GLOBAL OPTICAL MODEL POTENTIAL PARAMETERS FOR PROTON SCATTERING ON ^{6,7}Li AND ^{10,11}B NUCLEI

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Analysis of the elastic scattering of protons on ^{6,7}Li and on ^{10,11}B nuclei has been done in the framework of the optical model at the beam energies up to 50 MeV. Differential cross sections for the ^{6,7}Li and ^{10,11}B were measured over the proton laboratory–energy range from 400 to 1200 KeV, and combined with published differential cross sections for proton elastically scattering from ^{6,7}Li and ^{10,11}B between 0.5 MeV and 50 MeV, are analyzed in terms of the Optical Model. Depending on the measured data by us and literature data, we could enhance the potential parameters. Linear relationship between volume real potential (V_0) and proton energy (E_p) have been obtained. Also, surface imaginary potential W_D is proportional to the proton energy (E_p) in the range 0.700 and 14 MeV. Optical model parameters are found characterized volume integral per nucleon pair for the real and imaginary potentials, J_R and J_w. Good agreement between theoretical and experimental data in whole range. We attempt to make empirical relations describing the energy dependence of the optical-model potential.

Introduction

Optical-model analysis of proton scattering data have been carried out for a wide range of incident proton energies, and a few attempts [1-4] have been made to empirically determine the energy dependence of the optical-model potential. The optical model has been used extensively in the analysis of elastic scattering data for a wide variety of particles and a wide range of energies. In the energy region below 50 MeV, extensive proton elastic scattering data exist [5]. These have, in general been analyzed in terms of an optical model in which the interaction is represented as the scattering of a point particle (proton) by a potential of form

$$U_{op}(r)=U_c(r)+U(r)+iW(r)+U_{so}(r)+iW_{so}(r).$$

Where $U_c(r)$ is the Coulomb potential. The real term $U(r)$ is almost taken to have a volume form – $V_R f_R(r)$ with $f_R(r)=\{1+exp[(r-R_R)/a_R]\}^{-1}$, the Wood-Saxon form factor. This real central term thus involves three parameters V_R, R_R and a_R. The imaginary central term W(r) has been taken as a mixture of surface and volume terms. Below proton energies of about 20 MeV the surface form is satisfactory and may have a Gaussian or Wood- Saxon derivative forms. At proton above 20 MeV, a volume term as well as a surface term seems to be necessary, but good agreement with experiment is achieved with $R_s=R_v$ (say R_I) and $a_s=a_v$ (say a_I), leaving four parameters W_s, W_v, R_I and a_I for the imaginary central term. The spin-orbit term $[U_{so}+iW_{so}(r)]$, in the absence of convincing evidence to the contrary, it is usual to take W_{so}=0, leaving the three parameters V_{so}, R_{so}, and a_{so}. The model thus involves ten parameters although several analysis have been performed using more restricted sets by equating some of the geometrical parameters and/or neglecting one the imaginary terms [5]. A nuclear optical model calculation of neutron elastic scattering using five parameters has been made. Appropriate estimates of the effect of compound elastic scattering at low energies are included [6]. Many such analysis of nucleon scattering have now been made and is found that the potentials are quite similar for all nuclei and vary other slowly with the incident energy. The optical model is thus a successful way of describing elastic scattering in a wide range of conditions, and this provides confirmation of the overall correctness of the derivations of the potential from more fundamental considerations. An extensive analysis of differential cross sections for the elastic scattering of 9-22 MeV protons by range of nuclei (Perey 1963) showed that the form factors are fixed to the average values r_0= 1.25 fm and a_0 = 0.65 fm the depth of the real part, V_0, is given by:$V_0 = 53.3 - 0.55E_p - 27(N-Z)/A + 0.4\ Z/A^{1/3}$ [6].

Study of the energy dependence of proton elastic scattering on light nuclei did evidence an enhancement of the backward angles yield which cannot be predicted by conventional optical model calculations. The data thus collected constitute a set of differential cross sections concerning nearly every stable isotope in the A=9-70 mass region. The measurements reported in this paper further strengthen the hypothesis of existence of a correlation between proton elastic scattering and the structure of the target nuclei. Nuclear structure effects are also evident at forward angles at the filling of the 1p shell. A set of mass dependent optical-model parameters which produces acceptable fits at forward angles was derived [7]. Optical model analysis of the elastic scattering and polarization data cannot give unique values of the all parameters of the potential; rather it is certain combinations that correspond to a particular set of data [6].

In practice it is required to obtain the potential from the experimental data, and this may be done by systematically varying the parameters of the optical potential to optimize the overall fit to the data, using appropriate computer programs. Thus, for example, the fit to that data is insensitive to variations of V_0 and r_0 that keep $V_0r_0^2$ constant, and similarly for W_Da_D. Since the calculations of the potential are insufficiently precise to resolve these ambiguities, it is usual to fix the parameters of the form factors to average values and then to adjust the potential depth V_0, W_D, and W_S to fit the data. It is then possible to compare the basis of variation of these potentials with energy. Many such analysis of nucleon scattering has now been made and it is found that the potentials are quite similar for all nuclei and vary rather slowly with the incident energy. The optical model is thus a successful way of describing elastic scattering in a wide range of conditions, and this provides confirmation of the overall correctness of the derivations of the potential from more fundamental considerations. Various groups have previously reported measurements for proton scattering from ^{6}Li in the energy region 25-50 MeV [8-11]. A lot of experimental data were taken from [12].

The purpose of the present work is the obtaining of reliable information about potential parameters for interaction of protons with ^{6,7}Li and ^{10,11}B nuclei from the optical model analysis of elastic scattering especially at low energies. This will be useful to carry out cross-sections calculations for charged particles nuclear reactions, being of great significance for thermonuclear and astrophysics applications. For the analysis, the angular distributions on scattering of proton measured in total angular range were selected. Scattering cross-sections of protons at low energies were measured by us for the first time [13].

Peculiarity of measurements

Measurements of elastic scattering of protons on $^{10,11}B$ and $^{6,7}Li$ nuclei in low energy region were carried out with using the extracted beam from the complex UKP-2-1 tandem accelerator of the Institute of Nuclear Physics (National Nuclear Center, Republic of Kazakhstan) in the angular range 40-170°. The proton energy varied in the range 300 – 1200 KeV. The beam intensity was up to 300 nA. Scattered particles were detected using surface-barrier silicon counters.

Lithium targets were films deposited on thin bases of Al_2O_3 by the vacuum evaporation method (thickness of films in interval 10-100μg/cm^2 with the accuracy is not less than 5%). In experiments there was used the specially-manufactured scattering chamber with the lock equipment for $^{6,7}Li$-targets. In order to minimize the sublimation of the target the beam current was not more than 50 nA.

The similar data were obtained in experiments on elastic scattering of protons on ^{7}Li nuclei at energies of 450, 750 and 1000 keV. The errors of measured differential cross-sections are approximately equal to dimensions of presented dots and do not exceed 8%.

Results and discussions

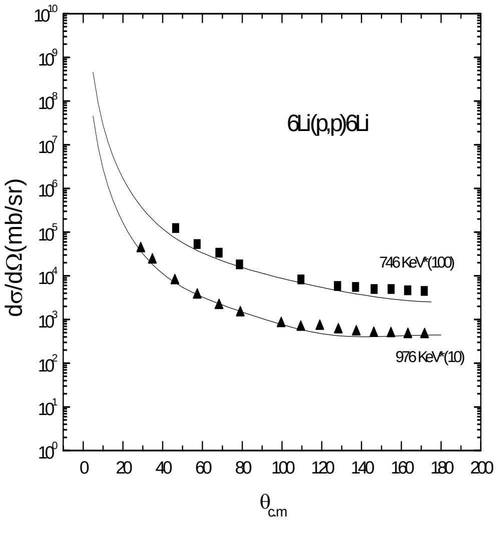
Our and literature data on elastic scattering were analyzed within the framework of the standard optical model with central potential, having the radial dependence in the Woods Saxon's form. Optical potential parameters were selected on the base of achieving the best agreement between theoretical and experimental angular distributions. Fulfilled calculations allowed reproducing the behavior of angular distributions of the protons elastic scattering on $^{6,7}Li$ and $^{10,11}B$ - nuclei in the total angular range by the absolute value.

The nuclear optical model has been outstanding successful in describing the elastic scattering of the neutrons and other nuclear particles above the energy of perhaps 6 MeV, where compound elastic scattering processes are not important. Below these energies it is necessary to include some estimate of the compound elastic scattering [14]. The whole body of data could be compared with calculations based on a chosen set of parameters. In order to make intelligent guess to how to change the parameters to get a better fit, we undertook a systematic study to see how each parameter affected the calculated angular distributions. In case of spin-orbit potential for example, the effect at low energy is the more sensitive on the second minimum relative to the position of the first minimum but this effect is small at higher energies. Table 1 contains the calculated parameters for protons scattered on ^{6}Li. Figure 1a and 1b show the comparison between calculated using optical model and experimental angular distribution of protons scattered from ^{6}Li.

Table 1 contains the optical parameters for protons scattering on 6Li nuclei.

Ep MeV	V0 MeV	r0 fm	a0	WD MeV	rD fm	aD fm	Vs MeV	rs fm	as fm	JR MeV.fm3	Jw MeV.fm3
0.746	57.2	1.050	0.67	0.355	1.923	0.650	9.30	1.020	0.200	454	17.5
0.967	56.3	1.050	0.68	0.355	1.923	0.570	9.30	1.020	0.200	454	22.19
3	55.08	1.050	0.78	0.87	1.923	0.575	9.30	1.020	0.200	437	55.72
5	52	1.050	0.93	1.18	1.923	0.820	15.6	1.020	0.770	407	75.58
10	50.00	1.050	0.90	2.78	1.923	0.654	4.66	1.020	0.200	391	148.3
12	47.52	1.050	0.764	5.03	1.923	0.490	12.23	1.020	0.200	385	304
14	46.86	1.050	0.85	6.72	1.923	0.423	9.86	1.020	0.200	378	309
25	38.99	1.050	0.65	3.89	1.930	0.547	5.517	1.020	0.200	270	111
29.5	37.16	1.050	0.75	2.50	1.923	0.654	2.816	1.020	0.200	152	111
35	33.35	1.050	0.67	2.90	1.923	0.660	3.65	1.020	0.200	142	100
40	34.1	1.050	0.737	2.60	1.928	0.680	3.08	1.020	0.200	125	106
45	30	1.050	0.71	2.96	1.923	0.690	2.33	1.020	0.200	122	112
49	24.55	1.050	0.87	1.58	1.923	0.516	2.13	1.020	0.266	64	98

The analysis of protons data, carried out in wide energy range, had shown that for ^{6}Li nuclei, the most suitable parameters values are r_0=1.05fm, r_c=1.3fm, r_D=1.923fm, a_s=0.20fm and r_s=1.02 fm. As expected the relation between W_D and E_p is linear. The strength parameters in table 1 can be represented by:V_0 = 56.10 - 0.61 E_p, W_D= -0.66 + 0.46E_p,
As it is seen from Figure 1a, and 1b there is a good agreement between theory and experiment in the whole angular range at all energies that give an evidence of pure potential character of protons scattering on lithium nuclei.



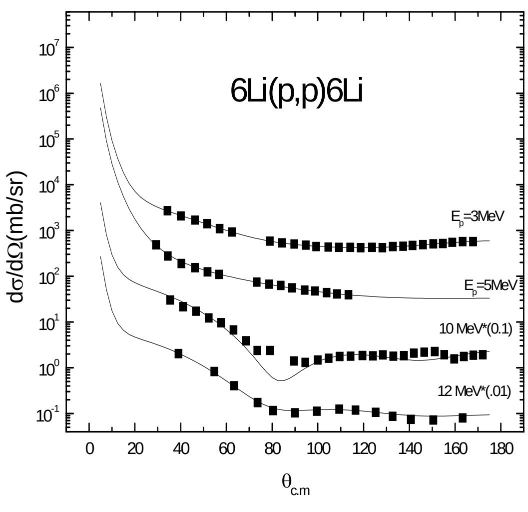


Fig.1a. Shows the comparison between calculated and experimental angular distribution of protons scattered on ^{6}Li where dots represent experimental data and lines represent the calculated values

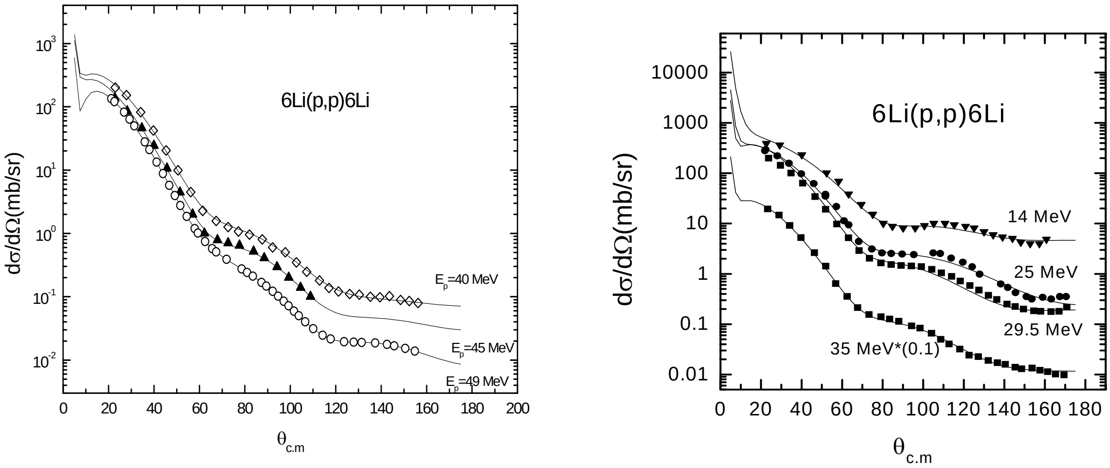


Fig. 1b. Angular distribution of protons scattered from ^{6}Li where dots represent experimental data and lines represent the calculated values

Figures 2 shows the relations between V_0, W_D and E_p and these relations are in a good agreement with results obtained in [15].

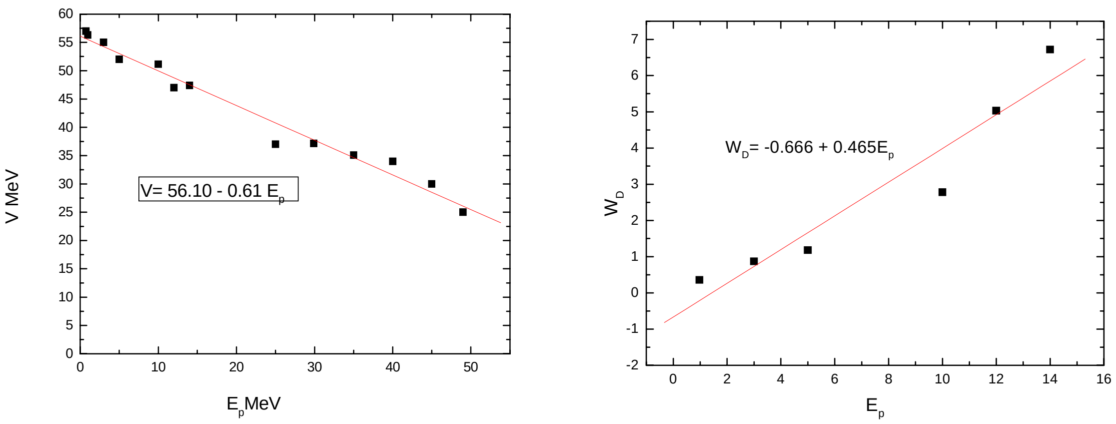


Fig. 2 shows the linear relation between V_0, W_D and E_p for ^{6}Li

It is noted that the energy dependence of the strength of the real central potential is close to that found for medium weight nuclei at energies from 10-20 MeV [16] (dV/dE_p = 0.55 and 0.33) and higher than the values from 20-60 MeV (0.22-0.32) [17]. The imaginary central part of the optical potential consisted of a surface absorption term only. It was found that even at higher energies the inclusion of small volume absorption term did not improve the fits appreciably [18].

^{7}Li

The parameters calculated for ^{7}Li is good agreement with those calculated for light nuclei by B. A. Watson et al. [15]. This give us normal starting point to deal with light nuclei and their behaviors in spite of our results are in the simplest form, we tried to put a lot relation in linear and others in second order. Fig. 8 shows also a comparison between calculated and experimental for ^{7}Li+p. As shown in figures 8 the differential cross sections calculated using optical parameters and experimental values are close to each other in spite of this situation is not completely true at low energies. The minimum of the peak is obtained at 80° as expected.

Table 2contains the optical parameters for protons scattering on ^{7}Li nuclei

E_p MeV	V_0 MeV	r_0 fm	a_0	W_D MeV	r_D fm	a_D fm	V_s MeV	r_s fm	a_s fm	J_R MeV.fm^3	J_w MeV.fm^3
0.346	56	1.17	0.65	0.70	1.80	0.504	12.48	1.17	0.50	228.31	11
0.451	62	1.17	0.60	0.30	1.80	0.504	12.48	1.17	0.50	220.49	4.09
0.991	55	1.17	1.04	0.93	1.80	0.87	18.86	1.17	0.74	535.89	32.18
1.03	55	1.17	1.03	0.93	1.80	0.79	18.80	1.17	0.747	535.89	27.25
3.1	49.67	1.17	0.84	1.012	1.80	0.80	12.86	1.02	0.51	316.03	30.23
4.0	49.129	1.17	0.913	2.198	1.80	0.346	11.988	1.17	0.769	367.27	19.84
4.2	48.358	1.17	0.936	2.210	1.80	0.205	12.822	1.17	1.055	379.82	10.99
5.0	48.956	1.17	0.945	3.798	1.80	0.361	11.689	1.17	0.656	370.82	10.20
10.3(s)	37.29	1.17	0.527	8.55	1.80	0.545	12.86	1.17	0.8	109.43	140.38
49.75	32.938	1.17	0.461	4.282	1.80	0.785	11.265	1.17	0.757	80.83	124.08
(S)	37.249		0.531	5.799		0.593	9.285		0.522		

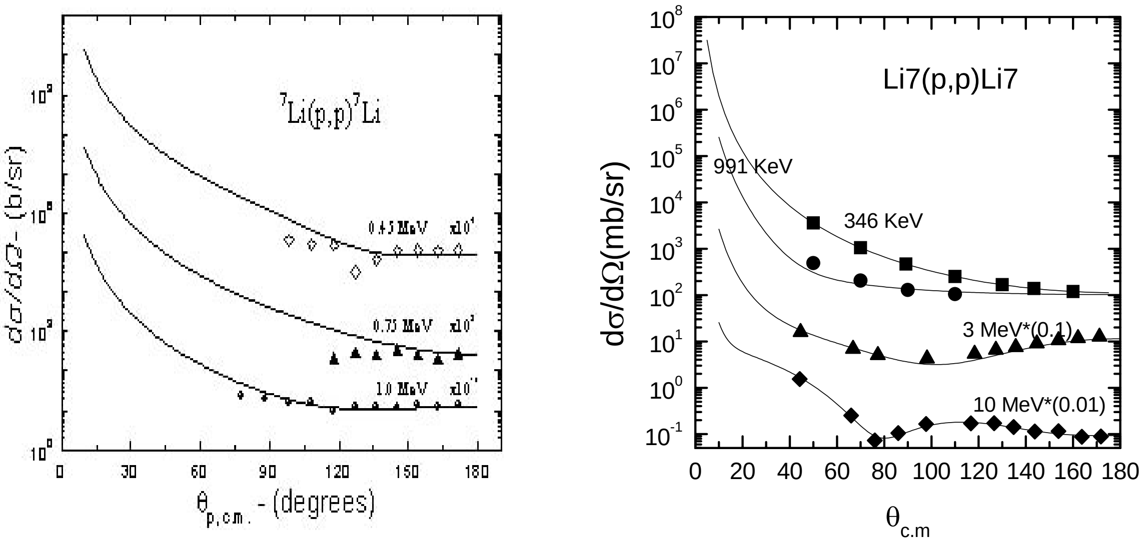


Fig. 3. Contains Li7+p angular distributions at different energies where dots represent experimental data and lines represent the calculated values using Optical model

^{10}B

In the analogous approach with the use of measured and literature data on the elastic scattering there are determined parameters of the potential of protons scattering on ^{10}B – nuclei for the wide energy range from the analysis of these data on the optical model. The description of experimental data, obtained in the present work, on the protons elastic scattering on the ^{10}B – nucleus is given in figure 5. Table 3 contains the optical parameters for protons scattering on ^{10}B nuclei which can be represented by: $V_0 = 56.68 - 1.15\ E_p$, $W_D = -0.58 + 0.56E_p$, $J_w = 8.91+1.3\ E_p$, and $J_R = 724-11.24\ E_p$.

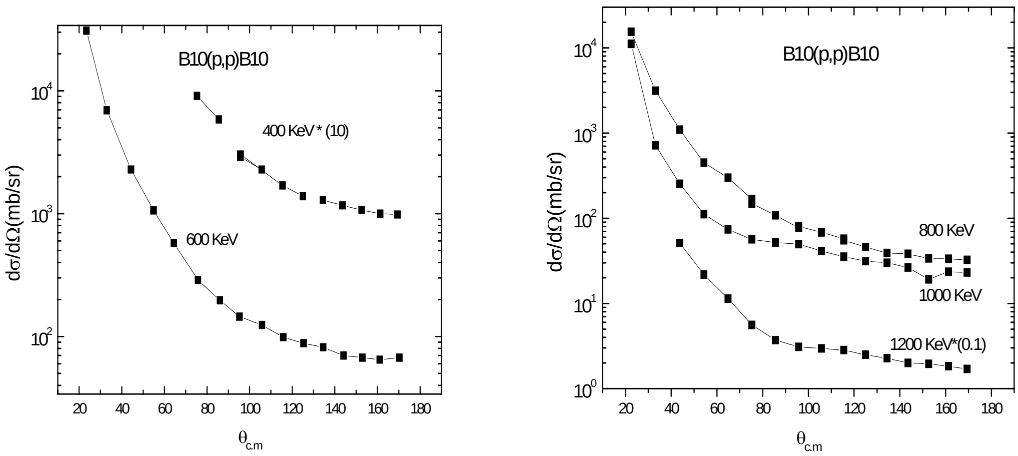


Fig. 4 shows the measured values of angular distribution 400, 600, 800,1000 and 1200 KeV for protons scattering on ^{10}B

As we see in the table the optical parameters obtained for protons scattering on ^{10}B nuclei is somewhat higher than $^{6,7}Li$ and we think the number of nucleons is the reason for this behavior. For heavy nuclei and bombarding energies above 10 MeV, Perey and others have shown that the optical model gives a satisfactory description of the elastic scattering of nucleons. The model has not enjoyed equal success in its application to light nuclei. N. Burtebayev and et. al. [13] reexamined optical model and its applicability to light nuclei.

The main objective of the analysis was to explore the possibility of finding a set of optical parameters that would produce the general features of nucleon scattering from light nuclei. Thus if any meaningful conclusions were to be drawn from the results, it was considered mandatory that the parameters vary smoothly with bombarding energy and that they give a reasonable description of nucleon scattering from several nuclei.

Table 3 contains the optical parameters for protons scattering on ^{10}B nuclei

Ep MeV	V_0 MeV	r_0 fm	a_0	WD MeV	r_D fm	a_D fm	Vs MeV	rs fm	as fm	JR MeV.fm3	Jw MeV.fm3
0.400	62	1.25	0.62	0.104	1.15	0.57	16.46	1.15	0.40	747.97	11
0.60	59	1.25	0.65	0.65	1.15	0.770	12.5	1.15	0.55	760.87	11
0.80	55.98	1.25	0.65	0.95	1.15	1.050	10.5	1.15	0.50	721.20	47
1	51	1.25	0.78	1.54	1.15	0.48	5.50	1.15	0.65	693.64	77
1.20	54	1.25	0.65	1.50	1.15	0.74	10.0	1.15	0.50	709	44
5.3	48.5	1.25	0.65	2.00	1.15	0. 54	12.50	1.15	0.84	631.65	38
8.5	46.5	1.25	0.65	7.20	1.15	0.50	10.50	1.15	0.57	599.67	125
10	45	1.25	0.65	6.80	1.15	0.54	9.50	1.15	0.50	580.32	118
13	43	1.25	0.65	7.80	1.15	0.54	12.5	1.15	0.50	554.53	150
17	46	1.25	0.65	9	1.15	0.54	12	1.15	50	593	173

Fig. 5 shows theoretical (optical model) solid line and experimental as points for angular distribution at different energies for proton scattering on ^{10}B.

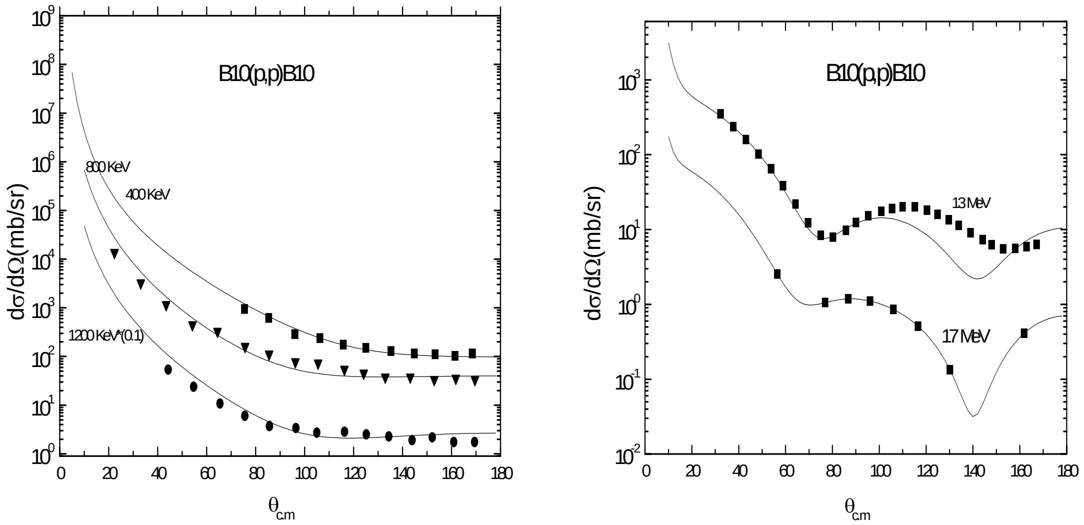


Fig. 5 shows theoretical (optical model) solid lines and experimental as points for angular distribution at different energies for proton scattering on ^{10}B

Depending on our calculations using Ecis88 and SPI-GENOA we could enhance the parameters and give all the relations in the simplest form in spite of they not exact linear, where it curved somewhat especially at very low energies which mean that the relations can be expressed in the second order.

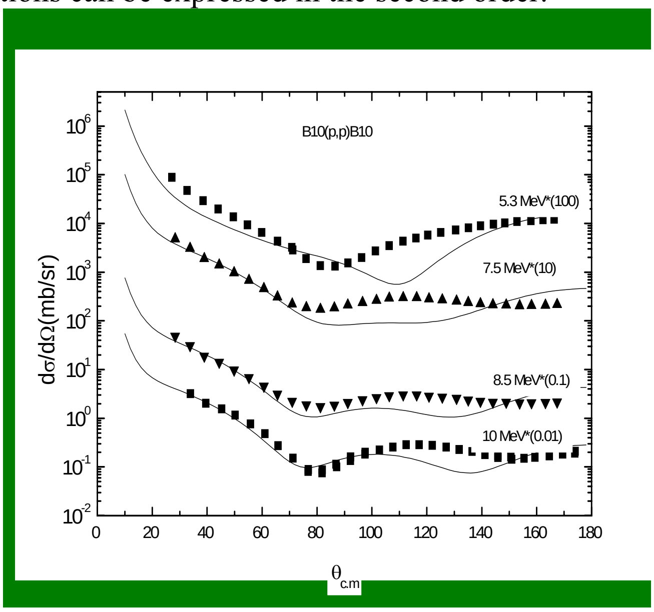


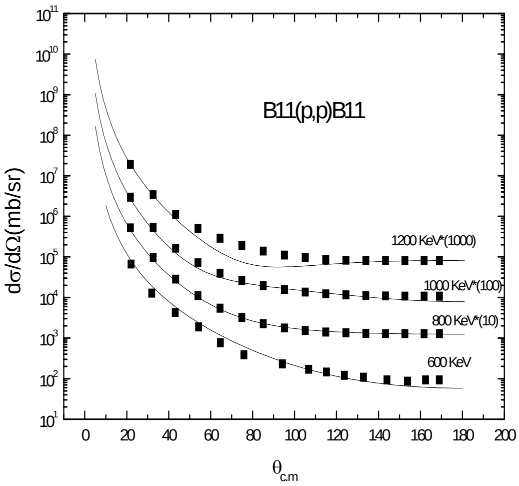
Fig. 6 shows theoretical (optical model) solid line and experimental as points for angular distribution at different energies for proton scattering on ^{10}B

^{11}B

Table 4contains optical parameters calculated for protons scattering on ^{11}B

Ep MeV	V0 MeV	r_0 fm	a_0	WD MeV	rD fm	aD fm	Vs MeV	rs fm	as fm	JR MeV.fm3	Jw MeV.fm3
0.60	54.16	1.25	0.64	0.51	1.15	0.75	5.80	1.15	0.58	650.80	11.19
0.80	52.70	1.25	0.75	2.57	1.15	0.66	9.02	1.15	0.50	800.79	16.61
1	47	1.25	0.98	1.82	1.15	0.91	26	1.15	0.50	690.80	21.86
1.20	45.19	1.25	0.92	1.90	1.15	0.61	15.60	1.15	0.52	814.63	33.22
13	43.95	1.25	0.65	8	1.15	0.70	5.50	1.15	0.57	562	139
15.80	44.50	1.25	0.65	8	1.15	0.70	10	1.15	0.57	573	139
17.35	41	1.25	0.65	8	1.15	0.50	10	1.15	0.57	535	139
20	39	1.25	0.65	9	1.15	0.50	10	1.15	0.57	502.95	157.37
30	34	1.25	0.55	5	1.15	0.81	14.43	1.15	0.71	392	164

At the energies calculated the first minimum is not exactly in reproduced, but the shape is similar to those of the experimental angular distributions. As obvious in ^{11}B+p case the first minimum is shifted from expected value at 80° to 70° and the second is shifted in the case of 15.8 MeV, 17.35 MeV and 20 MeV to left to the value 135° where in case of 13 MeV is shifted to 145° . In fair comparison between ^{10}B and ^{11}B we can see that the calculated values obtained for differential cross sections for ^{11}B+p is better than for those obtained in case of ^{10}B+p. The energy dependence of the strengths of the real potentials determined in present work VR= 56.10-0.61Ep.



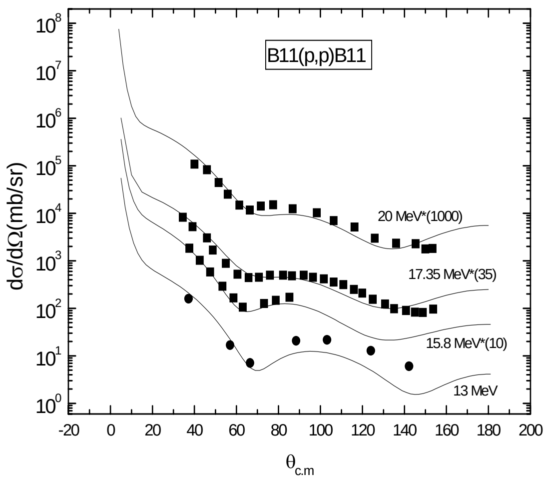


Fig. 6 shows comparison between experimental and calculated angular distribution of proton scattering on ^{11}B

The energy dependence of the strengths of the imaginary potentials W_D determined in present work especially in ^{6}Li the can be represented as: W_D= -0.66 + 0.46E_p, for $E_p \leq 14$ MeV and this for simplicity because our range extend from low energies 400 KeV to 50 MeV and this range make the task is somewhat difficult because at low energies the processes not pure elastic scattering, for higher energies W_D is inversely proportional with E_p.

We used W_v as constant value equal zero in spite of as mentioned in [23] that W_v values may variables between zero at low energies and W_v=1.15($E_{c.m}$-32.7MeV), for 32≤ $E_{c.m}$≤39MeV and W_v=7.5MeV for 39.3 MeV< $E_{c.m}$.

We should deal with J_R in special treatment because of physical meaning of it. As we calculate J_R and J_w and their energy dependence and we can also expect their mass number dependence but we did not analysis for this expectation. I'd like to concentrate on the point of obtained parameters where we use specially ^{6}Li in our analysis because of the fair agreement obtained in ^{6}Li and its important in astrophysics and cluster model interpretation, the fit obtained in these other analyses in table 5 are usually better than those of present work, where our analysis extracts over wider range.

Table 5 Comparison between optical-model parameters suggested in the present work and those found By perey (Ref. 2), B.A. Watson (Ref. 15)and by Fricke et. al. (ref. 17.).

Author	V_R (Mev)	W_D (MeV)	W_v (MeV)	V_{SO}(MeV)	a_R(F)	a_I(F)	a_{so}(f)	Radius Parameters(f)
Perey	53.3-0.55eb+0.4 Z/A$^{1|3}$+27 (N-Z)/A	13.5±2	None	7.5	0.65	0.47	0.65	$r_R=r_I=r_{SO}$=1.25
Fricke el al.	49.9-0.22Eb+0.4 Z/A$^{1/3}$+26.4 (N-Z)/A	Variable	2-4	6.04	0.75	0.63	0.738	r_R=1.16, r_I=1.37, r_{SO}=1.064
B. A. Watson	60.0-0.30Ed+0.4 Z/A$^{1/3}$+27 (N-Z)/A	0.64E For <13.8: 9.6-0.06E For E≥13.8	0 for E<32.7:(E-2.7)X1.15 For32.7≤E≤39 7.5 For E>39.3	5.5	0.75	0.50	0.57	$r_R=r_I=r_{SO}$=1.15-0.001E
Present work	56.10 - 0.61 Ep+0.4 Z/A$^{1|3}$+27 (N-Z)/A	1.05+ 0.738E $_p$-0.017E_p^2 For <13.8 2.19811+0.31652 E-0.00478 E^2 For E≥14	None	Variable	0.65	variable	0.2	r_R=1.05, rc=1.30, r_D=1.923

Conclusion

The present analysis shows that the optical model can give a good description of the general features of nucleon scattering from light nuclei at low energies and as our work concentrated at low energies where we can see poor description in case of ^{7}Li and normal in case of ^{6}Li and ^{10,11}B.

This evidenced by the fact that, to a fair degree, a single set of energy–dependent parameters is able to reproduce the differential cross sections of elastically scattering protons from 1p-shell nuclei.

There is no evidence that our parameters obtained in this analysis are the best.

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^{6,7}Li и ^{10,11}B ЯДРОЛАРЫНДА ПРОТОНДАРДЫҢ ШАШЫРАУЫНДАҒЫ ОПТИКАЛЫҚ ПОТЕНЦИАЛДЫҢ ГЛОБАЛЬДЫҚ ПАРАМЕТРЛЕРІ

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Энергиясы 50 Мэв дейін оптикалық модель шеңберінде ^{6,7}Li и ^{10,11}B ядроларында протонның серпімді шашырауына талқылау жасалынды. Энергия диапазоны 400 ден 1200 кэв протондардың болатын ^{6,7}Li и ^{10,11}B дифференциалдық қималары өлшенді. Берілгендерді өлшеу нәтижесінде олар потенциалдық параметрлерін сипаттауды жақсартады. Протонның энергиясы (E_p) мен көлемдік потенциал (V_0) арасындағы сызықтық тәуелділік алынды. Сондай-ақ беттік потенциал (W_D), (E_p) протонның энергиясына пропорционал, 0.700 және 14 МэВ энергия диапазонында.Оптикалық модель параметрлері J_R и J_W, шынайы және мнимый потенциалдар үшін қос нуклондыққа көлемдік интегралдар сипаттайды. Теория мен эксперимент арасында жақсы үйлесім бар.Біз оптикалық модель потенциалының энергетикалық тәуелділігін сипаттайтын эмпирикалық қатынасты шығаруға тырысамыз.

ГЛОБАЛЬНЫЕ ПАРАМЕТРЫ ОПТИЧЕСКИХ ПОТЕНЦИАЛОВ РАССЕЯНИЯ ПРОТОНОВ НА ^{6,7}Li и ^{10,11}B ЯДРАХ

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Анализ упругого рассеяния протонов на ядрах ^{6,7}Li и ^{10,11}B был сделан в рамках оптической модели при энергиях пучка до 50 МэВ. Дифференциальные сечения ^{6,7}Li и $^{10,\ 11}$B были измерены в диапазоне энергий протонов от 400 до 1200 кэВ. Благодаря измеренным данным и в соответствии перерасчету литературных данных, они улучшают описание параметров потенциала. Было получено линейное соотношение между объемным действительным потенциалом (V_0) и энергией протона (E_p). Также, поверхностный мнимый потенциал (W_D) пропорционален энергии протона (E_p) в диапазоне энергий 0.700 и 14 МэВ. Параметры оптической модели характеризуют объемный интеграл на нуклонную пару для реального и мнимого потенциалов, J_R и J_W. Наблюдается хорошее согласие между теорией и экспериментом во всем диапазоне. Мы пытаемся вывести эмпирические отношения, описывающие энергетическую зависимость потенциала оптической модели.