Journal of Physics: Conference Series **590** (2015) 012048 doi:10.1088/1742-6596/590/1/012048

The Long Range Potential Effect on the ^{20}O+^{12}C System for Near and Sub-barrier Fusion Cross Section

G. Kocak†, R. Kabak†

†Department of Physics, Erciyes University, 38039, Kayseri, Turkey

Abstract. In this study, we have analyzed the ^{20}O+^{12}C system within the framework of optical model by using miscroscopic folded potential, which is based on M3Y nucleon-nucleon effective interaction and a phenomenological potential. A significant underprediction appeared between experimental data and our results. To solve this problem, one of the important candidate is the use of the long range potential effect. By using the long range potential effect, we have achieved results that are consistent with experimental data for the ^{20}O+^{12}C system fusion cross section.

1. Introduction

The studies with neutron-rich radioactive beams provide new insight into production of new isotopes and nuclei. Fusion of very neutron-rich nuclei is also very important in order to determine the observables of neutron stars and for astrophysical interest. There are numerous studies for the near-barrier fusion with neutron-rich nuclei [1–6] and the studies with the exotic nuclei show unexpected behaviors in the barrier region, like several order magnitude enhancement of fusion cross section [7, 8].

One of the most important problem in the sub-barrier fusion studies with very neutron-rich nuclei is the enhancement of fusion cross section at sub-barrier energies. Recently, Rudolph *et al.* [9] measured the ^{20}O+^{12}C system fusion cross section for the near and sub-barrier energies and they have obtained the significant difference between the experimental and theoretical data. In this study, we investigated the fusion cross section for the near and sub-barrier region to explain the unexpected behavior of fusion excitation data. With this purpose, we have used the long range potential effect [10] to explain ^{20}O+^{12}C system fusion cross section for the energies near and below the Coulomb barrier.

2. Model

In this study, we have used optical model. In the optical model, the total potential $\mathrm{V_{total}(r)}$ consists of

$$V_{\mathrm{total}}(r) = V_{\mathrm{Nuclear}}(r) + V_{\mathrm{Coulomb}}(r) + V_{\mathrm{Centrifugal}}(r) \tag{1}$$

Coulomb and Centrifugal potentials are well-known. The Coulomb potential [11] due to a charge $Z_P e$ interacting with a charge $Z_T e$ distributed uniformly over a sphere of radius R_c is

$$V_{\mathrm{Coulomb}}(r) = \frac{1}{4\pi\varepsilon_\circ}\frac{Z_P Z_T e^2}{r}, \qquad r \geq R_c, \tag{2}$$

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

$$= \frac{1}{4\pi\varepsilon_\circ}\frac{Z_P Z_T e^2}{2R_c}\left(3-\frac{r^2}{R_c^2}\right), \qquad r < R_c, \tag{3}$$

where R_c is the Coulomb radius, and Z_P and Z_T denote the charges of the projectile P and the target nuclei T respectively. The centrifugal potential is

$$V_{\text{Centrifugal}}(r) = \frac{\hbar^2\, l\,(l+1)}{2\,\mu\, r^2} \tag{4}$$

where μ is the reduced mass of the colliding pair.

In order to make a comparative study of this reaction, we use two different potentials for the real part of the optical model potential: one is a phenomenological potential and the other one is the microscopic nucleon-nucleon double folding potential.

2.1. Phenomenological Potential

For the phenomenological potential, we used the Woods-Saxon shaped potential. This potential is

$$V_{\text{Nuclear}}(r) = \frac{-V_0}{(1+\exp(r-R_V)/a_V)} + i\frac{-W_0}{(1+\exp(r-R_W)/a_W)} \tag{5}$$

where $V_0 = 198$ MeV, $R_V = r_V(A_P^{1/3} + A_T^{1/3})$ with $r_V = 0,9$ fm, $a_V = 0,46$ fm. The imaginary part of the potential has the same Woods-Saxon volume shape as in Equation 5 and its parameters are $W_0 = 2$ MeV, $r_W = 1,0$ fm and $a_W = 0,8$ fm.

2.2. Nucleon-Nucleon Double Folding Potential (NN-DF)

The NN-DF potential evaluated by using the nuclear matter distributions for projectile ρ_P and target ρ_T nuclei with an effective NN interaction potential (ν_{nn}) is

$$V_{DF}(r) = \int\int \rho_P(r_1)\rho_T(r_1)\nu_{nn}(|\vec{r}+\vec{r}_2-\vec{r}_1|)d^3r_1 d^3r_2 \tag{6}$$

The DF potential which is based upon a realistic effective nucleon-nucleon (NN) interaction (Equation 7), folded with nuclear matter densities of both projectile and target nuclei:

$$\nu_{nn}(r) = 7999\frac{\exp(-4r)}{4r} - 2134\frac{\exp(-2.5r)}{2.5r} + J_{00}(E)\delta(r)MeV \tag{7}$$

The imaginary potential parameters which used in the phenomenological potential have taken for the NN-DF calculations. The code DFPOT [12] has been used for the microscopic DF potential calculation and the code FRESCO [13] has been used to obtain all reaction observables.

3. The Results

We have first analyzed the experimental data for the ^{20}O+^{12}C system total fusion cross section with the optical model by using phenomenological Wood-Saxon potential. Our results are shown in fig. 1.

There is large fusion cross section enhancement at the sub-barrier energies that can not explain by the optical model calculation. Therefore, we have performed the more realistic explanation by using microscopic nucleon-nucleon double folding potential to explain this reaction as can be seen in fig. 1.

But, neither the phenomenological Wood-Saxon potential nor the microscopic nucleon-nucleon double folding potential are enough to solve the low energy fusion cross section

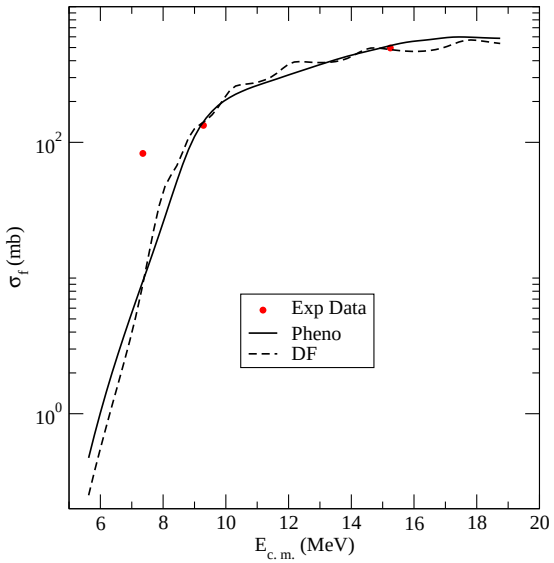


Figure 1. The phenomenological and microscopical results for the ^{20}O+^{12}C system, the black line gives phenomenological results and the dashed line shows DF results.

V_d	r_0	a
MeV	fm	fm
8.0	4.3	4.0

Table 1. The parameters of the additional potential.

enhancement problem. The underestimation has been raised between our results and the neutron-rich nuclei fusion cross section in all calculations.

Recently, Dapo *et al.* [10] showed that the importance of long range potential on the low energy observables. They found that the tail of the real potential has a significant effect on the cross section. To understand this relative dominance of the changes induced by long range versus short range of the potential, one can look to the concept of effective theory. In effective theories, a separation of scales is introduced to distinguish effects which occur at low energies (long range) and at high energies (short range). The low energy observables are dominated by the long range of the potential and are not sensitive to the short range [10]. By using this approximation, we have modified our total potential by adding a small additional potential. It has the derivatives of the Wood-Saxon shape and the parameters are shown in Table 1.

As it can be seen from the figure 2, the long range potential has significant effect on the low energy fusion cross section. We have obtained very good agreement with the experimental data by using this effect.

4. Conclusion

In this study, we have examined the fusion cross section with very neutron-rich nuclei. The optical model results by using phenomenological and microscopical potential are not enough to explain experimental data. The underestimation has been raised between experimental data and our results. To solve this problem, we have used the long range potential effect and obtained very good results. As a future studies, we will examine the neutron transfer between target and projectile and will compare the long range potential and transfer effect.

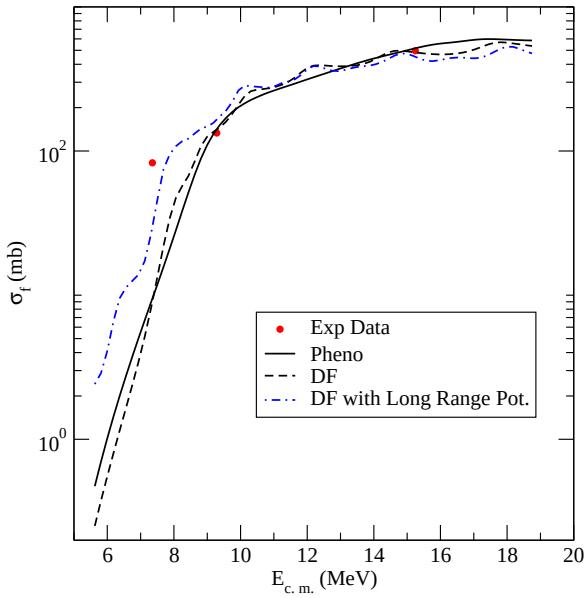


Figure 2. The results of the $^{20}O+^{12}C$ system fusion cross section after the inclusion of the long range potential effect

5. Acknowledgments

This work was supported by Research Fund of the Erciyes University. Project Number:FBA-2014-5224.

6. References

[1] Kolata J J *et al* 1998 *Phys. Rev. Lett.* ***81*** 4580
[2] Fomichev A S *et al* 1995 *Z. Phys. A.* ***351*** 129
[3] Trotta M *et al* 2000 *Phys. Rev. Lett.* ***84*** 2342
[4] Pietro A Di *et al.* 2004 *Phys. Rev. C* ***69*** 044613
[5] Penionzhkevich Yu E *et al* 2006 *Phys. Rev. Lett.* ***96*** 162701
[6] Raabe R *et al* 2004 *Nature* ***431*** 823
[7] Loveland W *et al* 2006 *Phys. Rev. C* ***74*** 064609
[8] Zagrebaev V I, Samarin V V and Greiner W 2007 *Phys. Rev. C* **75**, 035809
[9] Rudolph M J *et al* 2012 *Phys. Rev. C* ***85*** 024605
[10] Dapo H *et al* 2012 *Phys. Rev. C* ***85*** 044602
[11] Satchler G R 1983 *Nucl. Phys.* ***A409*** 3c
[12] Cook J 1982 *Comput. Phys. Commun. 25* 125
[13] Thompson I J *FRESCO, a coupled-channels code, unpublished*