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**Memo CP-D/626**

**Date:** 17 March 2010  
**To:** Distribution  
**From:** K. Hagino, K. Nishio, N. Otsuka  
**Subject:** New LEXFOR entry – Fusion  
**Reference:** Memo CP-E/110

Below is a new LEXFOR entry Fusion. This is an update of “Fusion, Fast Fission, and Deep Inelastic Scattering” in the current LEXFOR entry “Reaction mechanism”. The definition of “evaporation residue” proposed in Memo CP-E/110 is also included in this draft. New quantity code ,SIG,,ER is also proposed for an entry from India [1].

**Dictionary 236 (Quantities)**

, SIG , ER                      Evaporation residue production cross section

<b>Quantity</b>	<b>Reaction Type</b>	<b>Dimension</b>
, SIG , ER	CS	B

**Reference**

[1] S. K. Hui *et al.*, Phys. Rev. C62 (2000)054604 (EXFOR D6088)

**Fusion**

**Fusion**

For heavy ion reactions under suitable conditions, the incident projectile can overcome or tunnel the Coulomb barrier formed between projectile and target nuclei, and a composite system is formed. When nucleons which are contained in the interacting nuclei are fully equilibrated in the composite system with a time longer than those for the other reaction channel, the system reaches the condition called compound nucleus with a certain excitation energy, and thus the system does not have any memory in the entrance channel, it results in a compound nucleus in an excited state. This result is called fusion.

**Evaporation residue production**

A compound nucleus produced in the fusion reaction has two major de-excitation modes, fission and particle evaporation. The final product of the de-excitation process in which the nucleus undergoes the emission of one or several light particles (e.g. neutron, proton, alpha,  $\gamma$ - and X-rays) without interruption by fission is defined as evaporation residue.

Evaporation residues are clearly separated from the elastic-like products on the  $E - \Delta E$  plot. Recoil mass separators are used especially when the cross-sections are small due to the competition against fission in order to make a clear separation from the projectile- and target-like nuclei. Alternative methods to detect evaporation residues are measurement of their characteristic  $\gamma$ -, X-rays or  $\alpha$  decays.

**REACTION coding:** Process code FUS in SF3

**Example:**

<code>(...(8-0-16,FUS),,SIG)</code>	Fusion cross section
<code>(...(8-0-16,FUS),,SIG,,ER)</code>	Evaporation residue (production) cross section
<code>(...(8-0-16,FUS)0-NN-1,,SIG)</code>	Production cross section of neutron from evaporation of compound nucleus

**Quasi-fission**

The quasi-fission is defined as a process when the interacting two nuclei overcome or penetrate the Coulomb barrier and the system exchanges larger number of nucleons which is followed by disintegration into two fragments. The reaction time is far shorter than the decay time of a compound nucleus. In this case, the quasi-fission process is influenced by the entrance channel parameters such as mass asymmetry and bombarding energy between the colliding nuclei.

Do not mix up quasi-fission with fast fission which occurs when the Coulomb barrier disappears due to fast rotation of heavy systems (e.g. actinide beam) and the compound nucleus cannot be defined.

Because decomposition of fission into quasi-fission and fusion-fission is not straightforward, the yields for each fissions are not separated from the measured spectra, and therefore only the sum of both contributions is compiled with the process code F in REACTION SF3. (See **Fission**).

**Deep inelastic scattering (Not presently compiled)**

The case where the dinucleus system may or may not be formed, and a large part of the kinetic energy of the incident projectile is dumped into internal energy, but breaks apart after rotation, is called deep inelastic scattering.

**Quasi-elastic scattering (Not presently compiled)**

The case where the overlap of two nuclei is small and a few degrees of freedom are involved in the reaction is called quasi-elastic scattering. Quasi-elastic includes elastic scattering, inelastic scattering leading primarily to low excitation and nuclear transfer with small  $Q$ -value.

The reaction time decreases in the order of fusion, quasi-fission/deep inelastic scattering, quasi-elastic scattering, Coulomb excitation; although the boundaries

between these processes are not well defined. Especially, the boundary and order between quasi-fission and deep inelastic scattering is not very clear.

### **Sum rule**

The fusion cross section is the sum of fusion-fission cross section and evaporation residue cross section. The fission cross section is the sum of fusion-fission cross section plus quasi-fission cross section.

In Light system ( $Z_{\text{target}} + Z_{\text{projectile}} \leq 90$ ):

Fission cross section is negligible.

Intermediate system ( $90 \leq Z_{\text{target}} + Z_{\text{projectile}}$  and  $Z_{\text{target}} \cdot Z_{\text{projectile}} \leq 1600-1800$ ):

Quasi-fission cross section is small

Heavy system ( $Z_{\text{target}} \cdot Z_{\text{projectile}} \geq 1600-1800$ ):

The evaporation residue cross section is significantly small.

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