FAST FISSION COMPONENT IN FUSION REACTIONS WITH HEAVY IONS

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In previous papers (1), we have shown that some experimental observations suggested the existence of a very dissipative phenomenon, Fast Fission, intermediate between CN-formation (followed by de-excitation through fission) and Deep Inelastic Collisions :

1) the maximum ℓ-value contributing to fusion ℓ_{fus} (fusion cross section = compound evaporation residue cross section + symmetric fragmentation cross section) can be substantially larger than the ℓ-value at which the fission barrier vanishes, $\ell_{Bf=0}$.

2) the fission fragment mass distribution markedly broadens when $\ell_{fus} > \ell_{Bf=0}$ ($\ell_{Bf=0}$ = 86 for the CN ^{205}At).

This broadening, however, has been observed for very large ℓ-values (> 86). It could be attributed to a lowering of the mass asymmetry stiffness parameter at these high angular momenta, rather than to a different phenomenon occuring above $\ell_{Bf=0}$ (2). How can we experimentally determine which hypothesis is correct ? For a nucleus which as a very low intrinsic (i.e. for ℓ = 0) fission barrier, the value of $\ell_{Bf=0}$ is small. It is thus possible to get fusion events above $\ell_{Bf=0}$ which low ℓ-values. A broad mass distribution will support our previous conclusions ; a narrow one will support the other hypothesis.

For such a study, $^{278}110$ is a good candidate, since it has no liquid drop fission barrier. It was produced by ^{40}Ar ions on a ^{238}U target, for which we know that fusion occurs (3). The incident energy was 209 MeV, i.e. about 10 MeV above the interaction barrier, so that only small ℓ-waves contributed to fusion. The excitation energy was 45 MeV. The experimental set-up and data analysis allowed us to discriminate between binary events and sequential fission after quasi-elastic or deep inelastic reactions.

A schematic illustration of the binary events data shown by the two-dimensional plots of the center-of-mass kinetic energy versus the mass of one fragment (figure 1). At all angles, we observe the rounded triangle typical of fission events. The fully relaxed DIC events are mixing with the triangle edges, especially at angles close to the grazing angles, where DIC differential cross-sections reach their maximum value.

The mass distributions of these binary events exhibit a symmetric peak centered at the half-mass of the total system after substracting the tails of deep inelastic events around the grazing angles. Its FWHM is 95±6 u, much larger than the values (< 50 u) obtained by extrapolating as a function of A or Z^2/A, either the experimental data obtained for the fission of heavy compound nuclei at similar temperatures and angular momenta values, or the mass distribution widths calculated with the liquid drop model for nuclei having a fission barrier.

We conclude that a broad fission fragment mass distribution is not related to a large value of ℓ_{fus}. It is related to ℓ_{fus} being larger than $\ell_{Bf=0}$, in agreement with our previous interpretation than indeed a different process plays a role when fusion occurs at ℓ values larger than $\ell_{Bf=0}$.

For systems where the compound nucleus has a non-zero fission barrier at $\ell = 0$, FF events are never present alone, they are always mixed up with CN fission events. Now, we know that the FF component is symmetric and we can determine its mass distribution width. For that purpose, we choose the system with the largest set of data : ^{205}At formed by ^{40}Ar + ^{165}Ho (1). In order to calculate the contributions to the fusion cross section and the mass distribution widths of the two components (CN + FF) we take into account an increase of the CN-fission FWHM proportionnal to $E^{*1/4}$, we assume a sharp transition from CN to FF at $_{Bf=0}$ = 86, and we use the following relation :

$$\mathrm{FWHM}^2_{\mathrm{meas.}} = \frac{\sigma_{CN}}{\sigma_{Fusion}} \mathrm{FWHM}^2_{\mathrm{CN-fission}} + \frac{\sigma_{FF}}{\sigma_{Fusion}} \mathrm{FWHM}^2_{FF}$$

Results are presented in fig. 2. FWHM_{FF} increases only slightly with the incident energy. The increase is due to the increase in E* and possibly in ℓ_{fus}. Similarly, FWHM_{FF} for the system ^{237}Bk(^{40}Ar + ^{197}Au) lies in the range 80-90 u. A continuous increase of FWHM_{FF} with the total mass of the system is thus observed, providing a test for theoretical calculations (4).

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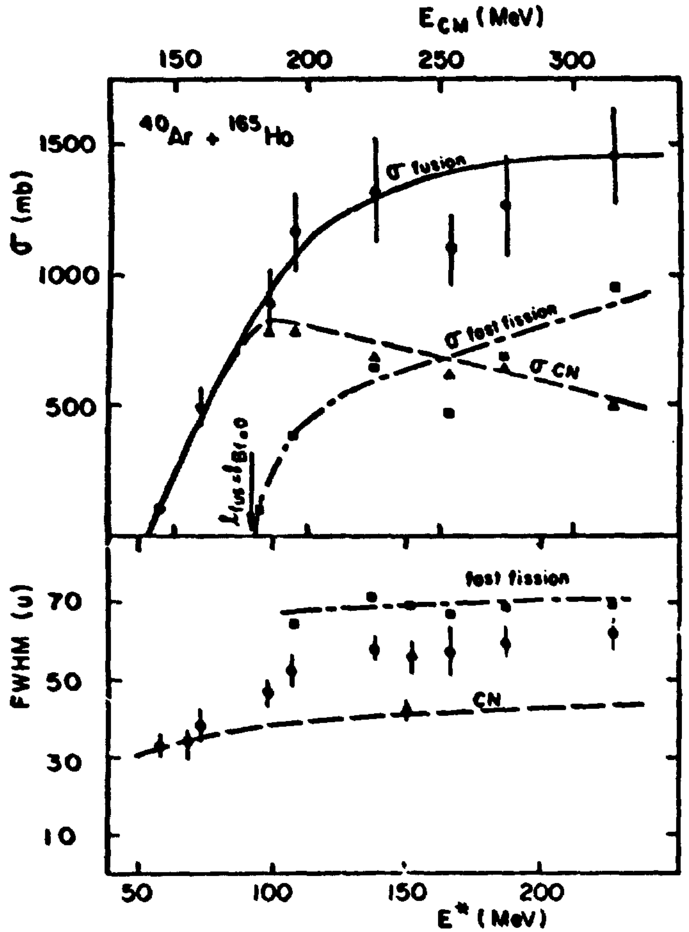

Figure 2 : Compound nucleus-fission and fast fission components in fusion-fission of the system $^{205}Ar(^{40}Ar + ^{165}Ho)$. Top : decomposition of the measured fusion cross section (full circles, full line drawn to guide the eye) into CN (triangles, dashed line) and FF (squares, dot-dashed line). Bottom : Widths of the fragment mass distributions. Measured for mixed CN + FF : full circles. CN fusion alone : measured values (full circles at low incident energies, and triangle obtained from Ne + Re data) and calculated curve (dashed line). FF component, obtained by relation 1 : squares and dot-dashed line. (There are more data points in the bottom part, since at 154 and 239 MeV c.m. only the mass distribution has been measured).

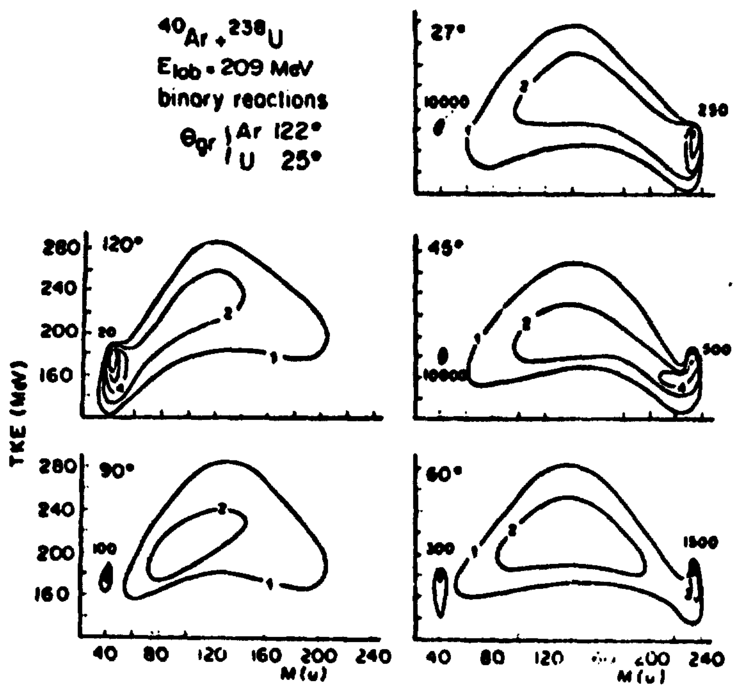

Figure 1 : Contour diagrams (relative levels) of the c.m. total kinetic energy versus the mass of the fragment detected at the indicated laboratory angles, for binary reactions induced by 209 MeV ^{40}Ar ions on ^{238}U.