Estimation of deformation from fragment energy spectrum

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It is well known that the intermediate mass fragments (IMF)/complex fragments emitted in low energy light heavy-ion reactions have different origins [1-5]. At low energy ($E_{lab} \leq 10$ MeV/A), the IMF are expected to be predominantly of compound nucleus origin. However, there may be contribution from other type of sources, viz., fusion-fission (FF), deep-inelastic (DI), etc. In Ref. [4] it was showed that the FF components come from the compound nucleus source while the DI components come from the intermediate velocity source. Again, in Ref [6] it was showed that a significant amount of proton yield was originated from pre-equilibrium emission. Phenomenological analyses of the experimental data also indicate the presence of a number of sources contributing to IMF emission [7,8].

In the present work, we have studied the fragments emitted in the reaction ^{20}Ne + ^{12}C at incident energy range 145 – 200 MeV. The ^{20}Ne ion beam from the Variable Energy Cyclotron at Kolkata was used for the experiment. The self-supporting target was ~ 550 μg/cm^2 ^{12}C. The emitted fragments ($3 \leq Z \leq 7$) have been measured using two ΔE-E Si telescopes (~10μm ΔE and ~300μm E) in a wide angular range 10°-50°.

The asymmetric binary fragmentation of the compound nucleus is considered as one of the dominant reaction mechanisms for the IMF emission in the low energy domain. According to this model, the emission of complex fragments may be thought of as a kind of fusion-fission process. In this scenario, the excited compound nucleus formed by the fusion of the two reactants undergoes dynamical deformation in the course of its time evolution. Subsequently it may enter into an exit channel configuration where the shape is deformed to look like a binary system connected by a small neck. With further deformation the neck ruptures, resulting in emission of two fragments. In this model there is no distinction between evaporation and fission. Therefore the formalism may be used for emission of all intermediate mass fragments from a compound nucleus.

The center-of-mass (c.m.) kinetic energy distribution of the binary fragments may be written as [1,9] $\boldsymbol{P(x)dx \sim exp(-x/T)}$
where $x = E_{c.m.}^{kin} - E_B$, and E_B is the Coulomb barrier in the exit channel. Since there are several experimental evidences that the exit channel is significantly deformed in the case of IMF emission, this exit channel deformation has to be properly incorporated in the calculation of E_B. The deformed barriers are calculated with the expression [10] $\boldsymbol{E_B = (Z_1Z_2e^2)/(a_1 + a_2 + d) + \Delta W}$
where Z_1, Z_2 and a_1, a_2 are the charges and semimajor axes of the two separating fragments where the fragments are taken to be prolate ellipsoids with their symmetry axes passing through the line joining the centers and d is the surface-to-surface separation distance at the conditional saddle point. The term ΔW is the higher order correction [10] to the barrier E_B.

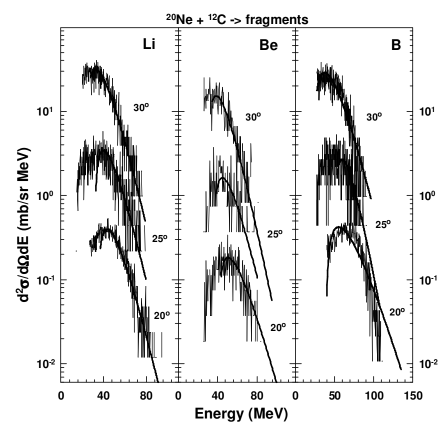

Fig. 1: Double differential cross-section for the fragments Li, Be, B emitted in the reaction ^{20}Ne (170 MeV) + ^{12}C plotted as a function of laboratory kinetic energy of the fragment. Solid curves show the results of the binary fragmentation model.

Assuming an isotropic angular distribution, the c.m. energy spectrum of the fragments can be transformed in the laboratory system using the following expressions [9]

$$\frac{d^2P(E_L,\Omega_L)}{dE_L d\Omega_L} = \frac{k^2\sqrt{E_L}}{4\pi T^2}\left(\frac{A_{CN}}{A_F E_{CN}}\right)^{3/2} \times \frac{G(E_L,\theta_L)}{[G(E_L,\theta_L)+E_B/k]^{1/2}} exp\left[-\frac{k}{T}G(E_L,\theta_L)\right]$$

with

$$G(E_L,\theta_L) = \left(\sqrt{\frac{A_{CN}E_L}{A_F E_{CN}}} - \cos\theta_L\right)^2 + \sin^2\theta_L - \frac{E_B}{k}$$

and $$k = \frac{E_{CN}A_F}{A_{CN}-A_F},$$ where A_F, E_L and θ_L are the mass number, energy and emission angle of the detected fragment in the laboratory, and E_{CN} is the laboratory kinetic energy of the compound nucleus.

The energy spectra of the fragments ($3 \leq Z \leq 7$) emitted in the ^{20}Ne + ^{12}C have been fitted using the binary fragmentation model. The predictions of the model have been shown in Figs. 1 and 2 for 170 MeV by solid curves.

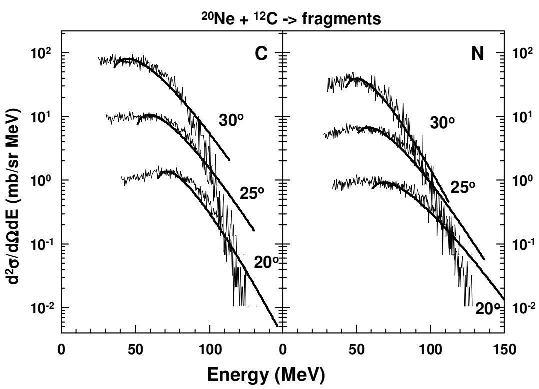

Fig. 2: Same as Fig. 1 for C and N fragments.

In this model it was assumed that the exit channel deformation is independent of the entrance channel. It has been found from Figs. 1 and 2 that the binary fragmentation model reproduces the shape of the energy spectra quite satisfactorily. This is indicative of the fact that the IMF emission is predominantly of compound nuclear origin and can be fairly well explained in terms of asymmetric binary splitting of a deformed compound system.

The Coulomb barrier has been extracted from these fittings for different exit channels. It was reported earlier that the composite systems formed in ^{20}Ne + ^{12}C reaction at 145 – 200 MeV have deformed shapes [6,11]. Here we use those reported parameters to calculate the deformed values of Coulomb barriers for different exit channels. The spherical Coulomb barriers have been calculated using r = 1.29 fm for all the exit channels.

Table 2: Different values of Coulomb barrier.

E_{lab} (MeV)		Fragment E_B (MeV) Li	Be	B	C	N
	Spherical	9.00	10.88	12.32	13.39	13.98
145	Deformed	5.954	7.199	8.151	8.856	9.247
	Extracted	5.78±0.33	6.99±0.42	8.33±0.18	8.96±0.45	9.37±0.67
158	Deformed	5.636	6.815	7.716	8.383	8.753
	Extracted	5.55±0.29	6.95±0.22	7.59±0.48	8.53±0.22	8.98±0.32
170	Deformed	5.477	6.621	7.497	8.146	8.506
	Extracted	5.43±0.22	6.69±0.21	7.67±0.32	8.21±0.18	8.63±0.32
180	Deformed	5.277	6.381	7.224	7.847	8.196
	Extracted	5.32±0.55	6.42±0.18	7.99±0.55	8.39±0.44	8.75±0.45
200	Deformed	5.183	6.267	7.096	7.709	8.051
	Extracted	4.99±0.32	6.21±0.23	7.37±0.35	7.84±0.35	8.23±0.45

The extracted values of Coulomb barrier have been compared with the spherical and deformed values in Table 1. Therefore the deformed configuration of the composite may be extracted from the emitted fragment spectra.

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