REPORTS OF THE NATIONAL ACADEMY OF SCIENCES
OF THE REPUBLIC OF KAZAKHSTAN
ISSN 2224-5227
Volume 5, Number 309 (2016), 20 – 25

N. Burtebayev[1], Zh.K. Kerimkulov[1], Y.S. Mukhamejanov[2], D.K. Alimov[2]A.S. Demyanova[3], A.N.Danilov[3]

[1]Institute of Nuclear Physics, Almaty, Kazakhstan
[2]Kazakh national university named after al-Farabi, Almaty, Kazakhstan
[3]NRC Kurcatov Institute, Moscow, Russia
e-mail: y.mukhamejanov@gmail.com

STUDY OF SCATTERING OFALPHA PARTICLES FROM ^{11}B NUCLEI AT 50 AND 65 MEV

Abstract. From the point of view of studying excited neutron halo states of light nuclei the states of ^{11}B nucleus is of particular interest, where both cluster configuration such as (2α + t) and the shell model structure can co-exist. Indeed, several studies have suggested that low-lying states ^{11}B, generally have a shell structure, while the cluster structure can be observed in the states with negative parity above or near the clusters breakup threshold.

Study of nuclear reaction is of a special interest as it could provide us with useful information about the nuclear structure, potential parameters, deformation, and transition probabilities. The α-nucleus interaction is an essential tool for the understanding of nuclear structure and nuclear reactions. The concept of the α-particle mean field has been widely used to unify the bound and scattering α-particle states in a similar way to use of the nuclear mean field to calculate the properties of bound single particle states and also the scattering of unbound nucleons by nuclei.

Processes of elastic scattering of ^{4}He ions from ^{11}B nuclei at energies 50 and 65 MeV were studied in this work. Analysis of elastic scattering was made within optical model. Imaginary part had the shape of phenomenological surface Woods-Saxon potential. The calculated theoretical cross sections are in good agreement with experimental data.

The theoretical significance of the study lies in the fact that the issue of the prevalence of light isotopes in the universe and the existence of the neutron halo remains open to this day. The practical significance of the research is to obtain new experimental data on nuclear reactions necessary for the evaluation of use of light nuclei, which will complement the existing base of nuclear data with new data on the cross sections of nuclear reactions and structure of light nuclei useful for the expansion of understanding of the nature of nuclear interactions at low and medium energies.

Keywords: elastic scattering, optical model, FRESCO, optical parameters.

Introduction. From the point of view of studying excited neutron halo states of light nuclei the states of ^{11}B nucleus is of particular interest, where both cluster configuration such as (2α + t) and the shell model structure can co-exist. Indeed, several studies have suggested that low-lying states ^{11}B, generally have a shell structure, while the cluster structure can be observed in the states with negative parity above or near the clusters breakup threshold [1-4].

The nuclear scattering of alpha particles in a number of studies [5-16] has established itself as an extremely important tool to obtain information about nuclear structure. However, the parameters of the optical potential of interaction between the particles with light nuclei at low and medium energies, derived from analysis of the angular distributions of the differential cross sections of elastic scattering in the optical model (OM), are subject to ambiguities and require reliable estimates.

In order to obtain reliable information about the potential of nuclear interaction, obtained in the cyclotron of the Institute of Nuclear Physics, the experimental data on the scattering of ^{4}He ions with an energy of 50.5 MeV [17] and in the cyclotron of the University of Jyväskylä at the energy of the incident particles of 65 MeV [18] on the ^{11}B nuclei were analyzed in the standard optical model with the potential in the parameterized form and finding its parameters by comparing the theoretical and experimental cross sections.

In this study, we carried out a comparative analysis of the elastic scattering of ^{4}He ions with ^{11}B nuclei in the optical model frameworks.

Methods and experiment results. The experimental angular distributions of the elastic scattering of

^{4}He ions on ^{11}B nuclei were measured on extracted beams isochronous cyclotron U-150M of the Institute of Nuclear Physics (Almaty, Kazakhstan) at Eα = 50 MeV and cyclotron K130 of the University of Jyväskylä (Jyväskylä, Finland) at Eα = 65 MeV.

The experiment used the self-supporting target of thin metal foil of 320 g/cm2 thick. For registration and identification of reaction products it was used ΔE-E technique. We use the telescope of silicon semiconductor detectors. Typical spectrum of scattered alpha particles on nuclei ^{11}B at 50.5 MeV is shown in Figure 1.

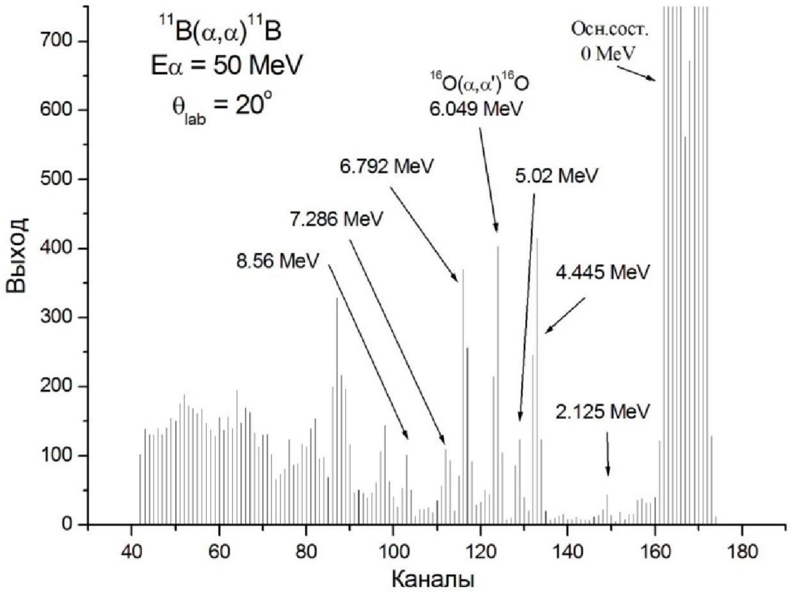

Figure 1 - Typical spectrum of the scattered helium ions on carbon nuclei at E = 50.5 MeV

The thicknesses of the targets was defined by a linear accelerator UKP-2-1 of the Institute of Nuclear Physics. To determine the target thickness there were measured yield curves of the reaction ^{27}Al(p,γ)^{28}Si in the vicinity of the resonance Ep = 992 keV [19] with the use of aluminum foil and spraying the target. The shift of this resonance in the reaction ^{27}Al(p,γ)^{28}Si, due to the loss of energy by protons during the passage of the film ^{11}B, was 62.0 keV, which corresponds to the thickness of the target of 320 g/cm2 (Figure 2). This method allowed us to determine the thickness of the target to a precision of no more than 5%.

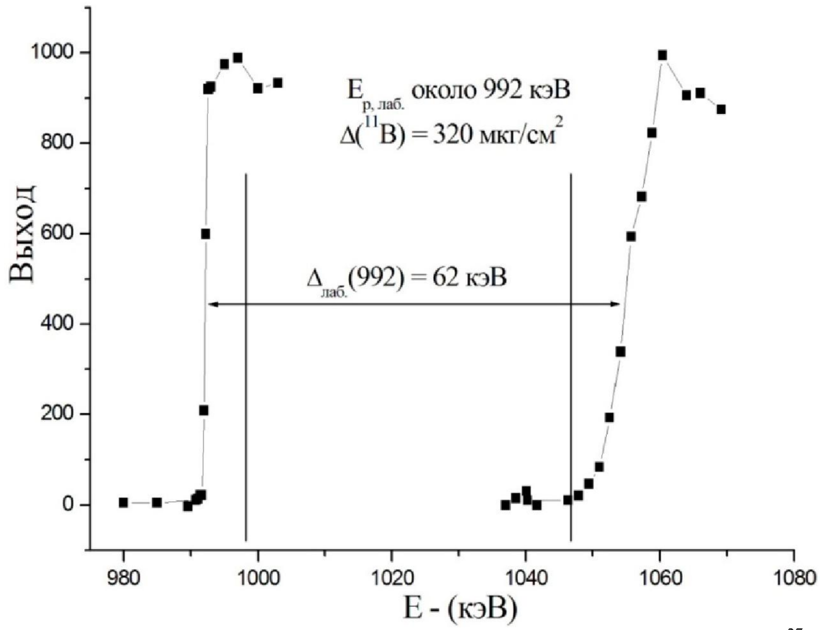

Figure 2 - Determination of the target thickness from the shift of the resonance of reaction ^{27}Al(p,γ)^{28}Si

Analysis of experimental data on the optical model of the nucleus. The data on elastic scattering were analyzed by the standard optical model of the nucleus, in which the influence of inelastic channels is accounted with phenomenological introduction of the imaginary absorbing part in the interaction potential between the colliding nuclei. Under this model, the elastic scattering is described by a complex interaction potential with radial dependence in the form of a Woods-Saxon:

$$U(r) = -Vf(x_V) - i[Wf(x_W)] + V_C(r), \tag{1.1}$$

where $f(x_i) = (1+\exp(x_i))^{-1}$, $x_i = (r - R_i)/a_i$ $R_i = r_i A^{1/3}$, $R_i = r_i A^{1/3}$,

$V_C(R)$ - the potential of a uniformly charged sphere of radius R = 1,28 $A^{1/3}$fm. taking into account the compact size of the incident particle, while analyzing the data at high energies we confined with volume type of absorption capacity for the imaginary part.

The parameters of the phenomenological optical potentials (OP) were chosen so as to achieve the best agreement between the theoretical and the experimental angular distributions. Theoretical calculations were made on the FRESCO program [20]. Automatically find the optimal parameters of OP was made by minimizing the value of χ^2/N. To limit discrete ambiguity in the OP parameters there were used the recommendations given in the Nolte work [21] for α-partial dispersion. The indicators of radial interaction potential parameters obtained in this work of global depending OP parameters: r_v = 1,205 fm and r_w = 1,65fm were recorded, and the theory fit the experiment was carried out by varying the remaining 4 OP parameters (V_R, W_V , a_R и a_W) .

The OP values are reported in Table 1. Also it was calculated volume integrals for the real part (J_V) and imaginary part (J_W) of optical potential at given energy.

Table 1 - Optical potential parameters

	E_b, МэВ	V_R, МэВ	r_0, фм	a_R, фм	W_V, МэВ	r_W, фм	a_W, фм	J_V, МэВ·фм^3	J_W, МэВ·фм^3
$^4He+^{11}B$	50.5	135	1,205	0,785	16,41	1,65	0,661	396,5	107,7
	65.0	127	1,205	0,8	19,41	1,65	0,761	380,5	131,5

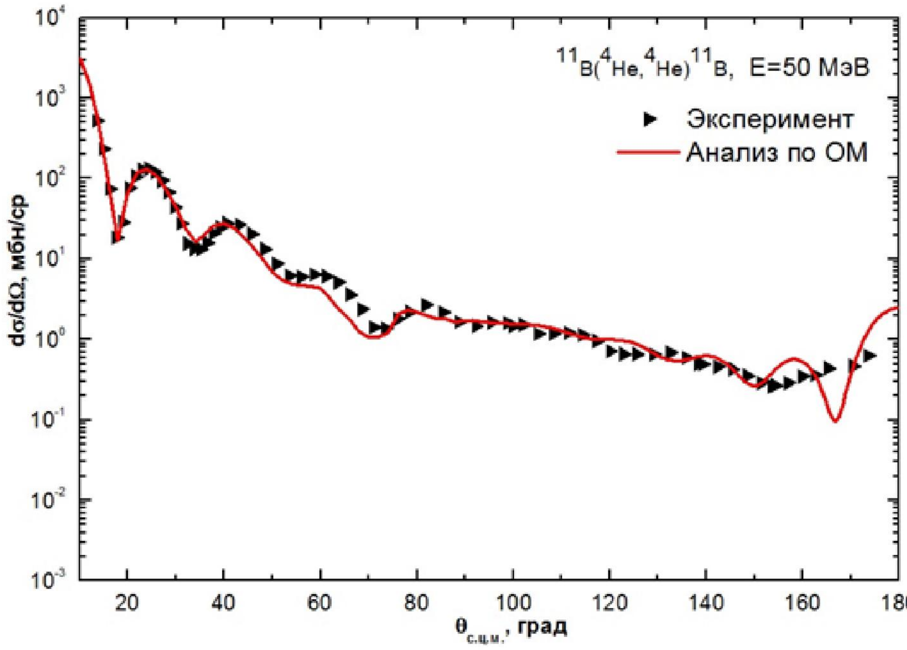

Figure 3 - The angular distributions of the elastic scattering of alpha particles on the nuclei 11B at energy of 50.5 MeV. Symbols - experimental data on elastic scattering; solid curve - calculation of the OM

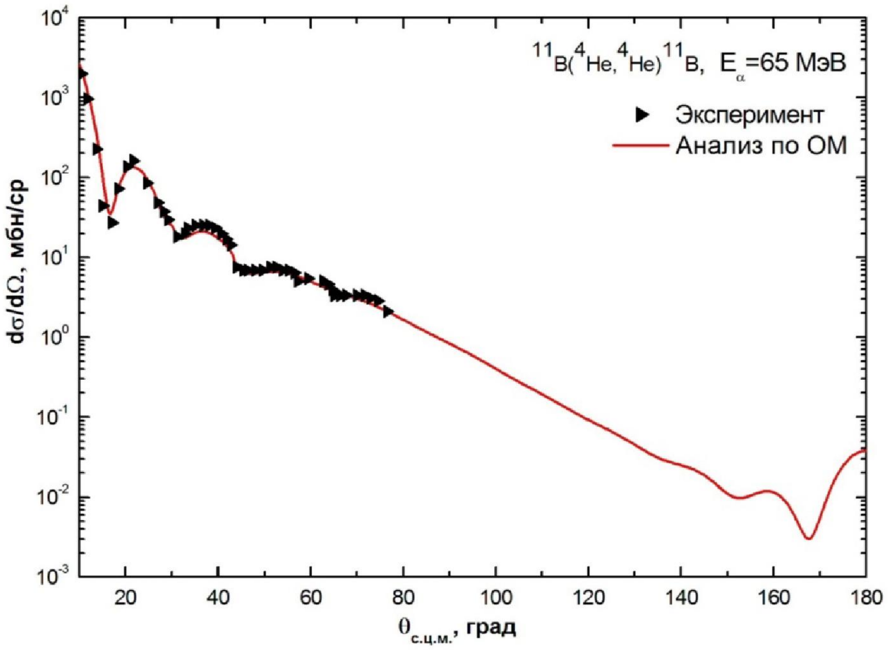

Figure 4 - The angular distributions of the elastic scattering of alpha particles in the nuclei 11B at 65 MeV.
Symbols - experimental data on elastic scattering; solid curve - calculation of the OM

Conclusion. Optimal physically reasonable values of the optical parameters of the potential were defined. These capabilities will be useful in the study of differential cross sections for reactions involving the nuclei.

This work was supported by a grant from the MES RK №1460 GF4.

ЛИТЕРАТУРА

[1] Navrátil P., Ormand W.E. Ab initio shell model with a genuine three-nucleon force for the p-shell nuclei. Phys. Rev. C 68, 034305 (2003)

[2] Nishioka H., Saito S., Yasuno M. Structure study of 2α + t system by the orthogonality condition model. Prog. Theor. Phys. 62, 424 (1979)

[3] Kanada-En'yo Y. Negative parity states of 11B and 11C and the similarity with 12C. Phys. Rev.C 75, 024302 (2007)

[4] Yamada T., Funaki Y.: α + α + t cluster structures and 12 C (0 + 2)-analog states in 11B. Phys.Rev. C 82, 064315 (2010)

[5] A. A. Ogloblin, A. N. Danilov, T. L. Belyaeva, A. S. Demyanova, S. A. Goncharov, and W. Trzaska.Effect of neutron halos on excited states of nuclei. Phys.Rev. C 84, 054601 (2011)

[6] A.A. Ogloblin , A. N. Danilov, T. L. Belyaeva, A. S. Demyanova, S. A. Goncharov, W. Trzaska, Observation of abnormally large radii of nuclei in excited states in the vicinity of neutron thresholds. Physisc of Atomic Nuclei, 2011, 74, No.11, 1548-1561

[7] A.S. Demyanova, A.A. Ogloblin, A.N. Danilov, S.V. Dmitriev, S.A. Goncharov, N. Burtebaev, J. Burtebaeva, N. Saduev, T.L. Belyaeva, H. Suzuki, A. Ozawa, Y. Abe, S. Fukuoka, Y. Ishibashi, S. Ito, T. Komatsubara, T. Moriguchi, D. Nagae, R. Nishikiori, T. Niwa, K. Okumura, H. Ooishi, K. Yokoyama and S. Kubono. Spectroscopy of ^{9}Be and observation of neutron halo structure in the states of positive parity rotational band. EPJ Web of Conferences66, 02026 (2014)

[8] T. L. Belyaeva, R. Perez-Torres, A. A. Ogloblin, A. S. Demyanova, S. N. Ershov, and S. A. Goncharov,Determination of neutron halo radii in the first excited states of ^{13}C and ^{11}Be with the asymptotic normalization coefficients method. Phys.Rev. C 90(2014)

[9] A. N. Danilov, T. L. Belyaeva, A. S. Demyanova, S. A. Goncharov, and A. A Ogloblin, Determination of nuclear radii for unstable states in ^{12}C with diffraction inelastic scattering. Phys.Rev. C 80, 054603 (2009)

[10] T. L. Belyaeva, A. N. Danilov, A. S. Demyanova, S. A. Goncharov, A. A. Ogloblin, and R. Perez-Torres,Large-angle α-particle scattering on ^{12}C and search for signatures of α-particle Bose condensation. Phys.Rev. C 82, 064618(2010)

[11] A. A. Ogloblin, T. L. Belyaeva, A. N. Danilov, A. S. Demyanova and S. A. Goncharov. Radius of ^{12}C in the excited 22+ Hoyle state. Eur.Phys. Jour. A 2013 49 No.46

[12] A.A. Ogloblin, A.S. Demyanova, A.N. Danilov, S.V. Dmitriev, T.L. Belyaeva, S.A. Goncharov, V.A. Maslov, Yu.G. Sobolev, W. Trzaska and S.V. Khlebnikov.Rotational band in ^{12}C based on the Hoyle state.EPJ Web of Conferences 66, 02074 (2014)

[13] A.N. Danilov, A.S. Demyanova, A.A. Ogloblin, S.V. Dmitriev, T.L. Belyaeva, S.A. Goncharov, Yu.B. Gurov, V.A. Maslov, Yu.G. Sobolev, W. Trzaska, S.V. Khlebnikov, N. Burtebaev, T. Zholdybayev, N. Saduyev, P. Heikkinen, R. Julin and G.P. Tyurin. Cluster states in ^{11}B.EPJ Web of Conferences 66, 03007 (2014)

[14] S.A. Goncharov, A.S. Demyanova, Yu.A. Gloukhov, A.N. Danilov, A.A. Ogloblin, T.L. Belyaeva, Yu.G. Sobolev, W.

Trzaska, G.P. Tuyrin and S.V. Khlebnikov.Study of the structure of the Hoyle state by refractive α-scattering .EPJ Web of Conferences 66, 03034 (2014)

[15] A.S. Demyanova, A.N. Danilov, S.V. Dmitriev, A.A. Ogloblin, T.L. Belyaeva, N. Burtebaev, P. Drobyshev, S.A. Goncharov, Yu.B. Gurov, P. Heikkinen, R. Julin, S.V. Khlebnikov, V.A. Maslov, N. Nassurlla, Yu.E. Penionzhkevich, Yu.G. Sobolev, W. Trzaska, G.P. Tyurin and V.I. Zherebchevskii, Spectroscopy of exotic states of 13C. EPJ Web of Conferences 66, 02027 (2014)

[16] A.A. Ogloblin, T.L. Belyaeva, A.N. Danilov, A.S. Demyanova and S.A. Goncharov. Nuclear Threshold States: Yesterday, Today, Tomorrow. AIP Conference Proceedings Vol 1224 (2010)

[17] N. Burtebaev, M. K. Baktybaev, B. A. Duisebaev, R. J. Peterson, S. B. Sakuta. Scattering of α particles on ^{11}B nuclei at energies 40 and 50 MeV.. Physics of Atomic Nuclei, 2005, Volume 68, Issue 8, pp 1303–1313.

[18] A. N. Danilov, A. S. Demyanova, S. V. Dmitriev, A. A. Ogloblin, T. L. Belyaeva, S. A. Goncharov, Yu. B. Gurov, V. A. Maslov, Yu. G. Sobolev, W. Trzaska, S. V. Khlebnikov, P. Heikkinen, R. Julin, G. P. Tyurin, N. Burtebaev, T. Zholdybayev. Study of rlastic and inelastic ^{11}B +α scattering and search for cluster states of enlarged radius in 11B// 2015, Volume 78, Issue 6, pp 777–793.

[19] Bulter J.W. Table of (p,γ) resonances by proton energy: E = 0.163 – 3.0 MeV.. U.S. Naval Research Laboratory. NRL Report. – 1959. – P. 5282-5299

[20] I.J. Thompson. Coupled reaction channels calculations in nuclear physics.Comput. Phys. Rep. 7 (1988)

[21] Nolte M., Machner H. and Bojowald J. Global optical potential for α particles with energies above 80 MeV. Physical Review C. – 1987. – Vol.36. – P.1312.

REFERENCES

[1] Navrátil P., Ormand W.E. Ab initio shell model with a genuine three-nucleon force for the p-shell nuclei. Phys. Rev. C 68, 034305 (2003)

[2] Nishioka H., Saito S., Yasuno M. Structure study of 2α + t system by the orthogonality condition model. Prog. Theor. Phys. 62, 424 (1979)

[3] Kanada-En'yo Y. Negative parity states of 11B and 11C and the similarity with 12C. Phys. Rev.C 75, 024302 (2007)

[4] Yamada T., Funaki Y.: α + α + t cluster structures and 12 C (0 + 2)-analog states in 11B. Phys.Rev. C 82, 064315 (2010)

[5] A. A. Ogloblin, A. N. Danilov, T. L. Belyaeva, A. S. Demyanova, S. A. Goncharov, and W. Trzaska.Effect of neutron halos on excited states of nuclei. Phys.Rev. C 84, 054601 (2011)

[6] A.A. Ogloblin , A. N. Danilov, T. L. Belyaeva, A. S. Demyanova, S. A. Goncharov, W. Trzaska, Observation of abnormally large radii of nuclei in excited states in the vicinity of neutron thresholds. Physisc of Atomic Nuclei, 2011, 74, No.11, 1548-1561

[7] A.S. Demyanova, A.A. Ogloblin, A.N. Danilov, S.V. Dmitriev, S.A. Goncharov, N. Burtebaev, J. Burtebaeva, N. Saduev, T.L. Belyaeva, H. Suzuki, A. Ozawa, Y. Abe, S. Fukuoka, Y. Ishibashi, S. Ito, T. Komatsubara, T. Moriguchi, D. Nagae, R. Nishikiori, T. Niwa, K. Okumura, H. Ooishi, K. Yokoyama and S. Kubono. Spectroscopy of 9Be and observation of neutron halo structure in the states of positive parity rotational band. EPJ Web of Conferences66, 02026 (2014)

[8] T. L. Belyaeva, R. Perez-Torres, A. A. Ogloblin, A. S. Demyanova, S. N. Ershov, and S. A. Goncharov,Determination of neutron halo radii in the first excited states of 13C and 11Be with the asymptotic normalization coefficients method. Phys.Rev. C 90(2014)

[9] A. N. Danilov, T. L. Belyaeva, A. S. Demyanova, S. A. Goncharov, and A. A Ogloblin, Determination of nuclear radii for unstable states in 12C with diffraction inelastic scattering. Phys.Rev. C 80, 054603 (2009)

[10] T. L. Belyaeva, A. N. Danilov, A. S. Demyanova, S. A. Goncharov, A. A. Ogloblin, and R. Perez-Torres,Large-angle α-particle scattering on 12C and search for signatures of α-particle Bose condensation. Phys.Rev. C 82, 064618(2010)

[11] A. A. Ogloblin, T. L. Belyaeva, A. N. Danilov, A. S. Demyanova and S. A. Goncharov. Radius of 12C in the excited 22+ Hoyle state. Eur.Phys. Jour. A 2013 49 No.46

[12] A.A. Ogloblin, A.S. Demyanova, A.N. Danilov, S.V. Dmitriev, T.L. Belyaeva, S.A. Goncharov, V.A. Maslov, Yu.G. Sobolev, W. Trzaska and S.V. Khlebnikov.Rotational band in 12C based on the Hoyle state.EPJ Web of Conferences 66, 02074 (2014)

[13] A.N. Danilov, A.S. Demyanova, A.A. Ogloblin, S.V. Dmitriev, T.L. Belyaeva, S.A. Goncharov, Yu.B. Gurov, V.A. Maslov, Yu.G. Sobolev, W. Trzaska, S.V. Khlebnikov, N. Burtebaev, T. Zholdybayev, N. Saduyev, P. Heikkinen, R. Julin and G.P. Tyurin. Cluster states in 11B.EPJ Web of Conferences 66, 03007 (2014)

[14] S.A. Goncharov, A.S. Demyanova, Yu.A. Gloukhov, A.N. Danilov, A.A. Ogloblin, T.L. Belyaeva, Yu.G. Sobolev, W. Trzaska, G.P. Tuyrin and S.V. Khlebnikov.Study of the structure of the Hoyle state by refractive α-scattering .EPJ Web of Conferences 66, 03034 (2014)

[15] A.S. Demyanova, A.N. Danilov, S.V. Dmitriev, A.A. Ogloblin, T.L. Belyaeva, N. Burtebaev, P. Drobyshev, S.A. Goncharov, Yu.B. Gurov, P. Heikkinen, R. Julin, S.V. Khlebnikov, V.A. Maslov, N. Nassurlla, Yu.E. Penionzhkevich, Yu.G. Sobolev, W. Trzaska, G.P. Tyurin and V.I. Zherebchevskii, Spectroscopy of exotic states of 13C. EPJ Web of Conferences 66, 02027 (2014)

[16] A.A. Ogloblin, T.L. Belyaeva, A.N. Danilov, A.S. Demyanova and S.A. Goncharov. Nuclear Threshold States: Yesterday, Today, Tomorrow. AIP Conference Proceedings Vol 1224 (2010)

[17] N. Burtebaev, M. K. Baktybaev, B. A. Duisebaev, R. J. Peterson, S. B. Sakuta. Scattering of α particles on 11B nuclei at energies 40 and 50 MeV.. Physics of Atomic Nuclei, 2005, Volume 68, Issue 8, pp 1303–1313.

[18] A. N. Danilov, A. S. Demyanova, S. V. Dmitriev, A. A. Ogloblin, T. L. Belyaeva, S. A. Goncharov, Yu. B. Gurov, V. A. Maslov, Yu. G. Sobolev, W. Trzaska, S. V. Khlebnikov, P. Heikkinen, R. Julin, G. P. Tyurin, N. Burtebaev, T. Zholdybayev. Study of rlastic and inelastic 11B +α scattering and search for cluster states of enlarged radius in 11B// 2015, Volume 78, Issue 6, pp 777–793.

[19] Bulter J.W. Table of (p,γ) resonances by proton energy: E = 0.163 – 3.0 MeV.. U.S. Naval Research Laboratory. NRL

Report. – 1959. – P. 5282-5299
[20] I.J. Thompson. Coupled reaction channels calculations in nuclear physics.Comput. Phys. Rep. 7 (1988)
[21] Nolte M., Machner H. and Bojowald J. Global optical potential for α particles with energies above 80 MeV. Physical Review C. – 1987. – Vol.36. – P.1312.

УДК 539.171

Н. Буртебаев[1], Ж.К. Керимкулов[1],Е.С. Мухамеджанов[2], Д.К. Алимов[2], А.С. Демьянова[3], А.Н.Данилов[3]

[1]Институт Ядерной Физики, Алматы, Казахстан;
[2]КазНУ им. аль-Фараби, Алматы, Казахстан;
[3]НИЦ Курчатовский Институт, Москва, Россия

ИССЛЕДОВАНИЕ ПРОЦЕССОВ РАССЕЯНИЯ АЛЬФА-ЧАСТИЦ НА ЯДРАХ ^{11}B ПРИ ЭНЕРГИЯХ 50 И65 МЭВ.

Аннотация. Изучение ядерных реакций представляет особый интерес, поскольку оно может предоставить полезную информацию о структуре ядра, параметрах потенциалов, деформации и вероятностях переходов. Взаимодействие α-частиц с ядрами является важным инструментом для понимания структуры ядра и ядерных реакций. Концепция среднего поля α-частицы широко используется для объединения состояний связанных и рассеиваемых α-частиц аналогичным образом с использованием ядерного среднего поля для расчета свойств связанных состояний одной частицы, а также рассеяние несвязанных нуклонов на ядрах.

В данной работе исследованы процессы упругого рассеяния альфа-частиц при энергиях 50 и 65 МэВ. Анализ упругого рассеяния был проведен в рамках оптической модели. В расчетах для действительной части комплексного ядерного потенциала были использованы как микроскопические потенциалы двойной свертки, так и феноменологические потенциалы. Мнимая часть имела форму феноменологического поверхностного Вудс-Саксонского потенциала. Теоретически рассчитанные сечения хорошо согласуются с экспериментальными данными.

Теоретическая значимость исследования состоит в том, что вопрос распространенности изотопов легких ядер во Вселенной и существования нейтронного гало остаются открытыми по сей день. Практическая значимость исследования состоит в получении новых экспериментальных данных по ядерным реакциям необходимых для проведения оценки наработки легких ядер, которые дополнят существующую базу ядерных данных новыми данными по сечениям ядерных реакций и структуре легких ядер, полезных для расширения понимании природы ядерных взаимодействий в области низких и средних энергий.

Ключевые слова: упругое рассеяние, оптическая модель, FRESCO, оптические потенциалы.

Н. Буртебаев[1], Ж.К. Керимкулов[1], Е.С. Мухамеджанов[2], Д.К. Алимов[2], А.С. Демьянова[3], А.Н.Данилов[3]

[1]Ядролық Физика Институты, Алматы, Қазақстан;
[2]әл-Фараби атындағы ҚазҰУ, Алматы, Қазақстан;
[3]ҰЗО Курчатов Институты, Мәскеу, Ресей

50 ЖӘНЕ 65 МЭВ ЭНЕРГИЯДАҒЫ АЛЬФА-БӨЛШЕКТЕРДІҢ ^{11}BЯДРОЛАРЫНДА ШАШЫРАУ ҚҰБЫЛЫСТАРЫН ЗЕРТТЕУ

Аннотация. Осы жұмыста50 және 65 МэВ энергияларда ^{4}He иондарының^{11}B ядроларынан серпімді шашырау процесстері зерттелген.Серпімді шашырау оптикалық модель аясында талданды. Потенциалдың жорамал бөлігі үшін Вудс-Саксон потенциалының беттік феноменологиялық түрі қолданылды. Теориялық есептелген қималар, тәжірибелік мәліметтермен жақсы үйлеседі.

Тірек сөздер: серпімді шашырау, оптикалық модель, фолдинг потенциал, нормалау коэфциенттері, FRESCO.

Сведения об авторах:
Буртебаев Нассурлла - профессор, д.ф.м.н., зам. директора института ядерной физики, Алматы, Казахстан, e-mail: nburtebayev@yandex.ru
Мухамеджанов Ержан - e-mail: y.mukhamejanov@gmail.com