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Treatise of angular distributions of ^{3}He elastic scattering from stable Selenium isotopes

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ABSTRACT

Angular distributions of ^{3}He elastic scattering reactions from stable Selenium isotopes have systematically calculated within the theoretical framework. Optical-model parameters for Woods-Saxon real and imaginary volume potentials have been used to illustrate the data. The corresponding ratios to Rutherford scattering and relevant barrier distributions of elastic scattering cross-sections have attained from 0º to 180º. The theoretical calculations shed light on a well-rounded definition of the empricial angular distribution data.

1. Introduction

In recent years, nuclear optical model has widely used to investigate the elastic scattering of nucleons or heavier particles by nuclei around an extensive area of energies.

Elastic scattering is one of the main reactions as well as the most prominent feature of nuclear collisions. In addition, we can obtain nuclear interaction parameters from the interpretation of elastic scattering data. The quantiles of the nuclear reaction are largely determined by the "elastic" movement of the particles interacting in the input channel and the particles composed in the output channel. This means that the interpretation of any nuclear process must start from careful investigation of the elastic scattering of nuclear particles in the reaction. The major purpose of investigations is to understand the average area encountered by the projectile as it passes through the core. This area is generally explained in terms of the potential of an Optical Model (OM).

Optical model is a potential combining of real and imaginary potential parameters. The real potential of optical model characterizes the elastic scattering of the reaction. The imaginary potential characterizes the deficiency of flux into inelastic channels. Real and imaginary potential parameters may be described over phenomenological or microscopic models (Cinan et al., 2018).

2. Theoretical Calculations

Optical model (OM) of elastic scattering the relativistic motion of the projectile and target particles were characterized via Schrödinger equation in quantum mechanics (Hogdson, 1963).

$$\left[-\frac{\hbar^2}{2m}\Delta + V_{OM}\right].\Psi_{\vec{k}}^{(+)}(r,\theta) = E\Psi_{\vec{k}}^{(+)}(r,\theta)$$

here $E = \hbar^2 k^2/2\mu$ is the relativistic movement energy, μ is the reduced mass, and V_{OM} is an optical potential (OP). There it

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was assumed that whole reaction channels can be identified by a convenient optical potential selection.

In application the optical potentials, presented below, with a basic radial connection is frequently employed

$$V_{OM}(r) = V_C(r) + V_N(r) + iW(r) + [V_{SO}(r) + iW_{SO}(r)].\left(\vec{l}.\vec{s}\right)$$

where $V_C + V_N$ are the potential of Coulomb and Nuclear interactions, the imaginary part of optical potential was selected in the volume or surface Woods-Saxon types. $V_{SO} + iW_{SO}$ is the spin-orbital potential that might be inserted when the projectile has a non-zero spin (Hogdson, 1963).

The relativistic movement wave function with an infinite limit condition is

$$\Psi_{\vec{k}}^{(+)}(r,\theta) \approx e^{ikrcos\theta} + f(\theta)\frac{e^{ikr}}{r}$$

here $f(\theta)$ is the scattering amplitude. To ascertain the scattering magnitude, the total wave function should be divided into the partial waves

$$\Psi_{\vec{k}}^{(+)}(r,\theta) = \sum_{l=0}^{\infty}(2l+1)i^l\psi_l(r)\,P_l(cos\theta)$$

Schrödinger equations must be desegrated numerically from $r = 0$ up to $r = R_{max}$. $V_N(r)$ and $W(r)$ can be unheeded and solely the Coulomb effect persists. The computational analysis is easily assembled with a common asymptotic posture of the partial wave

$$\psi_l(r) \approx e^{i\sigma_l}\frac{1}{2}[(F_l + iG_l) + S_l(F_l - iG_l)]$$

where F_l and G_l are Coulomb partial wave functions.

After finding the partial S-matrix elements, the nuclear scattering amplitude can be computed with

$$f_C(\theta) = -\frac{\eta}{2k}\frac{1}{sin^2\theta/2}exp[2i(\sigma_0 - \eta lnsin\,\theta/2)]$$

$$f_N(\theta) = \sum_{l=0}^{\infty}(2l+1)i^{2i\sigma_l}\frac{S_l - 1}{2ik}P_l(cos\theta)$$

here $\sigma_l = arg\Gamma(l+1+i\eta)$ are the Coulomb phase shifts, $\eta = k\,(Z_1Z_2e^2)/2E$ is the Sommerfeld parameter, $S_l = exp(\delta_l)$ are the partial matrix elements, and δ_l are the partial nuclear phase shifts. These parameters can be computed numerically by solving the radial Schrödinger equations (Cinan et al., 2018; Hogdson, 1963; Zagrabaev et al., 1999; Denikin et al., 2010; Karpov et al., 2015; Karpov et al.,2016)

then the differential cross section of elastic scattering is presented with

$$\left[\frac{d\sigma}{d\Omega}(\theta)\right]_{elastic} = |f_C(\theta) + f_N(\theta)|^2$$

3. Result and Discussions

All calculations have performed with the Nuclear Reaction Video (NRV) Project (Zagrabaev et al., 1999). On account of a given series of the optical model parameters, NRV code computes and presents all of the calculations in diagrammatic and chart forms. A detection of the parameters were carried out via a suitability of the elastic scattering angular dispersion calculated to the available experimental data (Zagrabaev et al., 1999; Denikin et al., 2010; Karpov et al., 2015; Karpov et al.,2016; Zumbro et al., 1983).

We have analyzed ^{3}He+^{stable}Se system at 24 MeV. Firstly, we have designated potential parameters for optical model. We have rescheduled optical model potential parameters. We have utilized Woods-Saxon shape or both the real and imaginary part of optical potential (Bechetti et al., 1971).

Optical potential parameters for our reactions have been listed in Table 1.

Table 1. The parameters of optical model for ^{3}He+^{stable}Se elastic scattering calculations at 24 MeV.

REACTIONS	$V_0(MeV)$	$r_0(R)(fm)$	$a(fm)$
$^3He + {}^{74}Se$	151.709	0.893(5.037)	0.72
$^3He + {}^{76}Se$	152.922	0.895(5.082)	0.72
$^3He + {}^{77}Se$	153.505	0.896(5.104)	0.72
$^3He + {}^{78}Se$	154.073	0.897(5.126)	0.72
$^3He + {}^{80}Se$	155.167	0.899(5.17)	0.72
$^3He + {}^{82}Se$	156.207	0.9(5.208)	0.72

$W_0(MeV)$		$r_0(R)(fm)$		$a(fm)$	
Before Fitting	*After Fitting*	*Before Fitting*	*After Fitting*	*Before Fitting*	*After Fitting*
37.026	-	1.042(5.877)	-	0.88	-
38.099	24.883	1.044(5.928)	1.001(5.684)	0.88	0.855
38.614	-	1.045(5.953)	-	0.88	-
39.116	15.502	1.046(5.978)	1.39(7.944)	0.88	0.847
40.083	77.48	1.048(6.027)	0.861(4.952)	0.88	1.001
41.002	-	1.051(6.082)	-	0.88	-

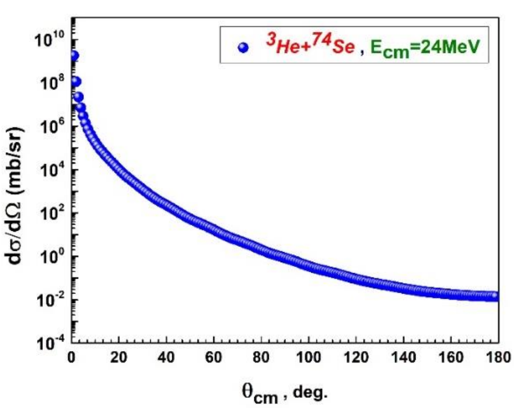
The total reaction cross sections σ_R have been calculated from the various sets of optical potentials. These results have been listed in Table 2.

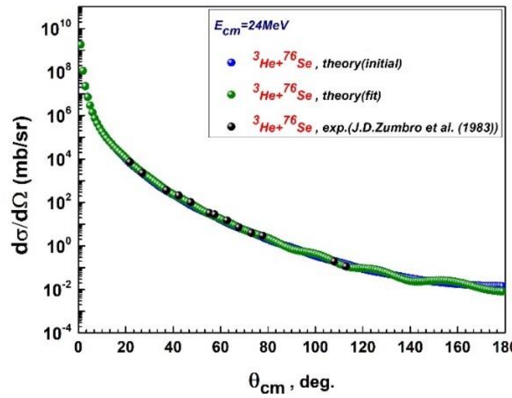
Table 2. Cross sections for ^{3}He+$^{stable}Se$ elastic scattering calculations at 24 MeV.

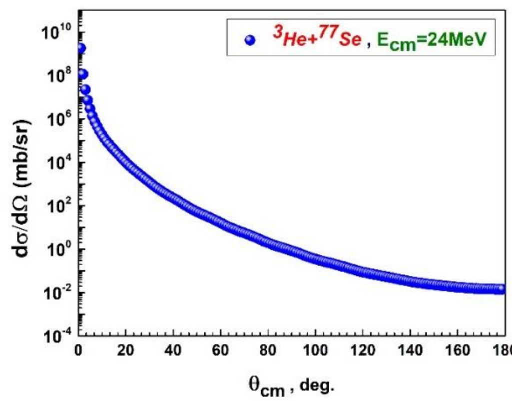
REACTIONS	σ_R, mb		σ_{tot}, mb	
	Before Fitting	*After Fitting*	*Before Fitting*	*After Fitting*
$^{3}He+^{74}Se$	1606.12	-	2665.59	-
$^{3}He+^{76}Se$	1639.06		2723.95	2246.63
$^{3}He+^{77}Se$	1655.32	-	2752.85	-
$^{3}He+^{78}Se$	1671.42	2084.20	2781.53	3527.88
$^{3}He+^{80}Se$	1703.25	1710.80	2838.38	2779.61
$^{3}He+^{82}Se$	1735.83	-	2896.28	-

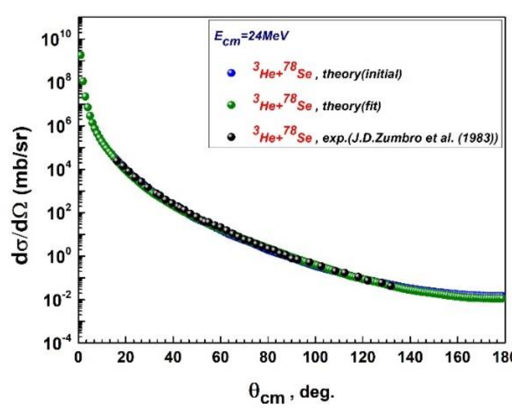
Cross section data for ^{3}He+$^{stable}Se$ have been calculated at an incident ^{3}He energy of 24MeV over the angular range of 0^0 to 180^0. The achieved calculations for optical model are indicated in Figure 1 and 2. We have matched theoretical results with experimental data. The black dots are the experimental data from literature (Zumbro et al., 1983; National Nuclear Data Center (NNDC)). Differentiation of the experimental (black dots) and optical model (blue dots curve) elastic scattering angular distributions were indicated for the ^{3}He+$^{stable}Se$ reactions at E_{cm}=24MeV. Computations were made with series of parameters of optical potential (blue dots curve) and behind self-acting fit of these parameters (green dots curve).

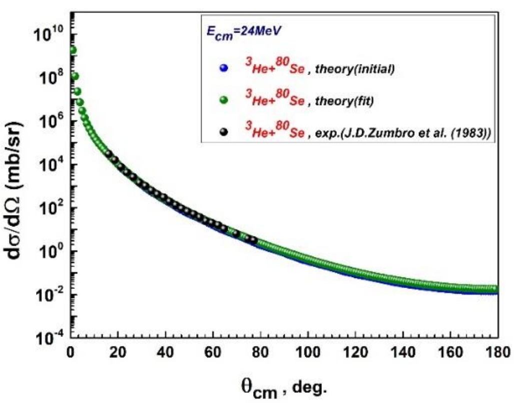
The qualification of our optical model computations were also verified via crosschecking their approximations of angular distributions from elastic scattering with announced experimental data at 24MeV.











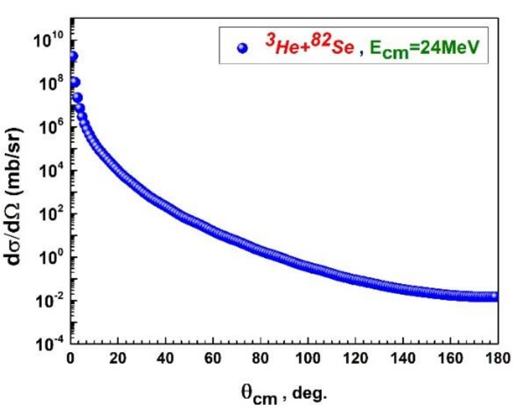
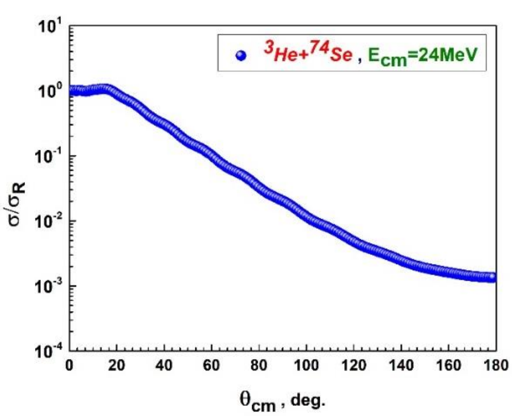
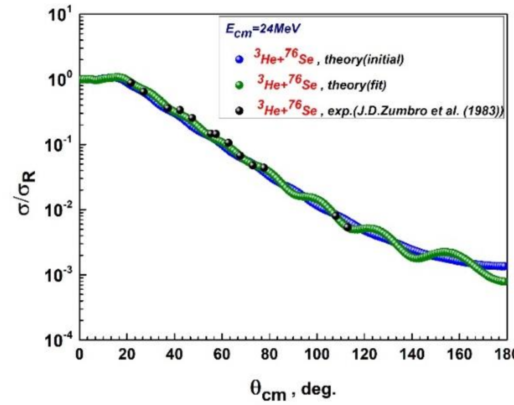
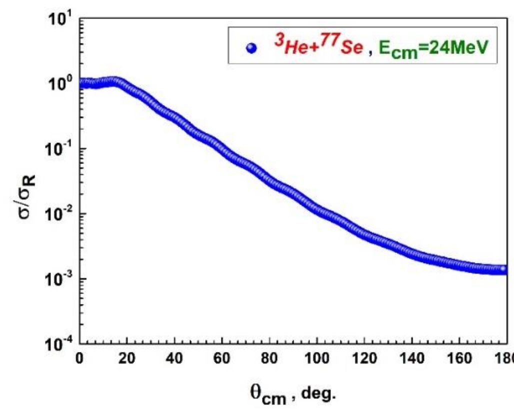
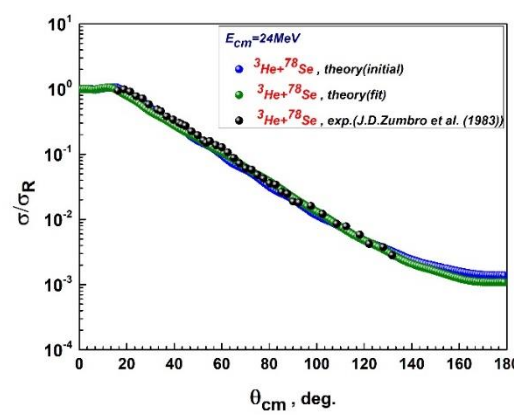


Figure 1. Theoretical and experimental angular distribution results for ^{3}He from stable Se isotopes at 24MeV (Zagrabaev et al., 1999; Denikin et al., 2010; Karpov et al., 2015; Karpov et al.,2016; Zumbro et al., 1983; National Nuclear Data Center (NNDC); International Atomic Energy Agency, Nuclear Data Section (IAEA-NDS); RIPL-3).









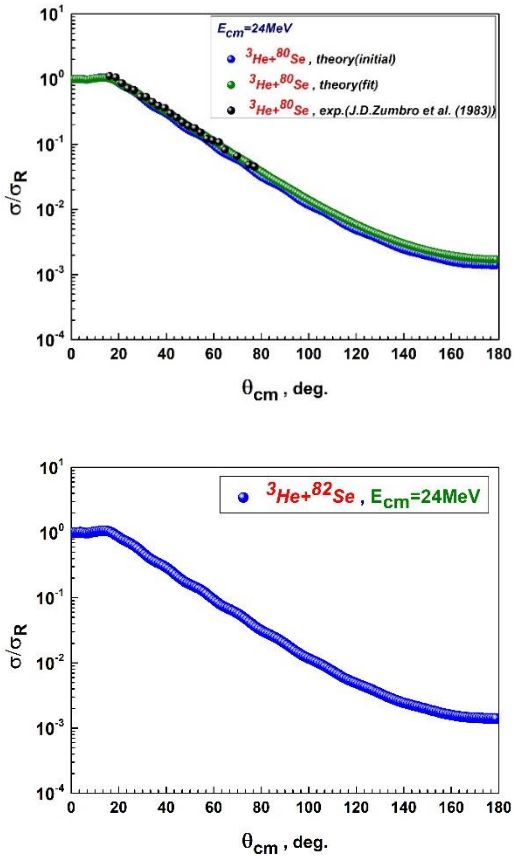


Figure 2. Theoretical and experimental angular distribution results for 3He from stable Se isotopes at 24MeV (Zagrabaev et al., 1999; Denikin et al., 2010; Karpov et al., 2015; Karpov et al.,2016; Zumbro et al., 1983; National Nuclear Data Center (NNDC); International Atomic Energy Agency, Nuclear Data Section (IAEA-NDS); RIPL-3).

4. Conclusions

Our study shows the importance of scattering as a dominant way to understand the key role of the target-projectile effects on the nuclear reaction mechanism at energies in the around the Coulomb barrier.

In this study, we have investigated 3He+stableSe reaction systems with optical model potential parameters at 24MeV. We have analyzed some experimental data on elastic scattering for a given combination of nuclei (projectile+target).

The calculated results are in a good agreement with the experimental data.

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