the experimental method. The folding angle between two fission fragments (Θ_{AB}), the LAB velocity of the fissioning system v, and the angle between the recoil direction and axis of the fission array are related through some function:

$$v = f(\phi,\Theta_{AB}) \qquad (1)$$

Looking at identical energy gates in both telescopes constituting the pair, one looks at two kinematical situations that are mirror images of each other. Thus, the angles ϕ in both cases are related to each other in a known way. One measures folding angles in coincidence with both telescopes, determining the set of two equations

$$v = f(\phi_R+\Theta_{FA},\overset{I}{\Theta}_{AB})$$

$$v = f(\Theta_{FA}-\phi_R,\overset{II}{\Theta}_{AB}) \qquad (2)$$

where Θ_{FA} denotes the angle of fission array in the LAB. Φ_R is the recoil direction and $\overset{I}{\Theta}_{AB}$, $\overset{II}{\Theta}_{AB}$ are folding angles in coincidence with two telecopes detecting IMFs at the same angle.

Since only two quantities are unknown in the equation system (2), ϕ_R and v, one can calculate them on the basis of two folding angles. Figure 2 shows folding angles as a function of the ejectile Z value for all IMF emission angles. Open symbols indicate predictions of folding angle values for 2-body final state situation (IMF + target residue). Solid symbols indicate measured values of the folding angle. Figure 3 shows plots of missing momentum components as a function of the ejectile Z values for all three angles measured. Two energy gates are shown for the 15° IMF detection angle. As one can see, the missing momentum has consistently much larger component along the beam direction, ($P_{\parallel}$ component) than the one perpendicular to the beam direction ($P_{\perp}$ component). Consistency of the data for all angles, favors the interpretation that up to 25% of the beam momentum is emitted prior to or simultaneously with the intermediate mass fragment. The data presented above suggest that complicated excitations involving numerous nucleon-nucleon collisions are not a good probe of complete fusion events at the energy E/A = 90 MeV (and probably somewhat below this value). Therefore, in models that

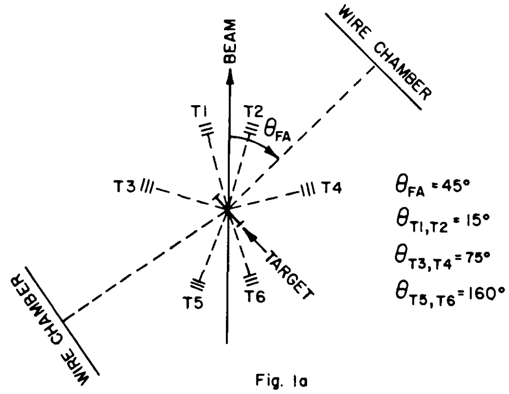

Fig. 1a

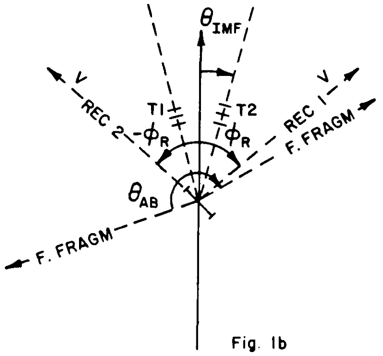

Fig. 1b

Figure 1a. Experimental arrangement.

Figure 1b. Principle of the experimental method.

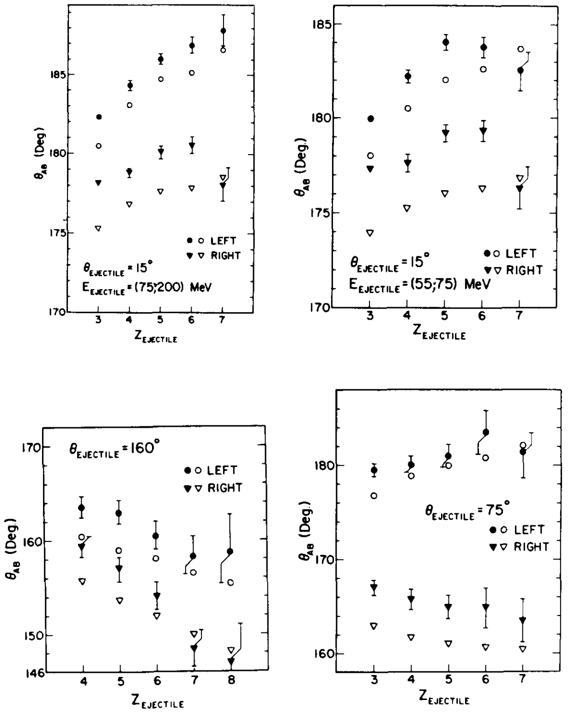

Figure 2. Folding angle as a function of the ejectile Z number. Solid symbols indicate measured values. Open symbols show folding angle expected in the case of the 2-body final state. Two energy gates are shown for the IMF emission angle 15°.

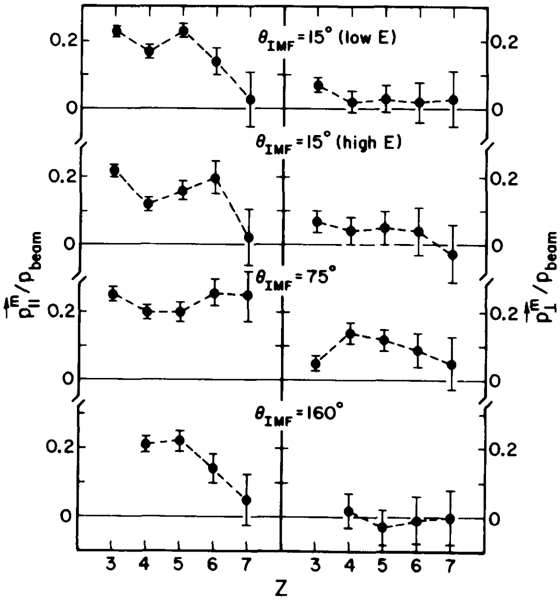

Figure 3. Missing momentum components for all three angles of IMF emission.

include only nucleon degrees of freedom, one should be very careful assuming that the entire beam energy is available in the reaction as an excitation energy, even in central collisions.

In order to determine whether the momentum transfer measurement was not biased by the fission trigger, the fission branching ratio was calculated. The fission branching ratio is defined as the ratio between the yield of coincidences normalized with the efficiency for fission fragment detection and inclusive yield of intermediate mass fragments. Figure 4 shows plots of the fission branching ratio for all three angles of IMF emission. At the 15° emission angle, the ratio is very close to 1.0 for all Z values. For 75° and 160°, one observes the dependence of the branching ratio on the ejectile Z value. The comparison between the measured fission branching ratios and calculations with the statistical model code (MBII-Ref. 9) strongly suggests that most of the IMF inclusive yields are seen in triple coincidences when the IMF is emitted at 15°. This result, in addition to the relatively small magnitude of missing momentum, suggests that the multiplicity of heavy fragments is very close to one. Emission of two heavy fragments with substantial cross section would decrease fission branching ratio dramatically.

The change in the dependence of branching ratio on the IMF atomic number when the IMF detection angle is increased, can be interpreted as a result of competition between fission and alternative modes of statistical decay of the excited target residue. The assumption must be made that the average charge and energy lost in the non-equilibrium phase of the reaction increases when the IMF emission angle increases. It, therefore, seems that large angle IMF emissions are associated with more central and violent

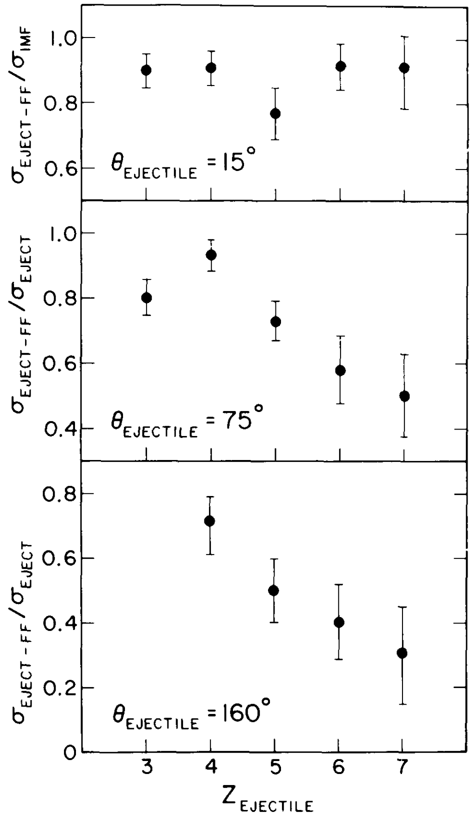

Figure 4. "Fission Branching Ratio" plotted as a function of the ejectile Z value for all three angles measured.

collisions, leading to the larger mass and energy loss before equilibrium is attained. On the other hand, IMF emission into small angles seems to be associated with more peripheral, less violent collisions that result in the very limited mass and energy loss (well reflected by the missing momentum value) in addition to the emitted IMF. It is very desirable to confirm this observation through IMF-light particle coincidences. It underlines important difference between the reaction mechanism producing IMFs emitted into forward hemisphere and IMFs emitted into more backward angles. IMFs detected in the backward hemisphere can possibly be used as a signature of the most violent central collisions. Light particles detected in coincidence with IMF can provide valuable information about the early stage of central collisions at intermediate energies.

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