INFLUENCE OF THE DENSITY DEPENDENCE FACTOR IN EFFECTIVE NUCLEON-NUCLEON FORCES AND INTERACTION OF ^{4}He-PARTICLES WITH STABLE NUCLEI

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Based on semi-microscopic folding model there has been studied influence of the density dependence factor for effective nucleon-nucleon forces on analysis of angular distributions for elastic scattering and total reaction cross-sections at interaction of ^{4}He-particles with stable

nuclei (A = 12–208) within the energy range of 21.0–141.7 MeV. Within the double-folding model 4 possible force variants with various density-dependent forces were considered.

INTRODUCTION

At low and medium energies the most popular method for joint analysis of experimental angular distributions (AD) and total reaction cross-sections (TRCS) is semi-microscopic folding model (SFM) [1]. Since ^{4}He-particle is a core for light exotic nuclei ^{6,8}He, it is of interest to continue systematic study at various variants of effective nucleon-nucleon forces.

For the first time in [2] we have investigated energy and mass dependencies for SFM parameters for ^{4}He-particles at low and medium energies. In those studies complete M3Y-interaction [3] was used as effective forces between nucleons of colliding nuclei and nucleon densities were calculated employing density functional method [4].

Present work based on SFM considers influence of density dependence factor for effective nucleon-nucleon forces (4 force variants considered) on AD and TRCS calculations for ^{4}He-particles interaction with stable nuclei (A = 12–208) at energies of 21.0–141.7 MeV. Corresponding experimental data (AD and TRCS) used for model verification are of high quality and low errors both with regard to angular and energy diapasons. Therefore, conclusions made upon the present study include important quantitative information and are valuable for further comparative analysis of experimental data on interaction of light exotic nuclei with stable nuclei.

EXPERIMENTAL DATA FOR ANALYSIS

To ensure unity of experimental conditions and reliability of analyzed cross-sections for interactions of ^{4}He-particles the experimental data on AD and TRCS previously used and verified by us in [2] were used. In order to investigate energy dependence of SFM parameters there were analyzed 15 AD at a moderate-weight nucleus ^{90}Zr at energies of ^{4}He-particles in the range of 21.0–141.7 MeV. Mass dependence was studied at two energy values (low and medium) of ^{4}He-particles ~ 50.5 and 141 MeV for nuclei A = 12–208. Errors of differential cross-section absolute values for elastic scattering comprised in AD 1–5% and only in several cases (minima of AD at large angles) achieved 6–10 %.

Experimental values TRCS used for investigations of energy and mass dependencies of PFM parameters are described in details in [2] and their errors comprised 4–7 % in this investigated energy region.

EFFECTIVE NUCLEON-NUCLEON FORCES AND APPROACH FOR CONSTRUCTION OF FOLDING-POTENTIALS

Factorization approach for density and coordinate dependencies of effective nucleon-nucleon forces is presented in [5, 6]:

$$V^{D(E)}(s,\rho)=V^{D(E)}(s)\,F(\rho) \tag{1}$$

where s − module of a radius-vector that binds two nucleons in colliding nuclei, superscripts D and E indicate "direct" and "exchange" components of effective forces.

As a part of forces that does not depend on matter distribution density throughout nuclei a complete M3Y interaction [7] based on G-matrix elements of Reid and Elliott interactions can be considered. Form of applied in this case isoscalar and isovector components of the M3Y-interaction is presented in [5].

Factor of density dependence is chosen in the standard form:

$$F_D(\rho)=C[1+d\,\exp(-\gamma\rho)], \tag{2}$$

$$F_B(\rho)=C[1+\alpha\rho^{\beta})]\;. \tag{3}$$

Here, $F_D(\rho)$ corresponds to DDM3Y-interaction and $F_B(\rho)$ – to BDM3Y one. We use M3Y-interaction without consideration of density dependence for further analysis as well as one of the variants of DDM3Y-interaction and two variants of BDM3Y-interaction with parameters, defined in [8]. These parameters are presented in table 1.

Table 1. Parameters of effective nucleon-nucleon forces.

Force	C	D	γ, fm^3	α, fm$^{3\beta}$	β
M3Y	1	0	–	0	–
DDM3Y1	0.2845	3.6391	2.9605	–	–
BDM3Y1	1.2253	–	–	1.5124	1
BDM3Y2	1.0678	–	–	5.1069	2

A procedure for construction of folding-potentials in the double folding model with a factor of density dependence and an approach for construction of nucleon densities are described in details in [5].

ANGULAR DISTRIBUTIONS AND TOTAL REACTION CROSS-SECTIONS FOR ^{4}He-PARTICLES

There are presented calculations of AD for elastic scattering of alpha-particles using four types of effective nucleon-nucleon forces (see Table 1) for 15 light, moderate and heavy nuclei at two energies of ~50.5 and ~141 MeV. Similar calculations were made for α-particle scattering at the nucleus ^{90}Zr at energy range of 21.0–141.7 MeV.

For investigations of the influence from the factor of effective force density dependence we took in consideration the same values for PFM parameters and used various nucleon-nucleon forces (BDM3Y1, BDM3Y2 and DDM3Y1). These values were obtained for the parameters at fitting of theoretical curves to experimental ones using M3Y-effective nucleon-nucleon forces in [2]. Parameters of PFM are presented in tables 2–4.

Table 2. Optimal values of SFM parameters and total reaction cross sections (mb) at nucleus ^{90}Zr for ^{4}He–particles at energy range of 21.0–141.7 MeV.

E_α, MeV	φ_v	N_W	φ_w	TRCS, mb			
				M3Y	BDM3Y1	BDM3Y2	DDM3Y1
21.0	0.010	0.10	-0.010	1007.6	1027.3	1013.3	1033.4
23.4	0.020	0.10	-0.010	1107.0	1126.5	1112.6	1132.6
25.0	0.020	0.10	-0.010	1181.7	1201.4	1187.2	1207.5
31.0	-0.017	0.18	0	1481.0	1500.4	1485.3	1505.7
35.4	0.050	0.10	0	1583.3	1620.3	1597.3	1632.9
40.0	0.045	0.12	-0.012	1830.9	1878.1	1852.4	1892.0
50.1	0.052	0.11	-0.010	1881.4	1922.2	1897.3	1935.6
59.1	0	0.25	-0.015	1829.8	1848.9	1832.4	1854.2
65.0	0	0.18	-0.025	1982.4	1905.3	1888.5	1910.7
79.5	0	0.26	-0.030	1968.6	1987.7	1970.2	1993.3
99.5	-0.20	0.35	-0.032	2049.4	2067.3	2049.3	2072.8
118.0	0	0.35	-0.024	2034.3	2002.2	1984.6	2007.2
141.7	0.013	0.30	-0.022	1972.4	1945.8	1927.9	1033.4

Table 2. Optimal values of SFM parameters and total reaction cross sections (mb) for ^{4}He–particles at $E_\alpha \sim 50.5$ MeV for nuclei A=12–124.

nucleus	φ_v	N_W	φ_w	TRCS, mb			
				M3Y	BDM3Y1	BDM3Y2	DDM3Y1
^{12}C	0	0.37	0	911.0	937.78	921.8	939.3
^{24}Mg	0	0.27	-0.012	1200.8	1226.4	1209.4	1228.8
^{28}Si	0	0.26	-0.010	1251.6	1272.2	1258.9	1276.2
^{48}Ti	0	0.25	0	1477.2	1502.7	1482.7	1503.8
^{50}Ti	0	0.26	-0.021	1616.6	1673.3	1652.1	1676.5
^{58}Ni	-0.011	0.22	-0.012	1550.6	1567.7	1552.4	1571.9
^{68}Zn	-0.015	0.21	-0.022	1742.3	1765.8	1748.5	1770.7
^{70}Zn	-0.010	0.24	-0.023	1776.4	1801.1	1783.4	1806.2
^{90}Zr	0.052	0.11	-0.010	1881.4	1922.2	1897.3	1935.6
^{94}Zr	0.053	0.13	-0.010	1968.2	2014.8	1987.2	2029.5
^{120}Sn	0.051	0.104	-0.007	2014.1	2060.5	2032.9	2075.2
^{124}Sn	0.051	0.13	-0.007	2084.4	2123.8	2095.4	2139.0

Table 2. Optimal values of SFM parameters and total reaction cross sections (mb) for ^{4}He–particles at $E_\alpha \sim 141$ MeV for nuclei A=12–208.

nucleus	φ_v	N_W	φ_w	TRCS, mb			
				M3Y	BDM3Y1	BDM3Y2	DDM3Y1
^{12}C	0.045	0.30	-0.012	725.8	731.01	710.1	731.9
^{40}Ca	0	0.30	-0.030	1442.1	1464.2	1444.4	1466.1
^{46}Ti	0.02	0.30	-0.030	1596.8	1621.9	1602.4	1624.4
^{48}Ti	0.026	0.30	-0.025	1589.1	1613.4	1594.1	1615.8
^{50}Ti	0.026	0.30	-0.022	1590.6	1614.0	1594.7	1616.3
^{58}Ni	0	0.30	-0.030	1694.1	1713.8	1694.6	1716.8
^{90}Zr	0.013	0.30	-0.022	1972.4	1945.8	1927.9	1950.0
^{208}Pb	0.0	0.30	-0.027	2892.5	2924.7	2900.6	2930.5

Fig. 1 presents curves for AD of elastic scattering (α-particles at ^{90}Zr-nucleus) in energy range of 21.0–141.7 MeV. From the figure one can see that at low energies of 21.0–25.0 MeV BDM3Y2-forces poorly describe experimental AD compared to the other three force types. Effective nucleon-nucleon forces M3Y, BDM3Y1 and DDM3Y1 provide equally satisfactory description of AD. With energy growth in the range of 31.0–141.7 MeV discrepancy in description of experimental AD using different effective forces vanishes. In [2] it was shown that effective M3Y-forces produce a good description of experimental TRSC. TRSC values were calculated with all 4 types of effective nucleon-nucleon forces (table 2) and practically don't distinguish from each other (the difference is equal to 2-3% per cent). Therefore, experimental TRCS (see Table 2) are described equally well by all 4 types of effective nucleon-nucleon forces.

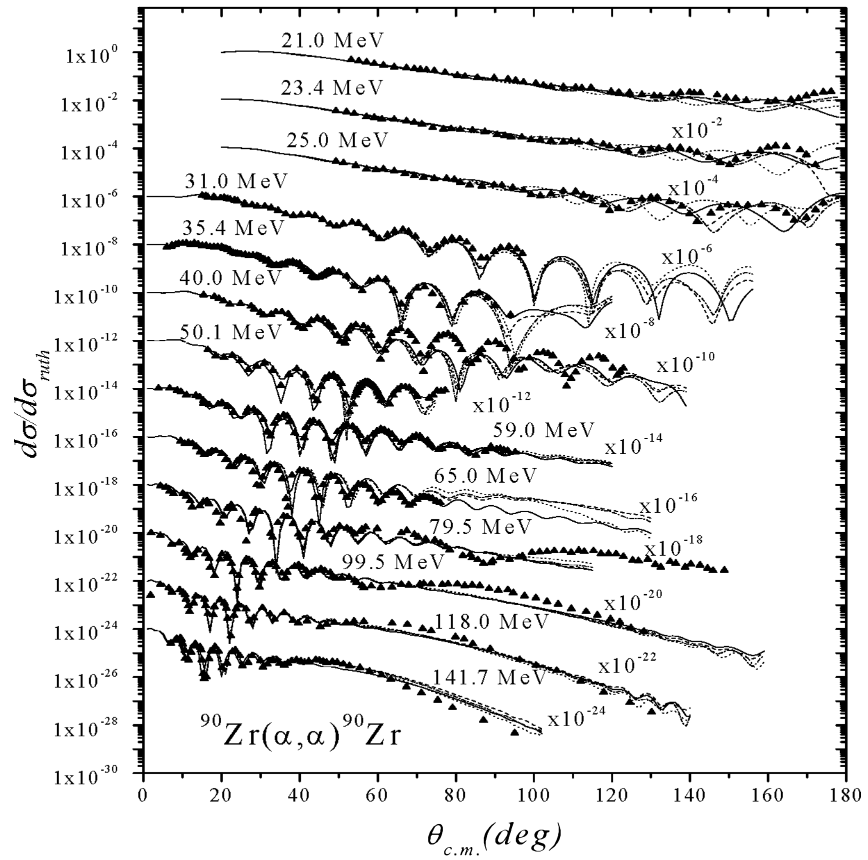

Fig. 1. Angular distributions of differential cross sections of elastic scattering for α–particles at ^{90}Zr. Triangles – experimental data, lines – SFM: solid – M3Y, dash – BDM3Y1, dotted – BDM3Y2, dash-dotted – DDM3Y1.

Figure 2 presents AD for elastic scattering of α-particles at various nuclei at energy ~ 50.5 MeV. From the analysis one can see that at energy ~ 50.5 MeV calculated curves for AD at different effective nucleon-nucleon forces are similar up to 30-40 degrees. In general, theoretical curves that correspond to different types of effective forces describe experimental AD of elastic scattering equally well at energy of about 50.5 MeV.

AD of elastic scattering for ^{4}He-particles at different nuclei at energy ~141 MeV are presented in fig. 2. For investigated nuclei-targets (^{12}C to ^{208}Pb) elastic scattering AD looks like rainbow at scattering angles of 40–80 degrees. In elastic scattering AD For nuclei ^{12}C and ^{40}Ca one can get quite good agreement between theoretical and experimental curves for those angles where the rainbow is observed and in case of consideration of BDM3Y2 effective nucleon-nucleon forces. At the same time we were not able to improve description of experimental AD for nuclei ^{12}C and ^{40}Ca at scattering angles exceeding 40 degrees when used M3Y effective forces. For other angles (^{46}Ti to ^{208}Pb) considerable discrepancy in description of various types of effective forces is not revealed.

As in case of energy dependence, for mass dependence at energies ~50.5 and ~141 MeV the experimental TRCS (tables 3 and 4) are described equally well by all 4 types of effective nucleon-nucleon forces.

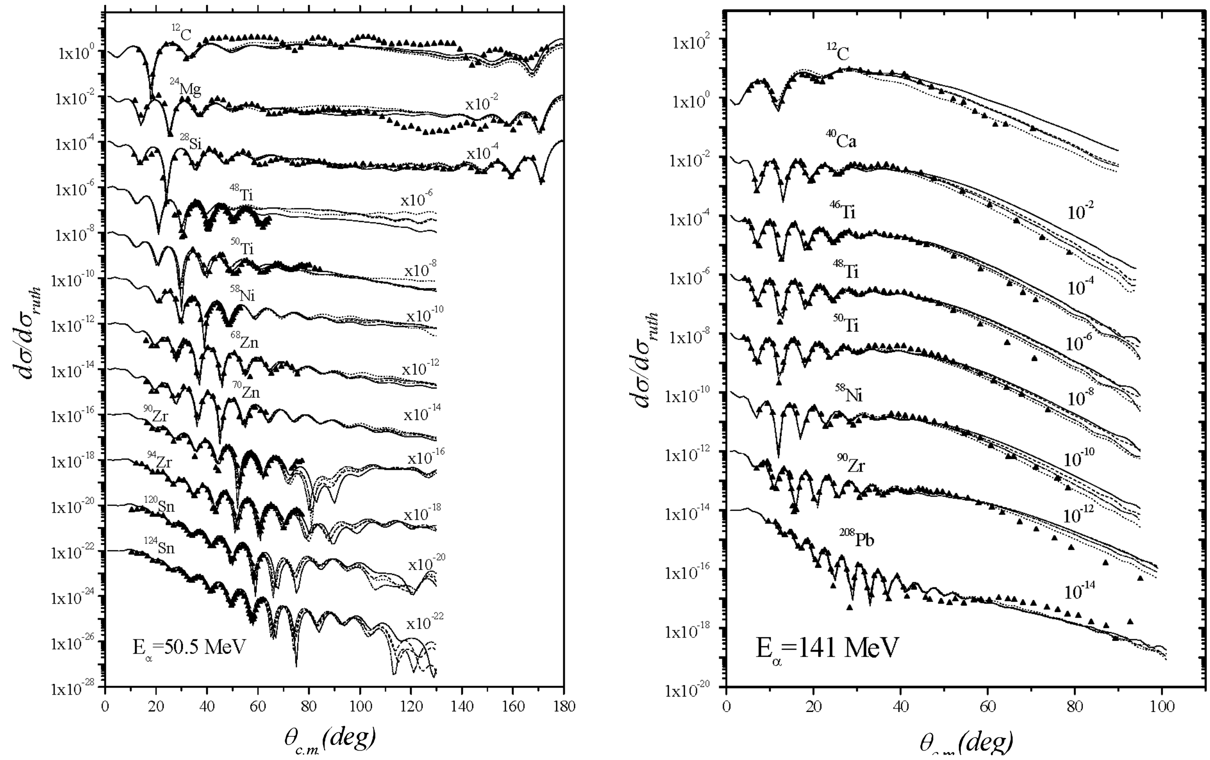

Fig. 2. Angular distributions of differential cross sections of elastic scattering for α–particles with E_α ~ 50.5 MeV and 141 MeV at nuclei A=12–208. Triangles – experimental data, lines – SFM: solid – M3Y, dash – BDM3Y1, dotted – BDM3Y2, dash-dotted – DDM3Y1.

REFERENCES

1. O.M. Knyazkov, I.N. Kukchtina, S.A. Fayans, *Fiz. Elem. Chastits At. Yadra* 30, 870 (1999); O.M. Knyazkov, I.N. Kuchtina, S.A. Fayans, *Fiz. Elem. Chastits At. Yadra* 28, 1061 (1997).
2. K.A. Kuterbekov, I.N.Kukhtina, T.K. Zholdybayev, Yu.E. Penionzkevich, Preprint JINR P17-2003-200, Dubna, 2003, 25 p. Submitted in *Yad.Fiz.*, 2005 № 3.
3. O.M. Knyazkov, A.A. Kolozhvari, I.N. Kukhtina, S.A. Fayans, *Yad.Fiz.* 59, 466 (1996).
4. A.V. Smirnov, S.V. Tolokonnikov, S.A. Fayans, *Yad.Fiz.* 48, 1661 (1988); S.A. Fayans, A.P. Platonov, G. Graw, D. Hofer, *Nucl. Phys.* A 577, 557 (1994); S.A. Fayans, S.V. Tolokonnikov, E.L. Trykov, D. Zawischa, *Phys. Lett.* B 338, 1 (1994).
5. D.V. Bolotov, O.M. Knyazkov, I.N. Kukhtina, S.A. Fayans, *Yad.Fiz.* 63, 1631 (2000).
6. A.M. Kobos, B.A. Brown, P.E. Hodgson et al., *Nucl. Phys.* A 384, 65 (1982).
7. G. Bertsch, J. Borysowicz, H. McManus et al., *Nucl. Phys.* A284, 399 (1977).
8. D.T. Khoa, W. von Oertzen, *Phys. Lett.* B 304, 8 (1993).