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A Microscopic Optical Potential for Deuteron *

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The microscopic optical potential for deuteron is obtained by folding the microscopic optical potentials of its constituent nucleons. The optical potential is used to predict the reaction cross sections and the elastic scattering angular distributions for some spherical target nuclei, and the results of theoretical calculation are compared with the experimental data available.

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The optical model is one of the most important basic models in nuclear reaction theory. The phenomenological optical model potential usually includes some adjustable parameters and is generated by adjusting its parameters to fit the existing experimental data. On the other hand, the microscopic optical potential (MOP) is obtained theoretically based on the nucleon-nucleon interaction and has no free parameters. At present, many deuteron optical model potentials are studied from the phenomenological approach.[1,2] There also exist some deuteron optical potentials constructed from a combined microscopic and phenomenological approach,[3,4] where the real parts are obtained microscopically by folding the M3Y effective interaction with the density distributions of the two colliding particles, but the imaginary and spin-orbit terms are given phenomenologically.

It is suggested in the folding model[5−7] that, to the first approximation, the optical potential of a composite particle is the sum of the optical potentials of its constituent nucleons averaged over their internal density distributions in the composite particle, namely, the microscopic optical potential for deuteron can be obtained by folding the microscopic optical potentials of its constituent nucleons in the ground state of deuteron. There is an isospin dependent nonrelativistic nucleon microscopic optical potential[8] which is obtained on the base of Skyrme nucleon-nucleon interaction, it is expressed analytically and can reproduce the experimental data very well. Encouraged by the success of the microscopic nucleon optical potential, this work makes use of the folding model to construct the microscopic optical potential for deuteron on the basis of the nucleon microscopic optical potential as described in the following.

The Hamiltonian of the system composed of the incident deuteron and the target nucleus may be written as

$$H = T_1 + T_2 + V_{12}(r_{12}) + V_1(r_1) + V_2(r_2), \tag{1}$$

where r_1 and r_2 are the positions of the nucleons in deuteron, T is the kinetic energy operator, $V_{12}(r_{12})$ is the interaction between the nucleons of the deuteron, $V_1(r_1)$ and $V_2(r_2)$ are the interaction of the neutron and the proton with the target nucleus. In the relative coordinate representation, the Schrodinger equation is

$$\Big[-\frac{\hbar^2}{2M}\nabla_R^2 - \frac{\hbar^2}{2\mu}\nabla_r^2 + V_{12}(r) + V_1\Big(\Big|\boldsymbol{R}+\frac{\boldsymbol{r}}{2}\Big|\Big) + V_2\Big(\Big|\boldsymbol{R}-\frac{\boldsymbol{r}}{2}\Big|\Big)\Big]\psi(\boldsymbol{R},\boldsymbol{r}) = E\psi(\boldsymbol{R},\boldsymbol{r}), \tag{2}$$

where $\boldsymbol{R}$ is the position of the centroid of deuteron. The deuteron wave function is denoted by $\chi(r)$, then

$$\Big[-\frac{\hbar^2}{2\mu}\nabla_r^2 + V_{12}(r)\Big]\chi(r) = \varepsilon_d\chi(r), \tag{3}$$

the solution $\psi(\boldsymbol{R},\boldsymbol{r})$ to Eq. (2) can be written as

$$\psi(\boldsymbol{R},\boldsymbol{r}) = \chi(r)\phi(\boldsymbol{R}) + F(\boldsymbol{R},\boldsymbol{r}).$$

Then multiplying Eq. (2) by $\chi(r)$ and integrating with respect to $\boldsymbol{r}$, one can obtain

$$\Big[-\frac{\hbar^2}{2M}\nabla_R^2 + V(R) - (E-\varepsilon_d)\Big]\phi(\boldsymbol{R}) + g(\boldsymbol{R}) = 0, \tag{4}$$

where $g(\boldsymbol{R})$ containing the dissociation of the deuteron is very small, so this term is neglected as in Refs. [6,7]. $V(R)$ is the optical potential for deuteron which can be expressed as

$$V(R) = \int |\chi(r)|^2\Big[V_1\Big(\Big|\boldsymbol{R}+\frac{\boldsymbol{r}}{2}\Big|\Big) + V_2\Big(\Big|\boldsymbol{R}-\frac{\boldsymbol{r}}{2}\Big|\Big)\Big]d\boldsymbol{r}. \tag{5}$$

In this work, V_1 and V_2 are the microscopic optical potentials for the neutron and the proton, respectively, with half the incident deuteron energy. The expressions of V_n and V_p are taken as those in Ref. [8]. Here $\chi(r)$ is expressed as

$$\chi(r) = \frac{N_d}{r}\big[\exp(-\alpha r) - \exp(-\beta r)\big], \tag{6}$$

where

$$N_d = \Big[\frac{\alpha\beta(\alpha+\beta)}{2\pi(\beta-\alpha)^2}\Big]^{1/2}, \tag{7}$$

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with $\alpha = 0.23\,\mathrm{fm}$, $\beta = 1.61\,\mathrm{fm}$.

The spin-orbit coupling potential for deuteron is considered as the sum of the spin-orbit potentials for its constituent nucleons,

$$V_{\rm SO}(r) = V_{\rm SO}^{n} + V_{\rm SO}^{p}, \tag{8}$$

where $V_{\rm SO}^{n}$ and $V_{\rm SO}^{p}$ are the nucleon spin-orbit potentials taken from Refs. [8,9].

By the MOP for deuteron, the radial dependences of the MOP, the reaction cross sections and the elastic scattering angular distributions for some spherical target nuclei are calculated. Here the calculated results for target nucleus ^{40}Ca are shown as an example.

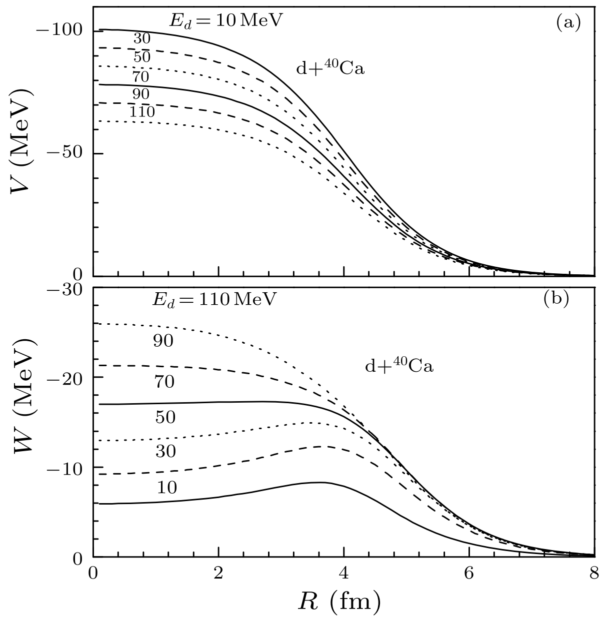

Fig. 1. Radial dependence of MOP for deuteron scattering from ^{40}Ca: (a) the real parts, (b) the imaginary parts.

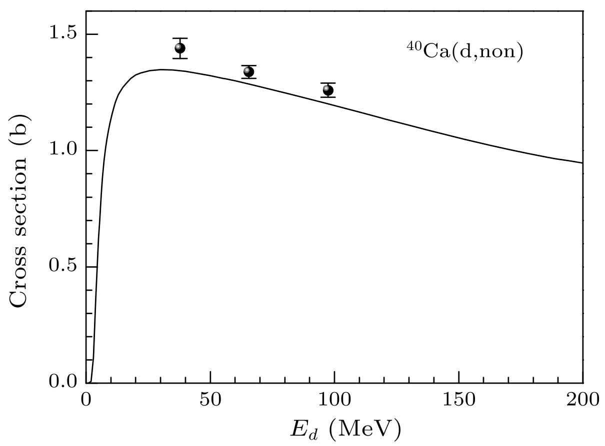

Fig. 2. Comparison of the calculated result (solid line) of the deuteron reaction cross section for ^{40}Ca with the experimental data (symbols).[10]

The radial dependence of the MOP for deuteron scattering from ^{40}Ca at incident energies of 10, 30, 50, 70, 90 and 110 MeV is shown in Fig. 1. In Fig. 1(a), the absolute value of the real part decreases with increasing radius and incident energy, while in Fig. 1(b), the absolute value of the imaginary part increases with increasing energy of incident deuteron. In addition, the dominant contribution of the imaginary part changes from the surface absorption to the volume absorption as the incident energy increases. These trends of real and imaginary parts are reasonable with general understanding.

The deuteron reaction cross section for ^{40}Ca is calculated with the MOP, and the comparison of the calculated result with the experimental data[10] is given in Fig. 2. The figure shows that the shape of the calculated result curve of reaction cross sections for ^{40}Ca is similar to the experimental data, but the magnitude of the calculated result is smaller than that of the experimental data.

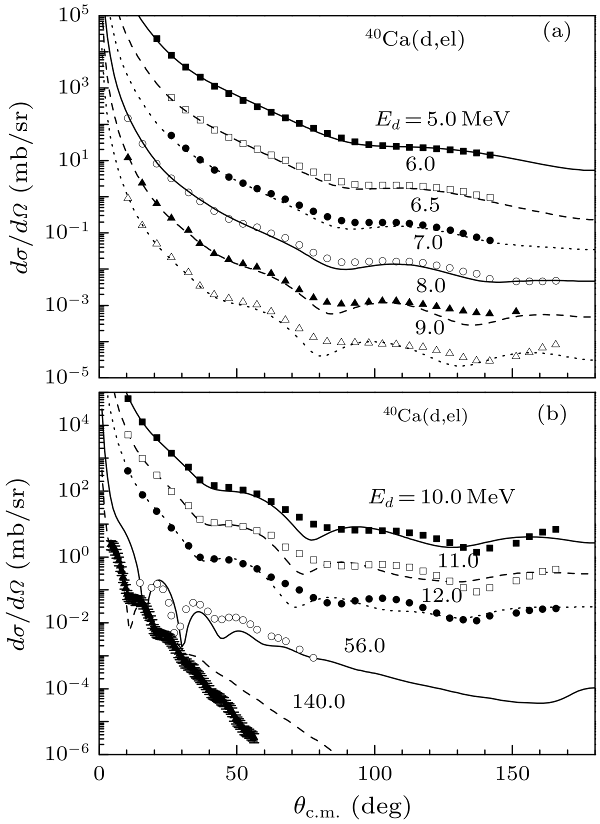

Fig. 3. Calculated elastic scattering angular distributions (solid line) at different incident deuteron energies compared with the experimental data (symbols)[11−14] for d+^{40}Ca reaction. The results are offset by factors of 10.

The elastic scattering angular distributions for ^{40}Ca at incident deuteron energies from 5.0 to 140.0 MeV are calculated, and compared with experimental data[11−14] in Fig. 3. The theoretical results at incident energies from 5.0 to 56.0 MeV are in overall agreement with the experimental data. However, the predicted magnitudes are larger than those of the experimental data at the angles greater than 35° for the case of 140.0 MeV. The reason for the discrepancy may be such that the contribution of the dissociation of the deuteron is neglected.

This potential is also used to predict the reaction cross sections and elastic scattering angular distributions for some other spherical target nuclei, the results are similar to those for the case of ^{40}Ca.

In summary, the microscopic optical potential for deuteron is obtained by folding the microscopic optical potentials of its constituent nucleons. The radial dependence of the MOP for deuteron scattering from ^{40}Ca is analyzed, showing reasonable trends. The reaction cross section and elastic scattering angular distribution for ^{40}Ca with incident deuteron energies from threshold up to 200 MeV are also predicted by this potential. The results show that the calculation of the reaction cross sections is consistent with the experimental data. Meanwhile in most cases, the calculated elastic scattering angular distributions are in agreement with the experimental data, although slight disagreement can be seen in the range of larger angles for higher incident energy.

References

[1] Avrigeanu M, Oertzen W V, Fischer U and Avrigeanu V 2005 *Nucl. Phys.* A **759** 327
[2] Han Y L, Shi Y Y and Shen Q B 2006 *Phys. Rev.* C**74** 044615
[3] Satchler G R and Love W G 1979 *Phys. Rep.* **55** 183
[4] Avrigeanu M, Leeb H, Oertzen W V, Roman F L and Avrigeanu V 2006 Proc. 11th Int. Conf. on Nuclear Reaction Mechanisms (Varenna 12-16 June 2006)
[5] Watanabe S 1958 *Nucl. Phys.* **8** 484
[6] Rook J R 1965 *Nucl. Phys.* **61** 219
[7] Perey F G and Satchler G R 1967 *Nucl. Phys.* A **97** 515
[8] Shen Q B, Han Y L and Guo H R 2009 *Phys. Rev.* C **80** 024604
[9] Vautherin D and Brink D M 1972 *Phys. Rev.* C **5** 626
[10] Auce A et al. 1996 *Phys. Rev.* C **53** 2919
[11] Hatanaka K et al 1980 *Nucl. Phys.* A **340** 93
[12] Leighton H G, Roy G, Gurd D P and Grandy T B 1968 *Nucl. Phys.* A **109** 218
[13] Bassel R H et al 1964 *Phys. Rev.* **136** 960
[14] Okamura H et al 1998 *Phys. Rev.* C **58** 2180