Fusion probability in heavy element formation

D.J. Hinde and M. Dasgupta

Department of Nuclear Physics, RSPhysSE, Australian National University, ACT 0200, Australia

The probability of nuclear fusion can be divided conceptually into two parts, the probability for capture of the two nuclei in the entrance-channel, and the probability of evolving from the capture configuration to the compact compound nucleus shape. If the system is captured, but does not form a compact compound nucleus, the reaction process is characterised as quasi-fission. The fusion cross-section can thus be written:

$$\sigma_{\mathrm{ER}} = \pi \lambda\!\!\!^{-2} \sum_{l=0}^{\infty} (2\ell + 1)\, T_\ell\, .(1 - \mathrm{P}^{\ell}_{\mathrm{QF}}), \tag{1}$$

where $\lambda\!\!\!^{-}$ is the reduced deBroglie wavelength, determined by the beam momentum, and $\mathrm{P}^{\ell}_{\mathrm{QF}}$ is the probability of quasi-fission. The capture probability T_ℓ for angular momentum ℓ is calculated in a coupled channels framework, in terms of the asymptotic properties of the individual colliding nuclei. Although this approach has successfully described the major features of capture cross sections, many open questions still remain.

The calculation of $\mathrm{P}^{\ell}_{\mathrm{QF}}$ requires modelling of the evolution of the combined system over the potential energy surface, and is in practice a difficult problem, although in principle it is simply a transport problem in a multi-dimensional space. To know whether a model calculation is successful, the experimental fusion cross section should be known. Unfortunately, it appears that the quasi-fission and fusion-fission events cannot be separated experimentally, so only the evaporation residues can be used as a signal of fusion. Then, the probability of fission from the compound nucleus should be known.

A framework is presented [1, 2] for the interpretation of evaporation residue cross sections, which in principle allows this limitation to be overcome, and the probabilities of quasi-fission to be determined experimentally. This has already shown that reactions previously assumed to fuse with unit probability, without the presence of quasi-fission, are in fact significantly inhibited by quasi-fission. This surprising result extends to reactions as mass-asymmetric as $^{19}\mathrm{F} + {}^{197}\mathrm{Au}$.

This framework is then applied to a wide range of existing and new experimental measurements, and the limitations of the approach, and the new insights which result from this approach are presented, including implications for the extra-push interpretation of measured evaporation residue cross-sections.

[1] A.C. Berriman et al., Nature **413** (2001) 144.

[2] D.J. Hinde, M. Dasgupta and A. Mukherjee, Phys. Rev. Lett. **89** (2002) 282701.