

STUDY OF ISOTOPIC EFFECTS IN CAPTURE PROCESS*

R.A. KUZYAKIN, V.V. SARGSYAN, G.G. ADAMIAN, N.V. ANTONENKO

Joint Institute for Nuclear Research, 141980 Dubna, Russia

(Received November 19, 2012)

The quantum diffusion approach is applied to study the isotopic dependencies of capture cross section and mean-square angular momentum in the reactions $^{48}\text{Ca} + ^{144,150,154}\text{Sm}$ and $^{40}\text{Ca} + ^{154}\text{Sm}$.

DOI:10.5506/APhysPolB.44.471

PACS numbers: 25.70.Jj, 24.10.-i, 24.60.-k

1. Introduction

Recently, many experimental and theoretical efforts have been devoted to the investigation of fusion, fission, and capture processes at sub-barrier energies [1–4]. Measurements of excitation functions down to the extreme sub-barrier energies are important for studying the long range behavior of the nucleus–nucleus interaction. The experimental data obtained are also of interest for solving astrophysical problems related to nuclear synthesis.

The main objective of the present work is to study the isotopic dependencies of the capture cross section and the mean-square angular momentum in the reactions $^{48}\text{Ca} + ^{144,150,154}\text{Sm}$ and $^{40}\text{Ca} + ^{154}\text{Sm}$. The quantum diffusion approach [3, 4] is employed. The collisions of nuclei are treated in terms of a single dynamic collective coordinate, the relative distance between the colliding nuclei. Our approach takes into consideration the fluctuation and dissipation effects in collisions of heavy ions that model the coupling with various channels [3, 4]. The deformation and neutron transfer effects are taken into account through the dependence of the nucleus–nucleus potential on the deformations and orientations of interacting deformed nuclei.

* Presented at the Zakopane Conference on Nuclear Physics “Extremes of the Nuclear Landscape”, Zakopane, Poland, August 27–September 2, 2012.

2. Calculated results

The isotopic dependence of the capture cross section is caused by the following reasons. The deformations of colliding nuclei depend on their neutron numbers and affect the nucleus–nucleus interaction potential. The isotopic effects are attributed to the neutron transfer if the Q -value promotes it. The nucleon distributions in the nuclei depend on the mass numbers and affect the height V_b and the shape of the Coulomb barrier. V_b decreases with increasing neutron number. Thus the nucleus–nucleus potential remains the important ingredient of our approach. By using this potential, we calculate the capture cross section σ_{cap} and mean-square angular momentum $\langle J^2 \rangle$ or any other observables.

To separate the effects of deformation and neutron transfer, we firstly consider the reactions $^{48}\text{Ca} + ^{144,150,154}\text{Sm}$ with deformed target-nuclei in which the Q -values for the neutron transfer are negative, *i.e.* the neutron transfers are suppressed. In Fig. 1, the calculated σ_{cap} for the $^{48}\text{Ca} + ^{154}\text{Sm}$

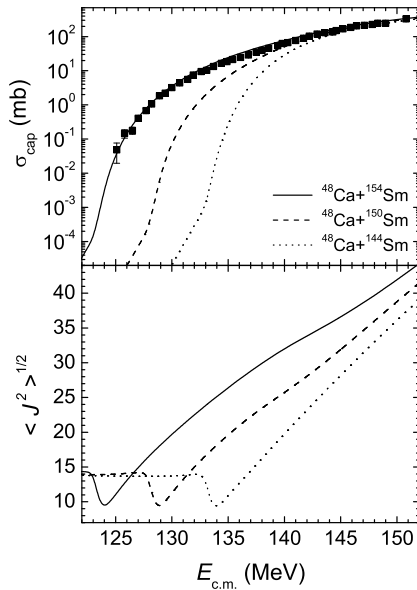


Fig. 1. The calculated capture cross sections (upper part) and mean-square angular momenta of captured system (lower part) *versus* bombarding energy E_{cm} for the $^{48}\text{Ca} + ^{144,150,154}\text{Sm}$ reactions. The experimental data (closed squares) for the $^{48}\text{Ca} + ^{154}\text{Sm}$ reaction are taken from Ref. [5]. The heights V_b of the Coulomb barriers for spherical nuclei are 139.3, 138.5, and 138.1 MeV, respectively. The following quadrupole deformation parameters are used: $\beta_2(^{48}\text{Ca}) = 0$, $\beta_2(^{144}\text{Sm}) = 0.05$ [3], $\beta_2(^{150}\text{Sm}) = 0.19$ [6], and $\beta_2(^{154}\text{Sm}) = 0.34$ [6].

reaction are in good agreement with the available experimental data [5] showing the strong effect of deformation. The quadrupole deformation of target-nucleus is the main reason for the enhancement of the sub-barrier capture cross section. As seen in Fig. 1, the decrease of the Sm mass number A leads to smaller values of the capture cross section at fixed E_{cm} or $E_{\text{cm}} - V_b$. Since $\beta_2(^{154}\text{Sm}) > \beta_2(^{150}\text{Sm}) > \beta_2(^{144}\text{Sm})$, the sub-barrier enhancement for the $^{48}\text{Ca} + ^{154}\text{Sm}$ ($^{48}\text{Ca} + ^{150}\text{Sm}$) reaction is larger than one for the $^{48}\text{Ca} + ^{150}\text{Sm}$ ($^{48}\text{Ca} + ^{144}\text{Sm}$) reaction.

One can see in Fig. 1 that there is a sharp fall-off of the σ_{cap} just under the Coulomb barrier. At E_{cm} about 6–15 MeV below the corresponding Coulomb barriers, the regime of interaction is changed (the turning-off the nuclear forces and, respectively, nuclear friction) [3, 4]. As a result, at smaller E_{cm} the cross sections fall with a smaller rate.

The increase of mass number A raises the mean-square angular momentum of captured system (Fig. 1). At energies 6–15 MeV below the barrier $\langle J^2 \rangle$ has a minimum. The position of the minimum is shifted to smaller energies with increasing A . On the left-hand side of this minimum, the dependence of $\langle J^2 \rangle$ on E_{cm} is rather weak.

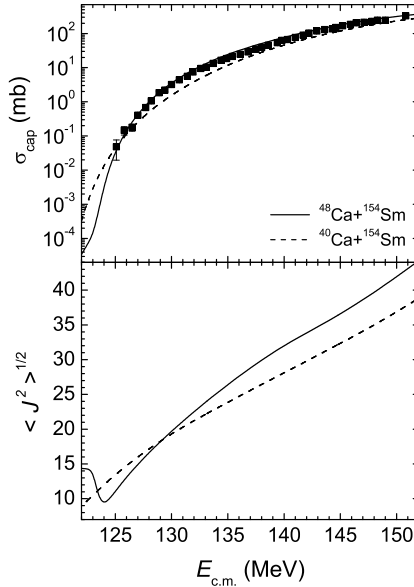


Fig. 2. The same as in Fig. 1, but for the reactions $^{40,48}\text{Ca} + ^{154}\text{Sm}$. The heights V_b of the Coulomb barriers for spherical nuclei are 140.7 and 138.1 MeV, respectively. The following quadrupole deformation parameters are used: $\beta_2(^{42}\text{Ca}) = 0.25$ [6], $\beta_2(^{48}\text{Ca}) = 0$, $\beta_2(^{152}\text{Sm}) = 0.31$ [6], and $\beta_2(^{154}\text{Sm}) = 0.34$ [6].

In Fig. 2 the calculated results for the capture cross sections and mean-square angular momenta of captured system are presented for the reactions $^{40,48}\text{Ca} + ^{154}\text{Sm}$. For the $^{40}\text{Ca} + ^{154}\text{Sm}$ reaction the Q -value for two-neutron transfer is positive, and this channel strongly affects the sub-barrier capture [3]. The two-neutron transfer occurs at large separations (before the crossing of the Coulomb barrier) that leads to the population of the first 2^+ state in the recipient nucleus [3]. After the neutron transfer in the reaction $^{40}\text{Ca}(\beta_2 = 0) + ^{154}\text{Sm}(\beta_2 = 0.34) \rightarrow ^{42}\text{Ca}(\beta_2 = 0.25) + ^{152}\text{Sm}(\beta_2 = 0.31)$ the deformation of the system increases and the mass asymmetry of the system decreases, and, thus, the value of the Coulomb barrier decreases. As a result, the capture cross section for the $^{40}\text{Ca} + ^{154}\text{Sm}$ reaction is larger than one for $^{48}\text{Ca} + ^{154}\text{Sm}$ at the deep sub-barrier energies (Fig. 2). Thus, the effect of the neutron transfer is an indirect effect of the quadrupole deformation.

3. Summary

Employing the quantum diffusion approach, we showed that the effects of the quadrupole deformation and neutron transfer strongly influence the isotopic trends of capture cross sections and mean-square angular momenta of captured systems. To check the predictions of our approach, it would be interesting to study experimentally the reactions $^{48}\text{Ca} + ^{144,150}\text{Sm}$ and $^{40}\text{Ca} + ^{154}\text{Sm}$.

This work was supported by the Russian Foundation for Basic Research Grant No. 12-02-31821-mol_a.

REFERENCES

- [1] C.A. Bertulani, *EPJ Web Conf.* **17**, 15001 (2011).
- [2] G. Montagnoli *et al.*, *Phys. Rev.* **C82**, 064609 (2010); *Phys. Rev.* **C85**, 024607 (2012).
- [3] V.V. Sargsyan *et al.*, *Eur. Phys. J.* **A45**, 125 (2010); *Phys. Rev.* **C84**, 064614 (2011); *Phys. Rev.* **C85**, 024616 (2012); *Phys. Rev.* **C86**, 014602 (2012); *Phys. Rev.* **C86**, 034614 (2012).
- [4] R.A. Kuz'yakin *et al.*, *Phys. Atom. Nucl.* **75**, 439 (2012); *Phys. Rev.* **C85**, 034612 (2012).
- [5] M. Trotta *et al.*, *Eur. Phys. J.* **A25**, 615 (2005).
- [6] S. Raman, C.W. Nestor, P. Tikkanen, *At. Data Nucl. Data Tables* **78**, 1 (2001).