Study of shell effects in fusion fission dynamics

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Introduction

The discovery of nuclear fission in 1938 coincided with the seminal developments of theories of quantum mechanics in the 1930s. To explain the newly discovered phenomena theoretical work based on classical and quantum physics was invoked, and the best minds of the time worked in the problem. It was evident that in order to explain the asymmetric mass split, quantum shell effects play the key role in the dynamics governing fusion fission. Various theories were proposed to explain the data from numerous experimental results with light/heavy ion induced fission as well as spontaneous fission.

As physics progressed experimentally as well as theoretically, the periodic table got extended (currently stretching upto 118 elements), and human kind was introduced to super heavy elements (SHE), which are elements with proton numbers more than 104. Classically, elements with more than 104 protons should not exist as the fission barrier would have been zero, and the element would undergo spontaneous fission. However, it is again the quantal shell effects which stabilizes these elements and the SHEs are formed with unique properties.

For the formation of the SHEs, nuclear reactions using heavy ions are used. Two types of nuclear fusion reactions are used for the synthesis of SHEs: cold fusion and hot fusion. In cold fusion reactions doubly magic nucleus ^{208}Pb is used as a target along with the suitable choice of projectile, while in hot fusion reactions doubly magic projectile ^{48}Ca is used on actinide targets. The selection of magic nuclei i.e., the number of shell closures in the target projectile combination has been a subject of intense scrutiny, with multiple experiments being carried out at accelerator facilities all over the world. C. Siemenel, *et al.* [1] showed that for reactions involving heavy ions the competing quasi-fission process which hinders the formations of SHE, is comparatively lower for reactions involving magic target-projectile combinations. However, the change in the fusion fission dynamics due to the change in magicity in the target projectile combination is not clearly understood. In order to elucidate that, a set of experiments were carried out with target projectile combinations which would involve a change in magicity. However the relative contribution of quasi fission in the reactions is expected to be absent, as the chosen reactions had charge products $Z_P Z_T$ less than 800. The study was carried out on the actinide nucleus ^{224}Th, populated through three different channels, (i) ^{16}O+^{208}Pb , where both the target ^{208}Pb and projectile ^{16}O being dou-

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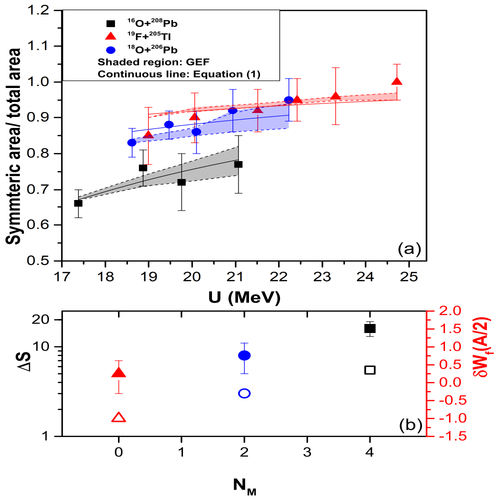

FIG. 1: (a) The ratio of the area under the symmetric to the total area of the mass distribution, as a function of excitation energy (see the text). The data has been fitted with Eqn (1) and using GEF code. (b) The calculated value of ΔS as a function of entrance channel magicity N_M (left axis). The variation of the shell correction at symmetry $\delta W_f(A/2)$ with the entrance channel magicity N_M has been shown in the right axis.

bly magic, (ii) ^{18}O+^{206}Pb , where both target projectile are proton shell closed, (iii) ^{19}F+^{205}Tl , where neither projectile nor target are shell closed. The experimental probe of fission fragment mass distributions, which is highly sensitive to the dynamics of the fusion fission process has been used in this extensive study.

Experimental details

The experiments with ^{16}O, ^{18}O and ^{19}F beams have been carried out at accelerator facilities at TIFR-BARC pelletron linac facility, Mumbai and IUAC pelletron facility, New Delhi on thin targets of Pb and Tl.The details of the setup is very similar to the experiment discussed in [2].

Result and discussion

The fission fragment mass distributions and the width of the distributions for one of the reactions (^{19}F+^{205}Tl) has been presented in [2]. It was found that for the reaction ^{16}O+^{208}Pb the width was higher than that of the other two reactions ^{18}O+^{206}Pb and ^{19}F+^{205}Tl . The presence of asymmetric components in similar systems were already shown in previous studies [3]. As this asymmetric component of the mass distribution arises from the shell effects in the dynamics of the fusion fission process, the ratio of the area under the symmetric component to the total area under the mass distribution curve was quantified as a function of excitation energy and shown in FIG. 1(a). The parametric equation was used to fit the data.

$$A_{Sym}/A_{Tot} = 1\text{-}(\Delta S/U)\exp(-\gamma U) \qquad (1)$$

Here, A_{Sym} is the area under the symmetric component and A_{Tot} is the total area. The functional form has been taken from Ignatyuk's prescription for shell damping of nuclear level density parameter (that influence the fission decay width) with excitation energy. The parametrization has been done with $U=E^*-B_f(l)$, where $B_f(l)$ is the fission barrier height, γ is the shell damping factor and was fixed at 0.064 MeV^{-1} . The parameter ΔS is related to the relative strength of the shell effects in the governing dynamics. ΔS is calculated from the fit and it is found that this relative strength parameter grows sharply (left axis plotted in logarithm scale in FIG. 1(b)) with entrance channel magicity. To relate this factor ΔS with a known shell parameter $\delta W_f(A/2)$ [4], a similar fit of the data (from the shaded region of FIG. 1(a)) has been obtained from GEF. A similar trend of the values in $\delta W_f(A/2)$ in FIG. 1 (b) (right y axis with hollow points) was seen with respect to the entrance channel magicity of the reaction. This further indicates the fact that there exist a correlation between the shell effects in the fusion fission dynamics with the entrance channel magicity of the nuclear reaction.

References

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