2023.04.18 Group meeting

Reading Phys. Rev. C **107**, 034603 (2023)

Fusion reactions in collisions of neutron halo nuclei with heavy targets

Junzhe Liu
Jizheng Bo
Lin Xiong

Hamiltonian and Wave function

Model Hamiltonian

$$H = h(r) + K + U^{(1)} + U^{(2)}$$

$h(r)$: the interaction between two fragments

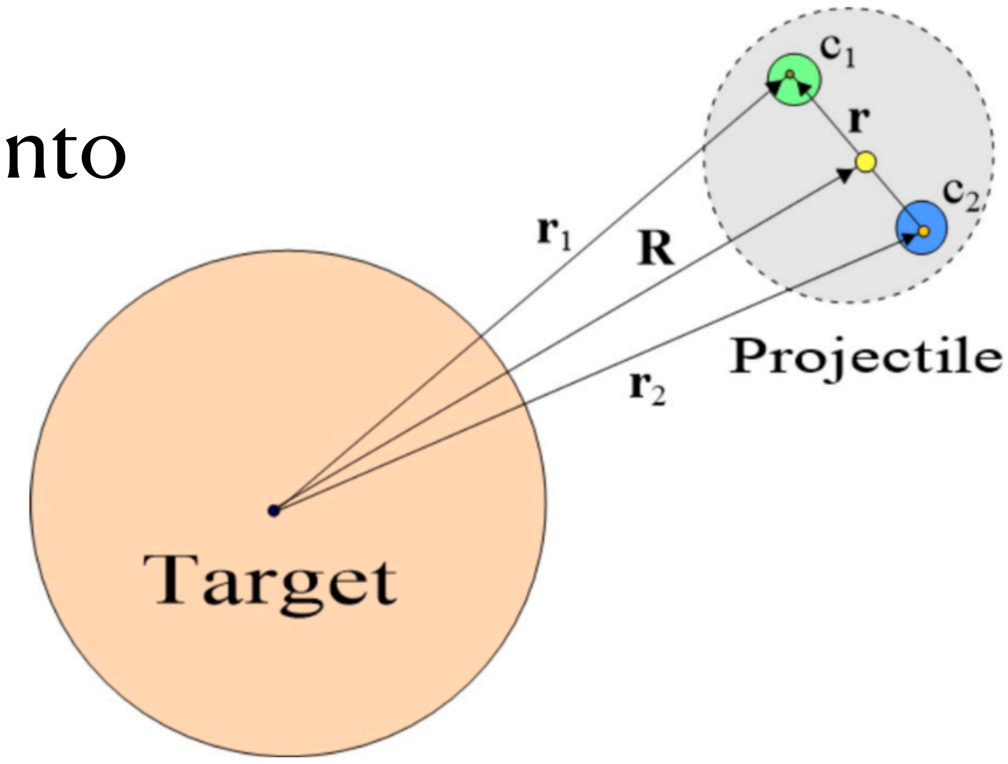
$U^{(i)}$: the fragment-target optical potential

K : the kinetic operator for relative motion

This CDCC wave function can be split into

bound and continuum components

$$\Psi^{(+)}(\boldsymbol{R},\boldsymbol{r}) = \Psi^{B}(\boldsymbol{R},\boldsymbol{r}) + \Psi^{C}(\boldsymbol{R},\boldsymbol{r})$$



[1] Cortes, M. R., Rangel, J., Ferreira, J. L., Lubian, J., & Canto, L. F. (2020). Complete and incomplete fusion of Li 7 projectiles on heavy targets. *Physical Review C*, *102*(6), 064628.

Fusion cross section

The optical theorem gives the fusion cross section

$$\sigma_{\mathrm{TF}} = \frac{1}{|N|^2}\,\frac{K}{E}\,\left\langle\, \Psi^{(+)} \,\middle|\, W^{(1)} + W^{(2)} \,\middle|\, \Psi^{(+)} \,\right\rangle$$

Assumption :

matrix-elements of the imaginary potentials connecting bound channels to bins are negligible.

$$\sigma_{\mathrm{TF}} = \sigma^{B}_{\mathrm{TF}} \;+\; \sigma^{C}_{\mathrm{TF}}$$

$$\sigma^{B}_{\mathrm{TF}} = \frac{1}{|N|^2}\frac{K}{E}\sum_{\beta,\beta'\in B}\left\langle \chi_\beta \middle| W^{(1)}_{\beta\beta'} + W^{(2)}_{\beta\beta'} \middle| \chi_{\beta'} \right\rangle$$

$$\sigma^{C}_{TF} = \frac{1}{|N|^2}\frac{K}{E}\sum_{\gamma,\gamma'\in C}\left\langle \chi_\gamma \middle| W^{(1)}_{\gamma\gamma'} + W^{(2)}_{\gamma\gamma'} \middle| \chi_{\gamma'} \right\rangle$$

[1] Cortes, M. R., Rangel, J., Ferreira, J. L., Lubian, J., & Canto, L. F. (2020). Complete and incomplete fusion of Li 7 projectiles on heavy targets. *Physical Review C, 102*(6), 064628.

Probability interpretation

Performing an angular momentum expansion:

$$\sigma_{TF}^{B} = \frac{\pi}{K^2} \sum_{J_T} (2J_T + 1)\ \mathscr{P}_B^{TF}(J_T) \qquad \sigma_F = \sum_J A(J)\mathscr{P}_J$$

$$\sigma_{TF}^{C} = \frac{\pi}{K^2} \sum_{J_T} (2J_T + 1)\ \mathscr{P}_C^{TF}(J_T) \qquad A(J) = 2\pi \times \boxed{\frac{J + 1/2}{K} \times \frac{1}{K}}$$

Correspond to the impact parameter b and its increment Δb

$A(J)$ is the area of a ring with radius b and thickness Δb

[1] Cortes, M. R., Rangel, J., Ferreira, J. L., Lubian, J., & Canto, L. F. (2020). Complete and incomplete fusion of Li 7 projectiles on heavy targets. *Physical Review C*, *102*(6), 064628.

Probability interpretation

$$\mathscr{P}^{ICF1}(J_T) = \mathscr{P}_C^{(1)}(J_T) \times \left[1 - \mathscr{P}_C^{(2)}(J_T) \right]$$ Fragment 1 is absorbed × 2 is not

$$\mathscr{P}^{ICF2}(J_T) = \mathscr{P}_C^{(2)}(J_T) \times \left[1 - \mathscr{P}_C^{(1)}(J_T) \right]$$ Fragment 2 is absorbed × 1 is not

$$\mathscr{P}^{SCF}(J_T) = 2\mathscr{P}_C^{(1)}(J_T) \times \mathscr{P}_C^{(2)}(J_T)$$ Two × fragment 1 and 2 are absorbed

$$\sigma_{\mathrm{CF}} = \sigma_{DCF} + \sigma_{SCF}$$
$$\sigma_{\mathrm{ICF}} = \sigma_{ICF1} + \sigma_{ICF2}$$
$$\sigma_{TF} = \sigma_{CF} + \sigma_{ICF}$$

[1] Cortes, M. R., Rangel, J., Ferreira, J. L., Lubian, J., & Canto, L. F. (2020). Complete and incomplete fusion of Li 7 projectiles on heavy targets. *Physical Review C*, *102*(6), 064628.

Comparison with previous work

In the previous IAV work:

$$\sigma_R = \sigma_{CF} + \sigma_{EBU} + \sigma_{inel} + \sigma_{NEB}^{(1)} + \sigma_{NEB}^{(2)}$$

In this paper:

$$\sigma_R = \sigma_{CF} + \sigma_{ICF} + \sigma_{EBU} + \sigma_{inel}$$

NEB = Inelastic breakup + Incomplete fusion + transfer

- Study the core excitation ? When the inelastic breakup is dominant?
- Compare the CF component ?

Fusion function reduction

Transformation into the dimensionless variables

Energy reduction $$x = \frac{E_{\text{c.m.}} - V}{\hbar\omega}$$

Fusion function $$F = \frac{2E_{\text{c.m.}}}{\hbar\omega R_B^2}\sigma_F$$

$$V(r) \simeq V_B + \frac{1}{2}\mu\omega^2\left(r - R_B\right)^2$$

$$\hbar\omega = \sqrt{\frac{\hbar^2\,|\,V''(R_B)\,|^2}{\mu}}$$

Wong's formula $$\sigma_F = R_B^2\frac{\hbar\omega}{2E}\ln\left[1 + \exp\left(\frac{2\pi(E_{\text{c.m.}})}{\hbar\omega}\right)\right]$$

$$F_0 = \ln[1 + \exp(2\pi x)]$$

Compare the calculation with the Wong's standard fusion function.

[2] Wong, C. (1973). Interaction barrier in charged-particle nuclear reactions. *Physical Review Letters, 31*(12), 766.