# Reaction dynamics of $^{90-136}$Zr projectile with carbon target using Glauber model

Mahesh K. Sharma[1],* R. N. Panda[2], Manoj K. Sharma[1], and S. K. Patra[3]
[1] School of Physics and Materials Science,
Thapar University, Patiala - 147001, India
[2] Department of Physics, ITER, Siksha O Anusandhan University, Bhubneswar-751 030, India and
[3] Institute of Physics, Sachivalaya marg Bhubneshwar-751 005, India

The investigation of structural properties of nuclei near and beyond the drip line is one of the major research interest of nuclear sciences community. Due to imbalance of the neutron to proton ratio towards the neutron drip line region, many exotic phenomenon have been observed in recent times. Neutron halo, Borromean structure [1, 2] of nuclei may be quoted as some possible examples. In present work our interest is to investigate the reaction cross section ($\sigma_R$) of $^{90-136}$Zr+$^{12}$C reaction in the frame work of Glauber formalism using densities from the well known relativistic mean field (RMF) model.

Figure 1 shows the behaviour of 2 neutron separation energy ($S_{2n}$) as a function of mass number (A). The value of $S_{2n}$ has been obtained using the separation between binding energy (B.E.)'s of two isotopes calculaed as:

$$S_{2n} = B.E.(Z, N) - B.E.(Z, N-2) \qquad (1)$$

The value of $S_{2n}$ decreases with increase in mass number for the considered set of isotopes of Zr. Where the negative values of $S_{2n}$ (-0.694 MeV) for $^{138}$Zr suggests, the non existence of the isotopes of $^{138}$Zr. So the neutron dripline may be fixed at 136 mass number for Zr.

For the reaction dynamics, we used well known Glauber approach [3]. The nuclear reaction cross section have been estimated as.

$$\sigma_R = 2\pi \int_0^{\infty} b[1 - T(b)]db, \qquad (2)$$

*Electronic address: maheshphy82@gmail.com

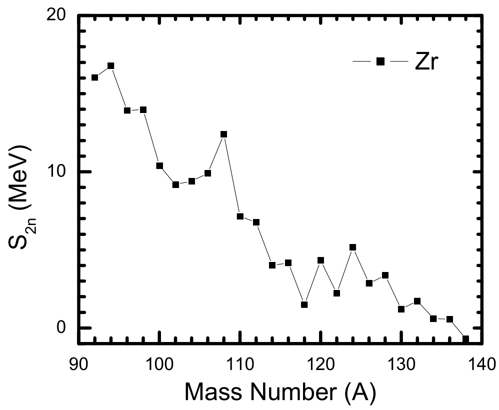


FIG. 1: The values of $S_{2n}$ in MeV as function of Mass number for isotopes of $^{90-138}$Zr.

where 'T(b)' is the transparency function with impact parameter 'b'. The main ingredient of the Glauber model is the densities of Projectile and target nuclei. The densities obtained from the axially deformed relativistic (RMF) with NL3* parameter set are used for estimation of reaction cross sections. The axially deformed density in term of z integrated density represented by:

$$\overline{\rho}(\omega) = \int_{-\infty}^{\infty} \rho(\sqrt{w^2 + z^2})dz, \qquad (3)$$

with $\omega^2 = x^2 + y^2$. It may be noted that the limitation of Glauber model, is referred to densities of projectile and target nuclei in terms of Gaussian coefficient calculated as.

$$\rho(r) = \sum_i^2 c_i \exp\left[-a_i r^2\right] \qquad (4)$$

The RMF densities of projectiles and target nuclei after fitting into gaussian in terms of their coefficients $c_i$ over the ranges $a_i$ are listed in Table I. The other important ingredient for

TABLE I: The Gaussian coefficients $c_i$'s and ranges $a_i$'s for the projectile and target for RMF(NL3*) densities.

| Nuclei | $c_1$ | $a_1$ | $c_2$ | $a_2$ |
|---|---|---|---|---|
| $^{12}$C | -1.14333 | 0.285974 | 1.47032 | 0.285598 |
| $^{90}$Zr | -1.93491 | 0.104764 | 2.01803 | 0.0912447 |
| $^{92}$Zr | -1.87213 | 0.102725 | 1.95953 | 0.0893431 |
| $^{94}$Zr | -1.82598 | 0.100502 | 1.91328 | 0.0872922 |
| $^{96}$Zr | -1.6857 | 0.0958992 | 1.76924 | 0.0829955 |
| $^{98}$Zr | -3.51062 | 0.0895011 | 3.59243 | 0.0835659 |
| $^{100}$Zr | -3.49969 | 0.0880882 | 3.58021 | 0.0822371 |
| $^{102}$Zr | -2.94498 | 0.0832801 | 3.02946 | 0.0773406 |
| $^{104}$Zr | -2.99652 | 0.083078 | 3.08182 | 0.0771525 |
| $^{106}$Zr | -1.48548 | 0.0867687 | 1.56787 | 0.0744713 |
| $^{108}$Zr | -1.8361 | 0.896362 | 1.91245 | 0.0779911 |
| $^{110}$Zr | -1.70335 | 0.0868453 | 1.78295 | 0.0752914 |
| $^{112}$Zr | -1.71589 | 0.0859533 | 1.79449 | 0.0745285 |
| $^{114}$Zr | -3.60381 | 0.0807617 | 3.68344 | 0.0755201 |
| $^{116}$Zr | -3.50281 | 0.079395 | 3.58313 | 0.0741661 |
| $^{118}$Zr | -2.68734 | 0.0725008 | 2.76871 | 0.0672239 |
| $^{120}$Zr | -2.53225 | 0.0703993 | 2.61244 | 0.0651472 |
| $^{122}$Zr | -2.60743 | 0.0702388 | 2.68885 | 0.0650754 |
| $^{124}$Zr | -1.39811 | 0.0757252 | 1.48496 | 0.0651232 |
| $^{126}$Zr | -1.43627 | 0.0731594 | 1.52184 | 0.0634588 |
| $^{128}$Zr | -1.45303 | 0.0724584 | 1.53614 | 0.0628575 |
| $^{130}$Zr | -2.02538 | 0.0888989 | 2.24996 | 0.0798319 |
| $^{132}$Zr | -1.95669 | 0.085172 | 2.16737 | 0.0765089 |
| $^{134}$Zr | -1.98589 | 0.085173 | 2.19976 | 0.0765081 |
| $^{136}$Zr | -1.91022 | 0.082706 | 2.10713 | 0.0739763 |

reaction cross sections are some energy and isospin dependent parameters such as $\sigma_{NN}$ in $(fm^2)$, $\alpha_{NN}$ and $\beta_{NN}$ in $(fm^2)$, which are estimated using from Ref. [4].

Figure 2 represents the charge radius ($r_c$) and reaction cross section ($\sigma_R$) obtained using the relativistic mean field densities for $^{90-136}$Zr isotopes. The upper panel of the figure shows the values of $r_c$ in $fm$ for various isotopes of Zr and lower panel of the figure consists the values of $\sigma_R$ in $mb$ for same set of isotopes at projectile energies ($E_P$) 30 MeV/A, 100 MeV/A and 1000 MeV/A as a function of mass number. It is clear from this figure that the $\sigma_R$ at energy 30

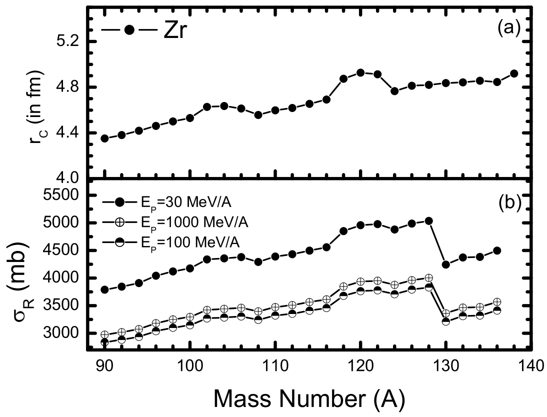


FIG. 2: (a) Show the variation of $r_c$ in $fm$ as a function of mass number and (b) Shows the values of $\sigma_R$ in $mb$ at energies 30MeV/A, 100 MeV/A and 1000 MeV/A as a function of mass number.

MeV/A is having higher magnitude than the 100 MeV/A. Where as the values of $\sigma_R$ at $E_P$=1000 MeV/A lie in between that of 30 MeV/A and 100 MeV/A. The comparison of figure 2(a) and 2(b) shows that the reaction cross sections increases almost linearly with changes radius.

In conclusion, the RMF based formalism suggest that $^{136}$Zr lies at drip line and reaction cross section find linear dependance on charge radius for $^{90-136}$Zr projectile considered in present study.

## References


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