Nuclear Reaction Studies of Stable and Unstable Nuclei

R. N. Panda*
School of Physics, Sambalpur University, Jyotivihar, Burla-768 019, India and
Department of Physics, ITER, Siksha O Anusandhan University, Bhubaneswar-751030, India

With the development of radioactive ion beams (RIBs) in various laboratories around the globe it could be possible to study about unstable nuclei. This has opened new channels in the context of both nuclear structure and nuclear astrophysics. Unstable nuclei play an influential role in many phenomena in the cosmos such as novae, supernovae, X-Ray and Gamma Rays Bursts (GRBs) and other stellar explosions. It is shown that in relativistic jets of GRBs or supernovae jets near the nascent neutron star, the formation of ultra neutron-rich and superheavy nuclei could be possible. The sources of the formation of these nuclei are the nuclear reactions and fusion phenomena in the cosmological objects. The study of various nuclear cross sections, such as, the total nuclear reaction cross sections (σ_r), differential elastic scattering cross sections ($\frac{d\sigma}{d\Omega}$), one nucleon removal cross sections (σ_{-1n}, σ_{-1p}) and Coulomb break-up cross sections enables us to know the nuclear structure of these unstable nuclei in detail, particularly the halo structure near the drip-lines. We are still far from the region with superheavy nuclei having lifetime of thousand years. Thus formation of superheavy elements (SHE) in the laboratory is one of the most challenging problem in Nuclear Physics.

In the present thesis, we have studied the nuclear reaction for both stable and unstable nuclei throughout the periodic table. We have applied the well known Glauber formalism [1] for various nuclear cross section calculations, such as, the total nuclear reaction cross sections (σ_r), differential elastic scattering cross sections ($\frac{d\sigma}{d\Omega}$), one nucleon removal cross sections (σ_{-1n}, σ_{-1p}) etc. For the evaluation of reaction parameters like σ_r, $\frac{d\sigma}{d\Omega}$, σ_{-1n} and σ_{-1p} through Glauber model [2], the nuclear structure input, like the densities of the target and projectile nuclei are required. Some reliable models like non-relativistic and relativistic mean field formalism are are used to get these inputs. To see the reliability of the model, we also calculated the bulk properties of such nuclei like binding energy (BE), root mean square charge radius r_{ch}, matter radius r_m and quadrupole deformation parameter β_2 for both light medium and heavy nuclei [3–5]. Study of these quantities enables to know the nuclear structure of unstable nuclei in detail, particularly the structure near the drip-lines. This also helps to study the formation of neutron-rich nuclei that are surrounded by a high pressure or temperature. During the calculations in non-relativistic model, the Skyrme interaction and for the relativistic one, the Relativistic Mean Field (RMF) theory developed by Green and Miller and later modified by Boguta and Bodmerma are used. The recently developed field theory motivated Relativistic Mean Field Effective Lagrangian approach (E-RMF) is also used at various places of the calculations. Several set of parameters like SKI4, SLy6, NL-SH, NL3, NL3*, G2 are used for this purpose. We have included Coupled Channel Formalism (CCF) for fusion cross section calculations [6].

We have studied the variation of σ_r with the incident energy of the projectile for various target and projectile nuclei. In most of the cases, the neutron-rich light mass nuclei are used as projectile and heavy nuclei as targets. In order to see the effect of the neutron-richness of the projectile in the exotic mass region, we repeated the calculations with various projectile masses without changing the target nucleus. We found that the total nuclear reaction cross section increases with in-

*Electronic address: rnpanda@iopb.res.in

crease of the projectile mass or with increase of neutron number of the target. Such a result is valid for both the normal and neutron-rich nuclei. Thus, our framework seems ideal for the simple analysis of the different ranges of data on total nuclear reaction cross sections of neutron-rich unstable nuclei. However, unlike the total nuclear reaction cross sections, the differential elastic scattering cross sections show marginal changes with the change of projectile mass. Specifically, we have calculated the total nuclear reaction cross section σ_r and the elastic differential scattering cross section $\frac{d\sigma}{d\Omega}$ for both the increasing projectile and target masses. In all cases, we find that σ_r increases with target mass. Analysing the elastic differential scattering cross section, however, we find that the magnitude of $\frac{d\sigma}{d\Omega}$ increases with scattering angle and it is more prominent at high incident energy per nucleon of the projectile nucleus. Similar to total nuclear reaction cross section, elastic differential cross section also shows greater sensitiveness with increase of mass number of the target [4].

Recently it has been reported by A. Marinov et al. that the evidence of a superheavy isotope with $Z = 122$ or 124 and a mass number A=292; has been found in natural Th using inductively coupled plasma-sector field mass spectrometry. The estimated half-life of this isotope is $t_{1/2} \geq 10^8$ years. Thus the application of the model to the recently discovered superheavy element Z=122 or 124 is interesting because of the possibility of the formation of the highly neutron-rich superheavy element in earth crust [6]. The reaction study of such superheavy system is done in the thesis work.The failure of Glauber model for halo systems and deformation effect for one neutron removal cross section is also explained [7]. 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. By the neutron or heavy ion (light neutron-rich nuclei) capture process the daughter nucleus becomes a superheavy element (SHE) 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 [6].

We have also studied the structural properties of the recently predicted thermally fissile neutron-rich $^{244-262}$Th and $^{246-264}$U nuclei in the frame-work of RMF model [8]. The results are compared with the finite range droplet model (FRDM) calculations and found remarkably closure with its predictions [8]. The obtained RMF densities are used to estimate the σ_r taking these fissile isotopes as target with ^{6,11}Li and ^{16,24}O as projectile. This results may be useful for experimentalists for the synthesis of neutron-rich thermally fissile Thorium and Uranium isotopes for the energy generation in future.

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