Study of probable target-projectile combinations for the synthesis of ^{304}120 using the Skyrme energy density formalism

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Introduction

Exploring the possibilities of synthesizing the super heavy elements is one of the most important problem in the modern nuclear physics. The nuclear structure properties play an important role in the synthesis of superheavy elements. Till now, elements up to $Z = 118$ has been synthesized through the hot and cold fusion reactions [1]. In cold fusion reactions, the magic shell target nuclei such as ^{208}Pb and ^{209}Bi are bombarded with projectile heavier than ^{48}Ca with an excitation energy of about 10-20 MeV for the formation of compound nucleus. On the contrary, in hot fusion reactions, ^{48}Ca projectile beam with actinide targets are used at higher excitation energy of about 30-40 MeV. After the successful experiments to synthesize elements up to $Z = 118$, the main aim is to extend the Periodic Table further in the superheavy mass region. The predicted extra stability in the superheavy mass region (island of stability), advocates the existence of proton shell closure Z = 120, 126 and neutron shell closure N = 184. In the present work, we have focused to study the isotope ^{304}120 due to the predicted doubly magicity at $Z = 120$ and $N = 184$. The main emphasis here is to explore the probable target-projectile combinations for the synthesis of ^{304}120 nucleus. In this work, the nuclear potential is extracted from the Skyrme energy density formalism [2] and capture cross-sections are calculated within the ℓ-summed Wong model[3].

Methodology

The nuclear interaction potential as a function function of separation R within the Skyrme energy density formalism is defined as

$$V_N(R) = E(R) - E(\infty) \qquad (1)$$

Here, $E = \int H(r)dr$ and H is the Skyrme Hamiltonian Density [2].
The nuclear potential along with Coulomb and centrifugal potential is further used to obtain the capture cross-section within the ℓ-summed Wong model [3]

$$\sigma_{E_{c.m.}} = \frac{\pi}{k^2} \sum_{\ell=0}^{\ell_{max}} (2\ell+1) P_\ell(E_{c.m.}) \qquad (2)$$

Here P is the penetration probability, calculated using the Hill-Wheeler approximation[3].

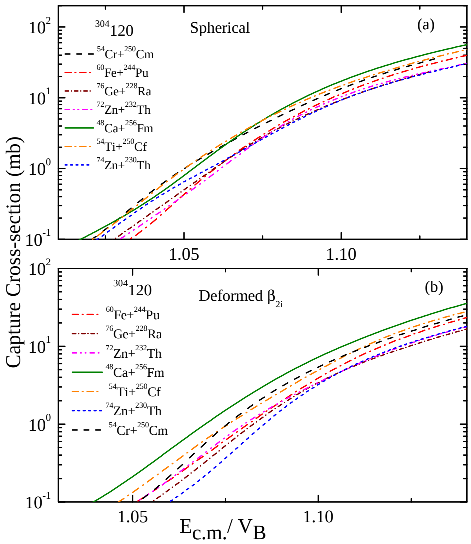

FIG. 1: The capture cross-section as a function of ratio of $E_{c.m.}$ and estimated fusion barrier V_B for the considered target-projectile combinations.

Results and Discussions

As mentioned above, we have investigated theoretically the possible target-projectile combinations for the synthesis of superheavy

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Table I

Projectile+Target	β_{21}	β_{22}	V_B (MeV) (Sph.)	(def.)	R_B (fm) (sph.)	(Def.)
^{54}Cr + ^{250}Cm	0.161	0.250	221.032	214.250	14.282	15.249
^{60}Fe + ^{244}Pu	0.185	0.237	233.176	225.880	14.363	15.324
^{72}Zn + ^{232}Th	0.011	0.205	255.269	250.044	14.503	15.141
^{76}Ge + ^{228}Ra	0.161	0.174	265.714	258.832	14.530	15.271
^{48}Ca + ^{256}Fm	0.000	0.240	192.401	187.841	14.241	15.038
^{54}Ti + ^{250}Cf	−0.011	0.250	206.175	201.301	14.334	15.138
^{74}Zn + ^{230}Th	0.139	0.195	254.759	247.995	14.532	15.305

TABLE I: The probable Target-Projectile combination (s) for the synthesis of ^{304}120, their respective quadrupole deformations, barrier height V_B, and position R_B obtained from Skyrme Energy Density Formalism [2] are tabulated.

element ^{304}120. The calculations are carried out in two phases: (i) The nuclear interaction potential is obtained using the semi-classical Skyrme energy density formalism considering the GSkI parameters [2]. (ii) The capture cross-sections as a function of centre of mass energy $E_{c.m.}$ are calculated using the ℓ-summed Wong model [3] We have considered seven most probable target-projectile combinations at comparable energy extracted from the quantum mechanical fragmentation theory (QMFT), viz. ^{54}Cr+^{250}Cm, ^{60}Fe+^{244}Pu, ^{76}Ge+^{228}Ra, ^{72}Zn+^{232}Th, ^{48}Ca+^{256}Fm, ^{54}Ti+^{250}Cf, ^{74}Zn+^{230}Th. We have calculated the interaction potential for these seven combinations for the spherical choice of colliding nuclei and then by including the effect of quadrupole deformations. The corresponding values of height V_B, and position R_B of fusion barrier at $T = 0$ MeV and $\ell = 0$ are listed in Table I. While comparing the results of spherical and deformed cases, it is observed that the barrier height for the deformed case shows a lower barrier than the spherical counter part. The highest barrier height V_B is observed for ^{76}Ge+^{228}Ra and the lowest for ^{48}Ca+^{256}Fm. Next, the capture cross-sections are calculated using the ℓ-summed Wong model [3]. Using the experimental capture cross-section for ^{64}Ni+^{238}U [5], the ℓ_{max} values are obtained from the sharp cut-off model. These value are interpolated using a polynomial fit in terms of $E_{c.m.}/V_B$ for ^{64}Ni+^{238}U system and this polynomial is further used to extract the ℓ_{max} values for the chosen target-projectile combinations. Fig. 1(a) shows the capture cross-sections for the considered seven P-T combination as a function of $E_{c.m.}/V_B$ for the spherical case. Among the considered combinations, ^{48}Ca+^{256}Fm is observed to give the highest cross-section at above the barrier energies followed by ^{54}Ti+^{250}Cf and ^{54}Cr+^{250}Cm reactions. However, the half-life of ^{256}Fm is 2.627 hour [4] and may be difficult to use as a target. Similarly, the half-life of ^{54}Ti is 1.5 sec and cannot be considered as a favourable projectile. Next, we have studied the effect of quadrupole deformations of the fusing nuclei on the capture cross-section for SHN ^{304}120. The capture cross-sections calculated including the quadrupole deformations are shown in Fig. 1(b). It is observed that inclusion of deformations enhances the capture cross-section, but the order of favorable target-projectile combinations remains unchanged. From the above analysis, it may be concluded that ^{54}Cr+^{250}Cm is the best possible target-projectile combination among the considered systems for the synthesis of ^{304}120 superheavy nucleus.

References

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