Strength of shell closures against excitation energy of a compound nucleus; The decay of ^{314}Ubh*

Dalip Singh Verma*
Department of Physics and Astronomical Science,
Central University of Himachal Pradesh, Dharamshala - 176215, INDIA

Introduction

In a recent work, "Investigation of the cold valley paths for the synthesis of isotopes of Ubh in optimum orientations" [1], the excitation functions for neutron evaporation have been compared for the hot and rotating compound nuclei formed in the reactions: ^{138}Ba+^{176}Yb and ^{68}Ni+^{246}Cf to obtain the optimum energy for the synthesis of isotopes of Ubh. On increasing the excitation energy of the fissioning system, the process of neutron evaporation (fusion-evaporation) competes with fission [2]. Fission of a compound nucleus can be understood by investigating the mass-distributions of the cross-section of fission fragments at various excitation energies, where the characteristic of mass-distribution, particularly the asymmetric one, is usually attributed to the effects of shell structure of the fissioning parent nucleus or final fission fragments [3]. So, it is interesting to explore the excitation energy correlation to the strength of shell closures.

In this work, the dynamical cluster-decay model has been used to analyse (i) the mass-distribution of fission fragments of the expected compound nucleus ^{314}Ubh in the reactions: ^{68}Ni+^{246}Cf and ^{138}Ba+^{176}Yb, at various arbitrary excitation energies (ii) the strength of shell closures of the fission fragments attributed to the peak I (around ^{138}Ba^{82}) and II (around $^{123}_{50}$Sn) against the excitation energy of compound nucleus. Projectiles of these reactions possess shell closures at Z=28 & N=82, respectively. The target of the first reaction is the heaviest possible so far.

Formalism

Dynamical cluster-decay model is based on the quantum mechanical fragmentation theory which is worked out in terms of the collective coordinate of mass (charge) asymmetry and (ii) relative separation R, characterizes, respectively, (i) the nucleon division (or exchange) between outgoing fragments and (ii) the transfer of kinetic energy of the incident channel (E$_{cm}$) to internal excitation (total excitation energy TXE or total kinetic energy TKE) of the outgoing channel. The compound nucleus excitation energy is related to its temperature T (MeV) as $E_{CN} = (A_{CN}/9)\,T^2 - T$ and the decay/fusion cross-section in terms of partial wave is

$$\sigma = \frac{\pi}{k^2}\sum_{l=0}^{\ell_{max}}(2\ell+1)P_0P;\; k=\sqrt{\frac{2\mu E_{cm}}{\hbar^2}} \quad (1)$$

where ℓ_{max} can be the critical angular momentum which is the function of incident channel energy and the internuclear separation at the scission point of compound nucleus or it may be $\ell_{DCM}^{B_f=0}$, an angular momentum at which the barrier against fission vanishes [4]. The preformation probability P$_0$ is the solution of the stationary Schrödinger wave equation in η-coordinate with potential calculated in hot and optimum orientations, where the deformation of the fragments have been taken up to β_2-order, of the fragments at scission point

$$P_0(A_i) = |\psi(\eta(A_i))|^2\sqrt{B_{\eta\eta}}\left(\frac{2}{A_{CN}}\right) \quad (2)$$

and the penetration probability in WKB approximation is

$$P = \exp\left[-\frac{2}{\hbar}\int_{R_a}^{R_b}\sqrt{2\mu(V(R)-Q_{eff})}dR\right] \quad (3)$$

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*Electronic address: `dsverma@cuhimachal.ac.in` where, R$_a$ and R$_b$ are the first and second turning points of the penetration path. Other details of the formalism can be seen at [1]. The fragment cross-section has been calculated by summing the partial wave cross-section up to $\ell_{DCM}^{B_f=0}$. Here, the maximum value angular momentum taken is $\ell_{DCM}^{B_f=0}$ instead of ℓ_c as it does not affect the structure of the distribution, it just adds to the magnitude of cross-section.

Calculations and Results

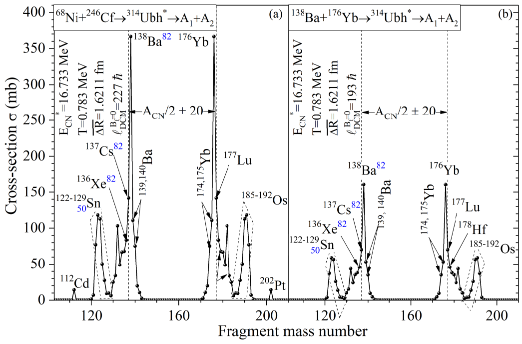

FIG. 1: Mass distribution of the cross-section of the fission fragments of the compound nucleus ^{314}Ubh* formed in (a) ^{68}Ni+^{246}Cf and (b) ^{138}Ba+^{176}Yb reactions.

Fig. 1 shows that the mass-distributions of cross-section for fission fragments have two peaks on either side of the symmetric mass division, i.e., peaks in the lighter mass region are around the fragment ^{138}Ba^{82} and ^{123}Sn. The respective peak seems to have been governed by the neutron and proton shell closures at N=82 and Z=50. It may be noted that the most probable channel ^{138}Ba+^{176}Yb lies just inside the symmetric mass region (A$_{CN}$±20). The fission fragment cross-section for the latter reaction is less than the former due to lesser number of partial waves. The mass asymmetry A$_L$/A$_H$=138/176 is the same for both reactions.

Fig. 2 shows the cross-section for most probable fission channels ^{138}Ba+^{176}Yb and ^{123}Sn+^{191}Os with respective shell closure at N=82 and Z=50 for the compound nucleus ^{314}Ubh formed in ^{68}Ni+^{246}Cf and ^{138}Ba+^{176}Yb reactions as a function of the compound nucleus temperature. It is clear from the figure that the cross-section for the channels with shell closure at N=82 decreases with the increase of the compound nucleus temperature while the channels with Z=50 first increases to a maximum value, at temperature ≈ 1.1 MeV, and then decreases with a rate close to the N=82 channels. The values of the fission fragment cross-section for the latter reaction is smaller than the former. The overall change of the cross-section with temperature for the outgoing channel with N=82 is more than Z=50. This means shell closure at Z=50 is stronger against excitation energy than at N=82 and plays a comparable role at higher excitation energy.

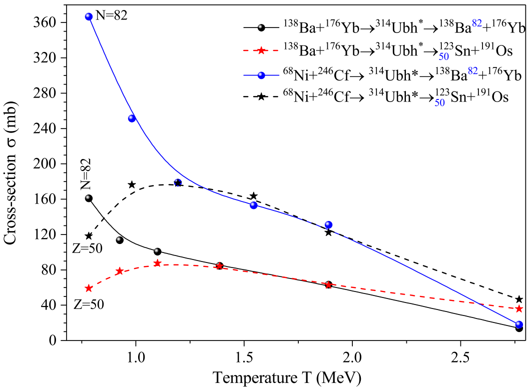

FIG. 2: Cross-section for the fission fragment combination at first and second peak of the mass distribution of the cross-section, shown in Fig. 1, as a function of temperature.

References

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