# Oriented collision between $^{15}$B and $^{12}$C studied within Glauber model using microscopically calculated densities

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## Introduction

Recent advancements in accelerator technology and polarized beams have created opportunities to study oriented collisions of deformed targets. We extend the Glauber model to calculate the interaction cross section for a spherical projectile and a deformed target at different orientation angles of the target. It has been found that the observed reaction cross sections of various systems at high energies can be reproduced with this model [1]. We have used the relativistic mean field (RMF) theory to find the density distribution of nucleons in the projectile and target which are utilised in the Glauber model.

We present the variation of interaction cross section of target and projectile with the orientation of deformed target. The difference in the cross section calculated assuming an equivalent spherical target against the expectation value of the cross section assuming a deformed target nucleus, is also presented.

## Formalism

We consider a deformed nucleus of spheroidal shape with $\theta$ being the angle between symmetry axis and the direction of collision. The axis of collision is $z$-axis and $b$ is the impact parameter. We fit a combination of two Gaussians to the densities of the nuclei obtained from RMF calculations [2]. The densities are written (for $\theta = 0$ and $b = 0$) as $\rho(x, y, z) = \sum_{i=1}^{2} c_i \exp\left[-a_i(x^2 + y^2) - d_i z^2\right]$ where the parameters $c_i, a_i$ and $d_i$ are fitted to reproduce the density distributions obtained from RMF calculations. $a_i \neq d_i$ for the target to account for its spheroidal shape.

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To find the nucleon density of the target at a point $(x,\ y,\ z)$ in space when the orientation angle of target is $\theta$, a coordinate transform is performed

$$\begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}. \qquad (1)$$

The nucleon density is then calculated as

$$\rho_T(x, y, z, \theta) = \sum_{i=1}^{2} c_{Ti} \exp\{-a_{Ti}(x_1^2 + y_1^2) - d_{Ti} z_1^2\}, \qquad (2)$$

where the subscript $T$ stands for target.

Since the projectile is considered spherical, $a_i = d_i$ with its center located at $\vec{b}$ given by

$$\vec{b} = b\ \cos\psi\ \hat{x} + b\ \sin\psi\ \hat{y}\ , \qquad (3)$$

where $\psi$ is the angle between the line joining the centers of the two nuclei and $x$-axis. Nucleon density of the projectile at any point $(x,\ y,\ z)$ is given by

$$\rho_P(x, y, z, b, \psi) = \sum_{i=1}^{2} c_{Pi} \exp\left[-a_{Pi} \{(x - b\ \cos\psi)^2 + (y - b\ \sin\psi)^2 + z^2\}\right]. \qquad (4)$$

Subscript P stands for projectile. Within the standard form of the Glauber model [3], the total interaction cross-section reads

$$\sigma_R(\theta) = \int [1 - T(b, \theta, \psi)]\ b\ db\ d\psi\ , \qquad (5)$$

where $\mathrm{T}(b, \theta, \psi)$ is the transparency function. It is the probability of the projectile not interacting with the target. It is given by [4]

$$T(b, \theta, \psi) = \left| \exp\{-\int d\vec{r} \int \rho_P(\vec{r})\rho_T(\vec{r'})\Gamma(\vec{s} - \vec{s'})d\vec{r'}\} \right|^2. \qquad (6)$$

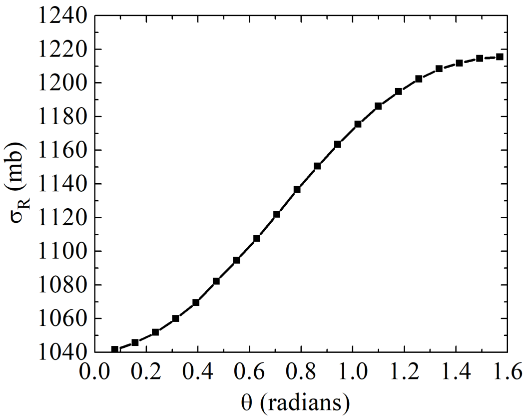


FIG. 1: Cross section ($\sigma_R$) as a function of orientation angle ($\theta$) for spherical projectile $^{12}$C and deformed target $^{15}$B.

Here, $\vec{r}$ is the three dimensional position vector of any point in space and $\vec{s}$ is the two dimensional position vector of the point in $x$-$y$ plane.

## Results and Discussion

For our calculations we choose $^{15}$B as the target and $^{12}$C as the projectile. We choose RMF parameters NL3 for $^{15}$B and NL-SH for $^{12}$C. $^{15}$B comes out to be prolate with a quadruple deformation ($\beta_2$) of 0.599. The calculated cross sections are plotted against orientation angle in Fig. 1 which varies smoothly in a sinusoidal way. As $\theta$ goes from 0 to $\pi/2$, in the prolate case, the density distribution is more wide spread in the $x$-$y$ plane, hence the probability of interaction is considerable even for large values of impact parameter ($b$). Therefore, we observe an increase in interaction cross section as $\theta$ goes from 0 to $\pi/2$.

There is a considerable difference between the cross sections at $\theta = 0$ and $\theta = \pi/2$ ($\sim$170 mb). This suggests that the orientation of the nuclei plays an important role in collision of deformed nuclei.

The expectation value of the cross section is calculated assuming all orientations have equal probability of occurrence. The expectation value is tabulated for different energies of $^{15}$B+$^{12}$C reaction, along with the cross sections calculated using spherical model and the experimental values, in Table I.

There is a small but observable difference in average cross section calculated considering a deformed target ($\sigma_{def}$) and the cross section calculated assuming spherical target ($\sigma_{sph}$).

TABLE I: Cross section for $^{15}$B+$^{12}$C reaction. The first column is energy of the projectile per nucleon in MeV. The second and third columns represent cross sections calculated using deformed and equivalent spherical target, respectively. The last column contains experimental data [5].

| Energy(A MeV) | $\sigma_{def}(mb)$ | $\sigma_{sph}(mb)$ | $\sigma_{exp}(mb)$ |
|---|---|---|---|
| 790 | 1144.2 | 1170.7 | 962±150 |
| 760 | 1139.5 | 1166.1 | 1000±20 |
| 740 | 1136.6 | 1162.9 | 965±15 |

## Conclusion

We have extended the Glauber model calculations for spheroidal targets. We have shown the change in interaction cross section with orientation of deformed target nucleus for $^{15}$B+$^{12}$C case. This work can be used in experiments with polarized beams and targets and studying high energy reactions involving deformed exotic nuclei.

The expectation value of the calculated cross section is also different from the cross section calculated assuming a spherical target.

## References


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