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РЕСПУБЛИКИ КАЗАХСТАН

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INVESTIGATION OF DEUTERON SCATTERING BY ^{7}Li NUCLEI AT ENERGY OF 14.5 MeV

Abstract. The pronounced cluster structure of lithium isotopes is an excellent test for verification the various theoretical nuclear models. The study of the cluster exchange mechanism in direct nuclear reactions opens new possibilities in determining the structures of these nuclei. The sets of parameters of optical potentials available in the literature are vary, that can lead to ambiguity in determining the cluster spectroscopic factors of the studied nuclei. Therefore, an experimental study of the scattering process at energy E = 14.5 MeV has been carried out in order to obtain an independent global systematic of optical potentials for the d + ^{7}Li system. New experimental data were obtained in the current paper on the elastic and inelastic scattering of deuterons on ^{7}Li nuclei at energy E = 14.5 MeV. In addition to this, in our analysis we used experimental data on elastic scattering, measured previously at deuteron energies from 7 to 28 MeV. The analysis of the differential cross sections was performed within the framework of the optical model. The optimal parameters of optical potentials for the studied nucleus are established. The obtained parameters in this work will be used in the analysis of the data on inelastic scattering of deuterons and the ^{7}Li (d, t) reaction to refine the structural characteristics of lithium isotopes.
Keywords: lithium nuclei, differential cross sections, elastic and inelastic scattering, optical potential.

Introduction

The systematics of the proton and α-particles scattering by light nuclei at an energy of about 10 MeV/nucleon showed an anomalous growth of cross sections at the large angles. It was shown [1–5], that other mechanism, such as exchange processes, make a significant contribution to the formation of a scattering cross section in this energy region.

At present, scattering of α-particles by ^{6}Li and ^{7}Li nuclei, having a pronounced cluster structure, was systematically studied. The anomalous large-angle scattering (ALAS), observed in [1-4], can be only described with taking into account the contribution of the cluster exchange mechanism, which is physically indistinguishable from potential scattering. Therefore, in a number of papers [4, 6], with taking into account this mechanism, it was possible not only to obtain more reliable parameters of the optical potentials, but also to extract the values of cluster spectroscopic factors from the cross sections analysis at large angles. In particular, the values of the spectroscopic factors were obtained for the configurations d +α, ^{3}He + t and t + α, and not only for the ground, but also for the excited states of the ^{6,7}Li nuclei from the analysis of the scattering of ^{3}He and α - particles. A systematic analysis of the deuteron scattering on ^{6}Li nuclei, performed in [4] in wide energy range, confirmed the possibility of describing the behavior of the cross sections at backward angles by the exchange mechanism. The differential cross sections of the transfer of the alpha cluster were obtained taking into account the channels coupling and the spectroscopic factor for the configuration of the ^{6}Li nucleus as d + α, which is close to 1.

In the present work, to determine the parameters of the optical potential for the ^{7}Li nucleus, the scattering of deuterons was studied not only at 14.5 MeV, but also at other energies using literature data.

Experimental method and results of the measurements

The experimental angular distribution of the deuteron elastic scattering by ^{7}Li was measured at the energy of 14.5 MeV. The deuteron beam was extracted from the U150-M isochronous cyclotron of the Institute of Nuclear Physics (Almaty, Kazakhstan).

The scattering chamber [7], used in the experiment, allowed to measure both in the region of small scattering angles (from 3° to 22°) and in the wide angular range (10°≤θ≤170°). The metal lithium with 90% enrichment of ^{7}Li was used as a target. It was manufactured by thermal evaporation of lithium on a thin alundum (Al_2O_3) film (30 μg/cm^2) in vacuum. After deposition, the target was transferred to a scattering chamber without breaking the vacuum. The target thickness was determined by weighing, as well as the energy losses of α-particles from the radioactive source ^{241}Am-^{243}Am-^{244}Cm and ^{239}Pu. The ^{7}Li target thickness was determined as 0.393 ± 0.030 mg/cm^2.

For the registration and identification of nuclear reactions products the Δ*E*-*E* method was used [8]. Thin surface-barrier silicon detectors with thicknesses of 100 or 50 μm (for small angles) and 30 μm (for large angles) were used as a Δ*E* counters. As the *E* counter, a surface barrier silicon detector with a thickness of 2 mm was used.

The angular distribution of the deuteron elastic scattering by ^{7}Li nuclei was measured in the angular range of 18^0–128^0 with step 2^0. The systematic error in the cross sections is related with the uncertainty of the target thickness (6–9%), of the solid angle of the spectrometer (1%) and of the calibration of the current integrator (<1%). The statistical errors of the analyzed data are 1-5% and reached 6-15% only in the minimum of the cross sections.

The energy resolution of the registration system (~ 150 keV) allowed to reliably identify all low-lying levels of the ^{7}Li nucleus. Typical spectrum of deuterons is shown in Fig. 1a. The transitions to states with excitation energies E_x = 0.478 MeV (1/2$^-$) and 4.65 MeV (7/2$^-$) as well as the elastic peak (3/2$^-$) were observed in the spectrum of deuterons. The peaks corresponding to the excited states of the ^{12}C (4.43 MeV) and ^{16}O (6.09 MeV) nuclei (due to the presence of carbon and oxygen impurities in the target) were not reliably separated from the 4.65 MeV state of the ^{7}Li nucleus. Thus, this state was excluded from further analysis.

The energy peaks located higher from the ground state of ^{7}Li belong to the nuclei of oxygen, aluminum (from the substrate) and carbon. The presence of carbon is due to its deposition on the target during the experiment.

When analyzing elastic scattering at small angles, the contribution of impurities was taken into account using literature data on the elastic scattering of deuterons by ^{12}C, ^{16}O nuclei at an energy of *E* = 13.6 MeV [9].

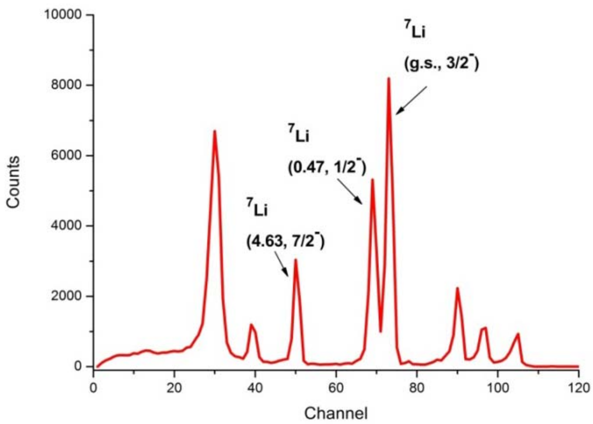

Fig. 1a. Energy spectrum of deuterons scattered by ^{7}Li (θ_{lab} = 70^o) at the energy of 14.5 MeV.

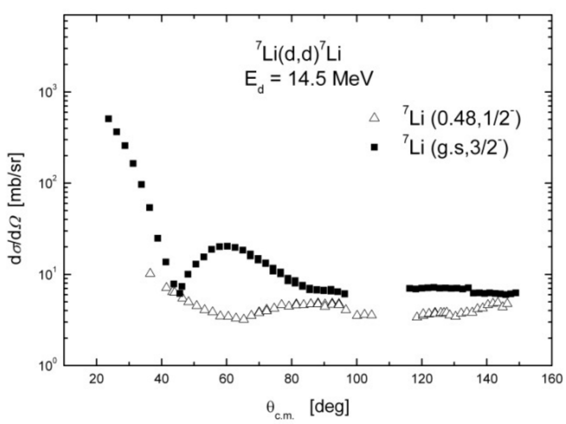

Fig. 1b. Differential scattering cross sections of deuterons scattered by ^{7}Li at *E* = 14.5 MeV.
Black squares - elastic scattering cross sections;
white triangles - inelastic scattering cross sections.

The Fig. 1b shows measured differential cross sections for deuteron scattering by ^{7}Li at the energy of 14.5 MeV. As it can be seen from figure, the diffraction structure is characteristic for the measured angular distributions. In contrast to deuteron scattering on ^{6}Li nuclei [4], for which a significant rise of the cross sections is observed in the backward hemisphere, the scattering cross sections for ^{7}Li gradually decrease with increasing of the scattering angle. This fact confirms the absence of deuteron cluster in the ^{7}Li nucleus. It should be noted that the experimental data measured at the energy of 14.5 MeV are in good agreement within experimental errors with literature data for the energy of 14.7 MeV [10].

Analysis of elastic scattering of deuterons by the optical model and discussion of the results

The differential cross sections of the elastic scattering were calculated in the framework of the optical model (OM) [11]. The parameters of the phenomenological optical potential (OP) were found by comparing the calculated angular distribution with the experimental data. The potential is used in the Woods-Saxon parameterization, which well reproduces the distribution of nuclear matter:

$$U(r) = -Vf(r) + i4a_D W_D \frac{df_w(r)}{dr} + V_{so}\left(\frac{h}{m_\pi c}\right)^2 \frac{1}{r}\frac{d}{dr} f_{so}(r)(LS) + V_C(r) \quad (1)$$

The first two terms are responsible for the nuclear central interaction with surface absorption. The third term is the spin-orbit potential. V and W_D are the depths of the real and imaginary parts of the optical potential with surface absorption. V_{SO} is the depth of the real part of the spin-orbit potential. Radial dependence $f_i(\mathrm{r})$ is described by the Woods-Saxon form factor with a reduced radius r_i and diffuseness a_i, where i is R, D or SO:

$$f_i = \left[1 + \exp((r - r_i A^{1/3}) / a_i)\right]^{-1}, \quad (2)$$

$V_C\ (r)$ is the Coulomb potential of uniformly charged sphere with radius R_C:

$$V_C(r) = Z_p Z_t e^2/R_C, \text{ when } r > R_C, \quad (3)$$

where Z_p, Z_t are the charges of the incident projectile (p) and the target (t). In our calculations $R_C = r_C A^{1/3}$, where r_C =1.30 fm.

The parameters of the potential corresponding to the best description of the experimental cross sections were found by minimizing the value of χ^2:

$$\chi^2 = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{\sigma^T(\theta_i) - \sigma^E(\theta_i)}{\Delta\sigma^E(\theta_i)}\right]^2, \quad (4)$$

where N - the number of experimental points in the angular distribution, σ^T and σ^E - the calculated and measured values of the differential scattering cross section at angle θ_i, $\Delta\sigma^E$- the uncertainty of the σ^E value.

It should be noted that choosing this potential as optimal, we follow the physically reasonable value of the volume integral of the real part defined as:

$$J_V = (1/A_p A_t) \int V(r) 4\pi r^2 dr, \quad (5)$$

where A_p and A_t are the mass numbers of the incident projectile and the target nucleus. Its value should be close to the corresponding value of the nucleon-nucleon ·interaction potential, which is approximately equal to 400 MeV fm^3 [12].

It is well known that the parameters of the optical potentials have discrete and continuous uncertainties [13]. Therefore, to eliminate the discrete uncertainty of the real part of the potential, the potential energy dependence is often used.

For this purpose, global systematic of the OP parameters for the d + ^{7}Li system was performed in a wide energy range using literature data. For this purpose, experimental data on the elastic scattering of deuterons on ^{7}Li measured at energies 7–12 MeV [14, 15], 14.7 MeV [10], 25 MeV [16] and 27.7 [17] were used.

It has been established that with energy increasing of the incident particle, the discrete uncertainty is eliminated, for example, at energies above 12 MeV/nucleon. According to this, first of all, the experimental data were analyzed at energies of 28 and 25 MeV. As starting parameters, the values from [18] were used, which were established by the global systematic of the optical potentials for the elastic scattering of deuterons in the energy range 20–90 MeV for the atomic mass range from A = 12 to A = 238.

The search of the parameters of the optical potential was carried out by fitting the calculated angular distributions with the experimental data using the FRESCO code [19]. To eliminate the discrete uncertainty in determining the optical parameters, the radii of the real (r_V) and imaginary (r_W) parts of the potentials were fixed. The theoretical calculations were fitted to experimental data by varying the 4 remaining OP parameters (V_R, W_D, a_R and a_D). The fitting of the calculated cross sections to the experimental data was performed at the maximum angular range. The diffuseness's (a), established in such approach, strongly depend on the energy at low energies (see Fig.2a) which probably reflect the effects of the resonances in the d + ^{7}Li system (set A in the Table). It can be seen from the figure 2a, the diffuseness's become constant with energy increasing.

The second set of OP (B) is obtained using these fixed values a_R = 0.9 fm and a_W = 0.75 fm. Next, to clarify the dynamics of eliminating discrete ambiguity, the dependence of χ^2 on the depth of the real part for this set was studied. The depth values varied from 30 MeV to 250 MeV with step of 10 MeV. The results are shown in figure 2b. It can be seen that several minimums are observed at low energies. This indicates the presence of discrete families of OPs. With energy increasing, the number of minimums decreases up to one.

As one would expect, with the increase in the energy of the incident particles, the discrete uncertainty of the depth of the real part of the potential was eliminated. The results of the description of the experimental angular distributions of the elastic scattering of deuterons on the studied nucleus are presented in Fig. 3. Since the experimental data on the elastic scattering at energies of 14.7 and 14.5 MeV are virtually indistinguishable within the limits of the error, the graphs show data at 14.7 MeV (these data cover more large angles).

As a comparison, Fig. 3 shows the calculations of the angular distributions of elastic scattering performed using the optimal OP sets from [20] (Set C); [21] (Set D) (see Table).

As can be seen from the Fig. 3, the theoretical calculations performed using the OP sets from this work better describe the differential cross sections for the elastic scattering of deuterons in the investigated energy range.

The optimal OP parameters established in this work will be used in the data analysis of the inelastic scattering of deuterons and ^{7}Li(d, t) reactions at energy of 14.5 MeV to clarify the structure of lithium isotopes.

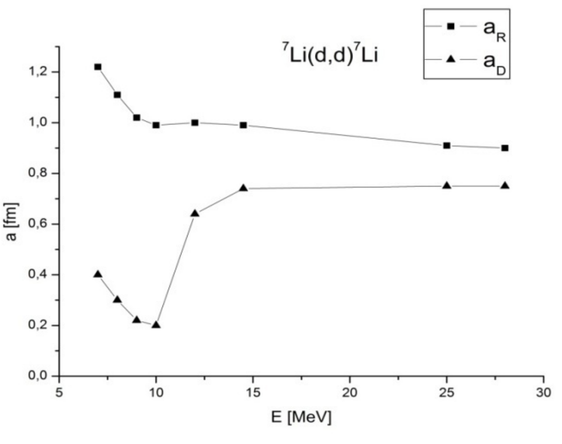

Fig.2a. The energy dependence of the OP diffuseness's for the deuteron scattering by ^{7}Li.

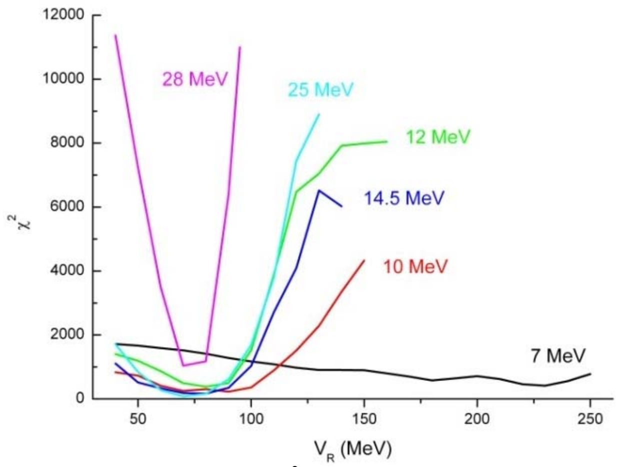

Fig. 2b. The dependence of χ^2 on the depth of the real part of the potential.

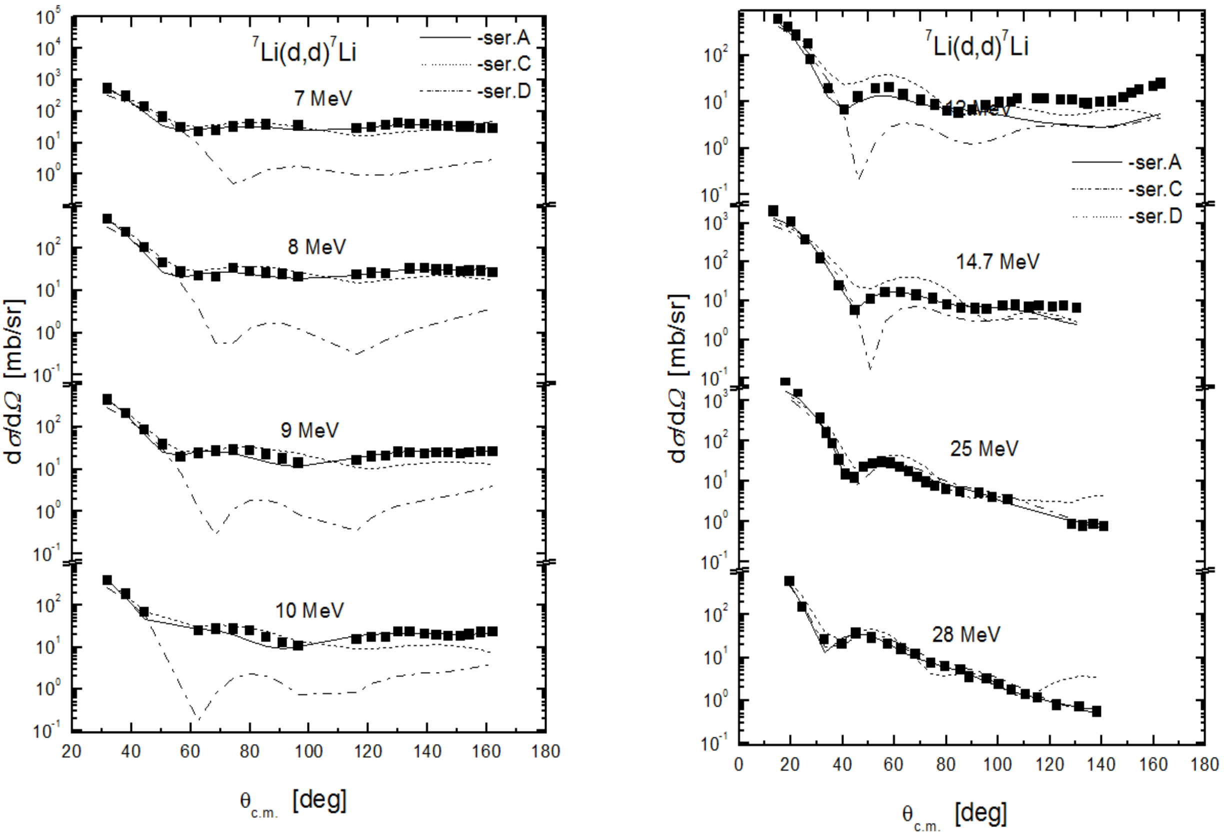

Fig. 3. Differential cross sections of the elastic scattering of deuterons on ^{7}Li nucleus at different energies. Symbols - experimental data, solid lines - OM calculations with set A; dotted lines - calculations with set C; dash-dotted lines - calculations with set D.

Table – Optical potential parameters for elastic scattering ^{7}Li + *d*

E_d, MeV	Set	V_R (MeV)	r_R (fm)	a_R (fm)	W_D (MeV)	r_D (fm)	a_D (fm)	V_{SO} (MeV)	r_{SO} (fm)	a_{SO} (fm)	r_C (fm)
7	A	62.96	1.17	1.22	9.08	1.325	0.4	6.76	1.07	0.66	1.3
	B	89.7	1.17	0.9	3.99	1.325	0.75	6.76	1.07	0.66	1.3
	C	66.0	1.35	0.9	4.5	2.37	0.3	8.0	0.86	0.25	1.3
	D	77.78	1.173	0.809	14.21	1.327	0.551	3.703	1.23	0.813	1.69
8	A	67.53	1.17	1.105	12.47	1.325	0.304	6.76	1.07	0.66	1.3
	B	91.62	1.17	0.9	4.36	1.325	0.75	6.76	1.07	0.66	1.3
	C	65.0	1.35	0.88	4.9	2.3	0.3	8.0	0.86	0.25	1.3
	D	77.62	1.173	0.809	14.13	1.327	0.551	3.702	1.23	0.813	1.69
9	A	72.65	1.17	1.02	19.22	1.325	0.217	6.76	1.07	0.66	1.3
	B	94.31	1.17	0.9	4.87	1.325	0.75	6.76	1.07	0.66	1.3
	C	62.0	1.35	0.86	6.0	2.15	0.3	8.0	0.86	0.25	1.3
	D	77.46	1.173	0.809	14.05	1.327	0.551	3.702	1.23	0.813	1.69
10	A	73.41	1.17	0.988	23.29	1.325	0.195	6.76	1.07	0.66	1.3
	B	95.85	1.17	0.9	4.65	1.325	0.75	6.76	1.07	0.66	1.3
	C	61.5	1.35	0.83	7.2	2.18	0.3	8.0	0.86	0.25	1.3
	D	77.29	1.173	0.809	13.974	1.327	0.551	3.702	1.23	0.813	1.69
12	A	68.84	1.17	1.0	11.08	1.325	0.64	6.76	1.07	0.66	1.3
	B	72.35	1.17	0.9	6.21	1.325	0.75	6.76	1.07	0.66	1.3
	C	64.0	1.35	0.79	10.5	2.1	0.3	8.0	0.86	0.25	1.3
	D	76.96	1.173	0.809	13.815	1.327	0.551	3.702	1.23	0.813	1.69
14.7	A	73.97	1.17	0.986	9.57	1.325	0.74	6.76	1.07	0.66	1.3
	B	73.08	1.17	0.9	7.95	1.325	0.75	6.76	1.07	0.66	1.3
	C	62.0	1.35	0.73	12.0	2.0	0.3	8.0	0.86	0.25	1.3
	D	76.49	1.173	0.809	13.60	1.327	0.551	3.702	1.23	0.813	1.69

Продолжение таблицы

E_d, MeV	Set	V_R (MeV)	r_R (fm)	a_R (fm)	W_D (MeV)	r_D (fm)	a_D (fm)	V_{SO} (MeV)	r_{SO} (fm)	a_{SO} (fm)	r_C (fm)
25	A	81.14	1.17	0.91	14.37	1.325	0.75	6.76	1.07	0.66	1.3
	B	75.94	1.17	0.9	10.7	1.325	0.75	6.76	1.07	0.66	1.3
	C	57.0	1.35	0.72	12.9	1.94	0.3	8.0	0.86	0.25	1.3
	D	74.60	1.173	0.809	12.78	1.327	0.551	3.70	1.23	0.813	1.69
28	A	75.32	1.17	0.9	10.28	1.325	0.75	6.76	1.07	0.66	1.3
	B	75.32	1.17	0.9	10.28	1.325	0.75	6.76	1.07	0.66	1.3
	C	55.62	1.35	0.72	12.9	1.94	0.3	8.0	0.86	0.25	1.3
	D	74.02	1.173	0.809	12.54	1.327	0.551	3.70	1.235	0.813	1.69

Conclusions

Differential cross sections of the deuteron elastic scattering by ^{7}Li were measured at the energy of 14.5 MeV in the angular range from 18^0 to 128^0. In addition to the angular distribution of elastic scattering, measured by us, in the optical-model analysis, we used other experimental data obtained earlier in the energy range of 7-28 MeV. As result, the optimal parameters of optical potentials were found, which correctly describe the angular distributions at the different beam energies in the full angular range.

It is shown that the diffusion parameter (a) strongly depends on the energy up to E_d = 15 MeV, and at higher energies this parameter practically does not change its values.

The dependence of χ^2 on the depth of the real potential shows that several minimums are observed at low energies and at the higher energies (E_d > 20 MeV) the number of minimums decreases up to one. This indicates the elimination of a discrete ambiguity in determining the real part of the potential.

REFERENCE

[1] Bachelier D, Bernas M, Boyard JL, Harney HL, Jourdain JC, Radvanyi P, Roy-Stephan M, Devries R (1972) Exchange effect in the 166 MeV α-particle elastic scattering on ^{6}Li, Nuclear Physics A, 195:361-368. DOI: 10.1016/0375-9474(72)91064-0 (in English).

[2] Goldberg VZ, Gridnev KA, Hefter EF, Novatskii BG (1975) Exchange effects in the scattering of α-particles and deuterons by ^{6}Li, Physical Letters B, 58:405-407. DOI: 10.1016/0370-2693(75)90572-9 (in English).

[3] Bragin VN, Burtebaev N, Duysebaev A, Ivanov GN, Sakuta SB, Chuev VI, Chulkov LV (1986) The role of exchange effects in the elastic scattering of α-particles and ^{3}He ions on ^{6}Li nuclei, Yad.Fiz., 44: 312-319. DOI: 10.1134/S1063778812040138 (in Russian).

[4] Sakuta SB, Artemov SV, Burtebaev N, Kerimkulov ZhK, Novatsky BG, Stepanov DN, Yarmukhamedov R (2009) The Role of Channels Coupling and Exchange Mechanisms with Deuteron in Anomalous Scattering of α-particles on ^{6}Li, Physics of Atomic nuclei, 72:2046-2055. (in English).

[5] Goldberg DA, Smith SM, Burdzik GF (1974) Refractive behavior in intermediate-energy alpha scattering, Phys Rev C, 10:1362. DOI: 10.1103/PhysRevC.10.1362 (in English).

[6] Sakuta SB, Burtebayev N, Burtebayeva JT, Duisebayev A et al. (2014) The channel coupling and triton cluster exchange effects in scattering of ^{3}He ions on ^{6}Li nuclei, Acta Phys Pol B, 45:1853-1863. DOI: 10.5506/APhysPolB.45.1853 (in English).

[7] Artemov SV, Bazhazhin AG, Baktybaev MK, Burtebaev N, Duysebaev A, Duysebayev BA, Zarifov RA, Kadyrzhanov KK, Karakhodzhaev AA, Sakhiev SK, Satpayev NK, Sargaskaev AM, Seytimbetov AM (2006) Bulletin of the National Academy of Sciences of Kazakhstan [Izvestija Akademii Nauk Kazahstana serija fizicheskaja] 6:61-64. (in Russian) **https://doi.org/10.32014/2018.2518-1726**

ISSN 2518-1726 (Online), ISSN 1991-346X (Print)

[8] Artemov SV, Bazhazhin AG, Burtebaev N, Baktybaev M K, Karakhodzhayev A A, Nam IV, Nebesny AF, Radiuk GA, Yakushev VP (2009) Instruments and Experimental Technique [Pribory i Tehnika Jeksperimenta] 1:1668-170. (in Russian).

[9] Vereshchagin AN, Korostova IN, Sokolov LS, Tokarevskii VV, Chernov IP (1969) News of the National Academy of Sciences of Kazakhstan [Izvestija Akademii Nauk Kazahstana serija fizicheskaja] 32:573. (in Russian) **https://doi.org/10.32014/2018.2518-1726**

ISSN 2518-1726 (Online), ISSN 1991-346X (Print)

[10] Matsuki S, Yamashita S, Fukunaga K, Nguyen DC, Fujiwara N, Yanabu T (1969) Elastic and inelastic scattering of 14.7 MeV deuterons and of 29.4 MeV alpha-particles on ^{6}Li and ^{7}Li, Jpn Phys J, 26:1344. DOI: 10.1143/JPSJ.26.1344 (in English).

[11] Hodgson PE (1967) The Optical Model of the Nucleon-Nucleus Interaction, Annual Review on nuclear Science, 17:1-32. DOI: 10.1146/annurev.ns.17.120167.000245 (in English).

[12] Barret R (1977) Nuclear sizes and structure, Clarendon Press, Oxford. ISBN-10: 0198512724.

[13] Goldberg DA and Smith SM (1972) Criteria for the Elimination of Discrete Ambiguities in Nuclear Optical Potentials, Phys Rev Lett, 29:500-504. DOI: 10.1103/PhysRevLett.29.500 (in English).

[14] Abramovich SN, Guzjovskii BYa, Dzyuba BM, Zvenigorods AG, Trusillo SV, Sleptsov GN (1976) Physics of Atomic nuclei [Yad. Fiz.] 40:842. (in Russian).

[15] Bingham HG, Zander AR, Kemper KW, Fletcher NR (1971) Elastic scattering of deuterons by ^{6}Li and ^{7}Li at 8.0–12.0 MeV, Nuclear Physics A, 173:265-272. DOI: 10.1016/0375-9474(71)90344-7 (in English).

[16] Burtebayev N, Burtebayeva JT, Duisebayev A et al. (2015) Mechanism of the ^{7}Li(d,t) reaction at 25 MeV energy of deuterons, values of spectroscopic factors and asymptotic normalization coefficients for the ^{7}Li → ^{6}Li+n vertex, Acta Phys Pol B, 46:1037-1054. DOI: 10.5506/APhysPolB.46.1037 (in English).

[17] Slobodrian RJ (1962) Scattering of 27.7 MeV deuterons on beryllium and boron, Nuclear Physics, 32:684-694. DOI: 10.1016/0029-5582(62)90370-X (in English).

[18] Daehnick WW et al (1980) Global optical model potential for elastic deuteron scattering from 12 to 90 MeV, Phys Rev C, 21:2253. DOI: 10.1103/PhysRevC.21.2253 (in English).

[19] Thompson IJ (1988) Coupled reaction channels calculations in nuclear physics, Comput Phys Rep, 7:167-212. DOI: 10.1016/0167-7977(88)90005-6 (in English).

[20] Avrigeanu M, Oertzen W, Fischer U, Avrigeanu V (2005) Analysis of deuteron elastic scattering on ^{6,7}Li up to 50 MeV, Nucl Phys A, 759:327. DOI: 10.1016/j.nuclphysa.2005.05.153 (in English).

[21] Yinlu H, Qingbiao S (1997) Analysis and Prediction of the Cross Sections of d + ^{6}Li and d + ^{7}Be Reactions for Energy up to 30 MeV, INDC (CPR), 042/L:27. (in English).

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ЭНЕРГИСЫ 14.5 МэВ ДЕЙТРОНДАРДЫҢ ^{7}Li ЯДРОЛАРЫНАН ШАШЫРАУЫН ЗЕРТТЕУ

Аннотация. Литий изотоптарының айқын кластерлік құрылымы - әр түрлі теориялық ядролық модельдерді тексеру үшін өте жақсы сынақ болып табылады. Тікелей ядролық реакциялардағы кластерлік алмасу механизмін зерделеу осы ядролардың құрылымын анықтау үшін жаңа мүмкіндіктер ашады. Әдебиеттегі оптикалық потенциалдар параметрлерінің жиынтығы әртүрлі, бұл зерттеліп жатқан ядролардың кластерлік спектроскопиялық факторларын анықтаған кезде бірмәнділіктің болмауына әкелуі мүмкін. Сондықтан, d + ^{7}Li жүйесі үшін оптикалық потенциалдардың тәуелсіз глобалдық жүйелігін алу үшін E = 14.5 МэВ энергиясында шашырау процесіне эксперименттік зерттеу жүргізілді. Жұмыс барысында E = 14.5 МэВ энергиясы жағдайында ^{7}Li ядроларында дейтрондардың серпімді және серпімсіз шашырауы бойынша жаңа эксперименттік деректер алынды. Сонымен қатар біздің сараптамадада дейтрондардың 7 - 28 МэВ аралығында серппімді шашырауының эксперименталдық мәндері қамтылды. Ядроның оптикалық моделінің шеңберінде энергиялардың кең ауқымында серпімді шашыраудың дифференциалдық қималарына талдау жүргізілді. Нәтижесінде, зерттелген ядро үшін оптикалық потенциалдардың оңтайлы параметрлері анықталды. Осы жұмыста алынған параметрлер келешекте литий изотоптарының құрылымдық сипаттамаларын нақтылауға қажетті дейтрондардың серпімсіз шашырауы және ^{7}Li (d, t) реакцияларының бойынша деректерді талдау кезінде пайдаланылады.

Түйін сөздер: литий ядросы, дифференциалдық қима, серпімді және серпімсіз шашыраулар, оптикалық потенциал.

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ИССЛЕДОВАНИЕ РАССЕЯНИЯ ДЕЙТРОНОВ НА ЯДРАХ ^{7}Li ПРИ ЭНЕРГИИ 14.5 МэВ

Аннотация. Выраженная кластерная структура изотопов лития является отличным тестом для проверки различных теоретических ядерных моделей. Изучение механизма обмена кластерами в прямых ядерных реакциях открывает новые возможности определения структур этих ядер. Имеющиеся в литературе наборы параметров оптических потенциалов различны, что может привести к неоднозначности при определении кластерных спектроскопических факторов исследуемых ядер. Поэтому для получения независимой глобальной систематики оптических потенциалов для системы d + ^{7}Li проведено экспериментальное исследование процесса рассеяния при энергии E = 14.5 МэВ. В работе получены новые экспериментальные данные по упругому и неупругому рассеянию дейтронов на ядрах ^{7}Li при энергии E = 14.5 МэВ. В добавление к этому, в нашем анализе были использованы экспериментальные данные по упругому рассеяния, измеренные ранее при энергиях дейтронов от 7 до 28 МэВ. Анализ дифференциальных сечений проводился в рамках оптической модели. Установлены оптимальные параметры оптических потенциалов для исследуемого ядра. Полученные в данной работе параметры в дальнейшем будут использованы при анализе данных по неупругому рассеянию дейтронов и реакций ^{7}Li (d, t) для уточнения структурных характеристик изотопов лития.

Ключевые слова: ядра лития, дифференциальное сечение, упругое и неупругое рассеяние, оптический потенциал.

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МАЗМҰНЫ

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CONTENTS

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