Formation of superheavy elements in astrophysical objects

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Formation of super-heavy elements (SHE) in the laboratory is one of the most challenging problems in Nuclear Physics. So far the synthesis of Z=118 element has been possible [1]. Efforts are on to synthesize still heavier elements in various laboratories all over the world. It is certain that if an element is created through human efforts then most probably it may be present naturally somewhere in the Universe. Thus the mode of formation of superheavy or super-superheavy element in astrophysical object is a fundamental question in the field of Nuclear Astrophysics. The study of unstable nuclei with radioactive ion beam (RIB) facilities has opened an exciting channel to look up to some of the crucial issues in the context of both nuclear structure and astrophysics.

In a recent study, Satpathy et al. [2] claimed the neutron-rich U and Th-isotopes are thermally fissile and could release orders of magnitude more energy than ^{235}U in a new mode of fission decay called multi-fragmentation fission, which probably happened frequently in astrophysical objects and could be cause of the termination of the rapid neutron capture process. The main objective of the present letter is to study the reaction (σ_r) and fusion (σ_f) cross-sections of neutron-rich U and some other interesting exotic isotopes. The theoretical formalism to calculate the nuclear reaction cross-section using Glauber model approach has been given by R. J. Glauber [3]. The standard Glauber form for the reaction cross-section at high energies is expressed [3] as:

$$\sigma_r = 2\pi \int_0^\infty b\,\left[1 - T(b)\,\right] db, \quad (1)$$

where T(b), the transparency function,. The detailed formalism is available in Ref. [4]. The fusion cross-section is given by the formula [5]:

$$\sigma_f(E) = \sum_J \sigma_J(E) = \frac{\pi}{k_0^2} \sum_J (2J+1) P_J(E) \quad (2)$$

with $P_J(E)$ is the inclusive penetrability and other symbols have the standard meaning as defined in [5].

Analysis of Figures 1 and 2 shows that, the magnitude of σ_r and σ_f is optimum at ~ 30 to 200 MeV of the incident projectile energy. Beyond this range, the value of σ_r and σ_f decreases drastically. Both the cross-sections indicate the suitability of the incident projectile energy for a favorable condition of the formation of the fused elements in the astrophysical system. Thus, the chance of the formation of heavier element is maximum, if a

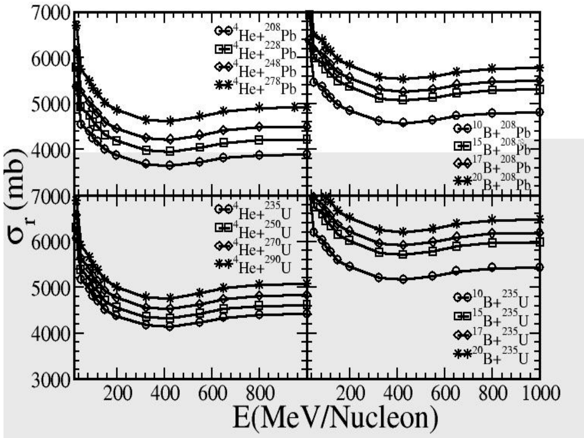

Figure 1 The nuclear reaction cross-sections taking He and B isotopes as projectile with different isotopes of Pb and U.

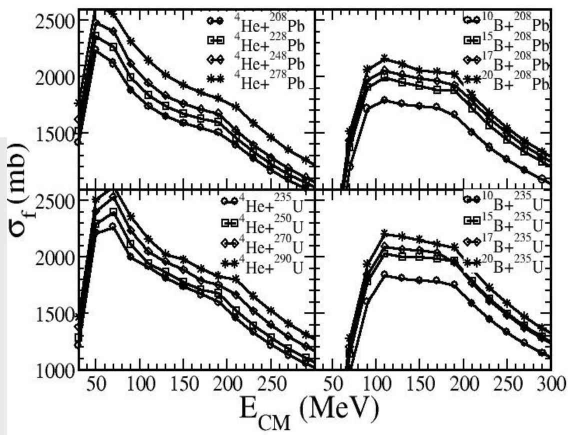

Figure 2 The nuclear fusion cross-sections taking He and B isotopes as projectile with different isotopes of Pb and U.

suitable energy range is created. A possible system for such case may be relativistic jets of Gamma Ray Burst (GRBs) or supernovae jets near the nascent neutron star [6, 7]. The high energy environment in such cosmological objects is because of the supernova shock [8] and it is quite common in the nascent neutron star or relativistic jets of GRBs [6, 7].

In summary, we estimated the reaction and fusion cross-section of various combinations of light and heavy isotopes. The enhanced cross-sections with increase of mass number for both the projectile and target made it possible for the formation of the heavier neutron-rich nuclei way beyond the normal drip lines predicted by the mass models. In the neutron or heavy ion (light neutron-rich nuclei) capture process, the daughter nucleus becomes a super-heavy element which may be available somewhere in the Universe in super-natural condition and can be possible to be synthesized in laboratories. Here the stability of the neutron-rich SHE or super-SHE against spontaneous fission arises due to widening of the fission barrier because of the excess number of neutrons.

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