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Abstract

The polarizations of the secondary protons from the (p,2p) reactions on nuclei ^{6}Li, ^{7}Li, ^{28}Si at 1 GeV of the initial proton energy have been measured in a kinematically complete experiment. Two final protons from the reaction were detected in coincidence by means of a two-arm magnetic spectrometer at non-symmetric scattering angles $\Theta_1 = 15° \div 26°$, $\Theta_2 = 58.6°$ in the momentum range of the residual nucleus up to 150 MeV/c. Both arms of the spectrometer were equipped by a multiwire proportional chamber polarimeter. The experimental data have been analyzed in the framework of the the distorted wave impulse approximation. It is shown that the polarization of the recoil protons produced at angle Θ_2 in the (p,2p) reaction with the ^{7}Li P-shell proton can be described in terms of the effective polarization of the latter using the single-particle shell wave function of the nucleus. The polarization data for both secondary protons from the reaction ^{28}Si(p,2p)^{27}Al also point out on the effective polarization of the D-shell protons of ^{28}Si. Being extracted from the measured polarization of the recoil protons from the reaction ^{6}Li(p,2p)^{5}He, the effective polarization of the ^{6}Li P-shell proton can not be described in the framework of the single-particle shell model of the nucleus with LS-coupling at large values of the residual nucleus momentum $K_B \geq 90$ MeV/c. As expected the recoil proton polarization in interactions with the S-shell protons of ^{6}Li, ^{7}Li follows the predictions in the impulse approximation with depolarization effects being the only ones taken into account.

1 Introduction

In medium-energy quasi-free scattering processes [1], the nuclear target nucleon is in general polarized before it is knocked out. According to Th.A.J.Maris [2], in the (p,2p) reactions the effective polarization P_{eff} of the protons on the nuclear shells with orbital momentum $l \neq 0$ arises due to the nuclear spin-orbit coupling and absorption of the secondary protons in the nuclear matter. Non-zero value of the P_{eff} is only achieved at a non-symmetrical scattering kinematics of the secondary protons.

One can measure this polarization [2÷4] in (p,2p) reactions using a polarized proton beam, because the matrix element for medium-energy proton-proton scattering has a strong spin dependence. Several (p,2p) coincidence experiments with polarized protons have been performed [5,6] and the measured asymmetries have clearly confirmed the occurrence of large polarizations of the nuclear nucleon. The effective polarizations measured in TRIUMF [6] at proton beam energy 200 MeV for the nuclei ^{16}O and ^{40}Ca are in reasonable agreement with the theoretical expectations [2,4,6] following from the single-particle shell model and calculated in the distorted wave impulse approximation (DWIA).

It should be noted that, since the effective polarization is caused by correlations of the spins and orbits of the nuclear nucleons, its measurement may give direct information on the structure of the ground state of the target nucleus and/or of the involved final state of the residual nucleus. It has been shown [7], for instance, that the value of P_{eff} is very sensitive to the nucleon-nucleon correlations in a nucleus .

Another experimental possibility to observe the P_{eff} is measuring the secondary proton polarization, primary beam being unpolarized. In the framework of the DWIA, which is a good approximation at high proton beam energy , the polarizations of the secondary protons (P_1, P_2) produced at the (p,2p) reaction are related with the effective polarization of nuclear protons by formulae :

$$P_1 = \frac{P + K_{nn} P_{eff}}{1 + P P_{eff}} \ , \qquad (1)$$

$$P_2 = \frac{P + D_{nn} P_{eff}}{1 + P P_{eff}} \ , \qquad (2)$$

where P and K_{nn}, D_{nn} - polarization and depolarization parameters in the elastic pp-scattering , respectively, and index 2 corresponds to the recoil protons. In the pure impulse approximation (IA) the P_{eff} is equal to zero and P_1=P_2=P.

The main goal of the present work is to measure the polarizations of secondary protons produced in the A(p,2p)B reaction at 1 GeV on light nuclei and try to explain the experimental results in terms of the P_{eff} using the single-particle model of the nuclei.

We have performed the most extensive measurements of the polarization of the recoil protons (P_2) for nuclei ^{6}Li [8], ^{7}Li selecting the events from scattering on P- and S-shell nuclear protons. Since the effective polarization of S-shell protons is expected to be equal to zero, the S-shell polarization data can be used for estimation of the depolarization and off-shell effects. In 1998 year the first data for both polarizations P_1 and P_2 have been obtained for nuclei ^{6}Li and ^{28}Si .

2 Experimental method

The polarization measurements were performed at non-symmetric scattering angles $\Theta_1 = 15° \div 26°$, $\Theta_2 = 58.6°$ of the final protons under the conditions of a coplanar quasi-free scattering geometry and a complete reconstruction of the reaction kinematics. We measured the momenta K_1 and K_2 of the secondary protons and their scattering angles Θ_1, Θ_2. With these variables and the proton beam momentum K_0 the nuclear proton separation energy ΔE and the residual nucleus momentum $\vec{K}_B$ for each $(p, 2p)$-event can be calculated. The latter is equal in impulse approximation to the momentum (K) of nuclear proton before the interaction ($\vec{K}_B = -\vec{K}$). In the polarization measurements resolution on the residual nucleus momentum $\vec{K}_B$ was ± 12 MeV/c.

The general layout of the experimental setup is shown in Fig.1. External proton beam of the PNPI synchrocyclotron was focused onto the unpolarized target T1 (from CH_2, ^{6}Li, ^{7}Li, ^{28}Si) of a two-arm spectrometer (the magnetic spectrometers MAP and NES). The beam intensity was monitored by the scintillation telescope M1, M2, M3 and ranged from $5 \cdot 10^{10}$ to 10^{11} protons/(s$\times$cm^2) . The two-arm spectrometer was used for registration of the secondary protons from the (p,2p) reaction in coincidence and for measurement of their momenta and outgoing angles. The polarization of the recoil protons P_2 was measured by polarimeter located in the region of focal plane of the low-energy spectrometer NES. The polarimeter consisted of carbon analyzer T3 (with thickness 72.5 mm) and proportional chambers PC5-PC8 . In 1998 year the spectrometer MAP was also equipped by the polarimeter (proportional chambers PC1-PC4 and analyzer T2 with thickness 170 mm) to measure the polarization (P_1) of the high-energy protons produced in the (p,2p) reaction. The main parameters of the two-arm magnetic spectrometer [9] are listed in Table 1.

The recoil spectrometer NES was installed at a fixed angle $\Theta_2 = 58.6°$. The momentum settings of the spectrometers MAP,

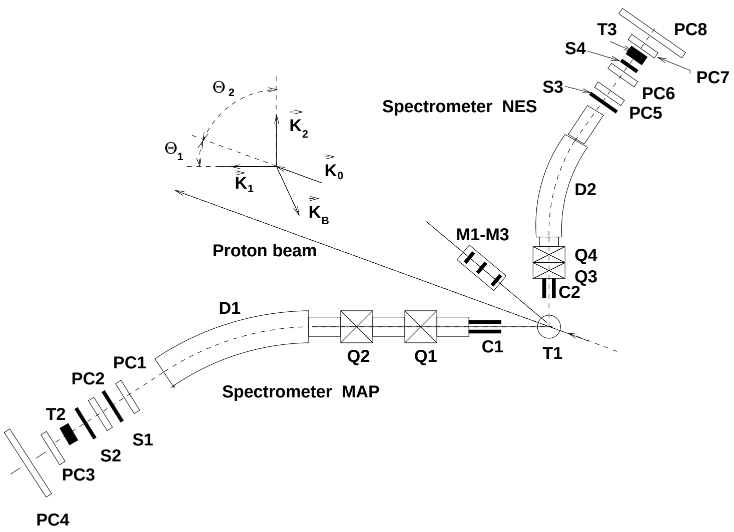

Figure 1: The experimental setup. T1 is the target of the two-arm spectrometer, Q1-Q4 are magnetic quadrupoles, D1,D2 are dipole magnets, C1,C2 are collimators, S1-S4 and M1-M3 are scintillation counters. PC1-PC4 (PC5-PC8) and T2 (T3) are respectively the proportional chambers and carbon analyzer of the high-momentum (low-momentum) polarimeter. Shown above is the kinematics for the (p,2p) reaction.

Table 1: Parameters of the Magnetic spectrometers

Spectrometer	NES	MAP
Maximum particle momentum $(K/Z)^{max}$, GeV/c	1.0	1.7
Axial trajectory radius ρ, m	3.03	5.5
Deflection angle β, deg.	42.2	24.0
Dispersion in focal plane D_f, $mm/\%$	16	22
Solid angle acceptance Ω, sr	$4.5 \cdot 10^{-3}$	$4.0 \cdot 10^{-4}$
Momentum acceptance ΔK, MeV/c	40	150
Energy resolution (FWHM), MeV	~ 2.0	~ 1.5

NES were also unchanged in the experiment. Both spectrometers were tuned to the elastic pp-scattering kinematics at the angles close to $\Theta_1 = 21.75°$ and $\Theta_2 = 58.6°$. Various values of the residual nucleus momentum K_B were achieved by changing the angular position Θ_1 of the spectrometer MAP. The experimental conditions were chosen such that in the regions of $\Theta_1 < 21.75°$ and $\Theta_1 > 21.75°$ the signs of the scalar product $(\vec{K}_0 \cdot \vec{K}_B)$ as well as the signs of the effective polarization of the P-shell proton were opposite.

The time differences between signals from the scintillation counters S1 and S4 (TOF) were measured. The TOF measurements served to control the level of the accidental coincidence background. We recorded events from two neighbour bunches of the proton beam. One of them contained only the background events. In the off-line analysis, these events were used for estimation of the background polarization and the background contribution at the main bunch containing the correlated (p,2p)-events.

To find the polarization P_1, P_2 of the secondary protons produced in the $(p, 2p)$ reaction, azimuthal ϕ_s and polar Θ_s angles of scattering from the analyzers T2, T3 have been calculated using the track information from proportional chambers PC1-PC4, PC5-PC8.

The polarizations were defined as

$$P_{1,2} = \frac{\epsilon}{A} = \frac{2 < \cos\phi_s >}{A(\Theta_s, K_{1,2})}, \tag{3}$$

where ϵ is the azimuthal asymmetry found by averaging $\cos\phi_s$ over a set of events within the working angular range of $\Theta_s = 3° \div 14°$ and $\Theta_s = 5.5° \div 16°$ for the MAP and NES polarimeters, respectively. $A(\Theta_s, K_{1,2})$, which is averaged over the same set of events, is the carbon analysing power parametrized according to Ref.[10,11]. In the given experiment , the accidental background contribution amounted to less than 15%. The effect of this background on the polarizations was taken into account [9].

The proton separation energy spectra for the (p,2p) reactions on nuclei ^{6}Li, ^{7}Li and ^{28}Si , presented in Figs $2 \div 4$, allow to estimate the experimental resolution of the nuclear shells in the given work.

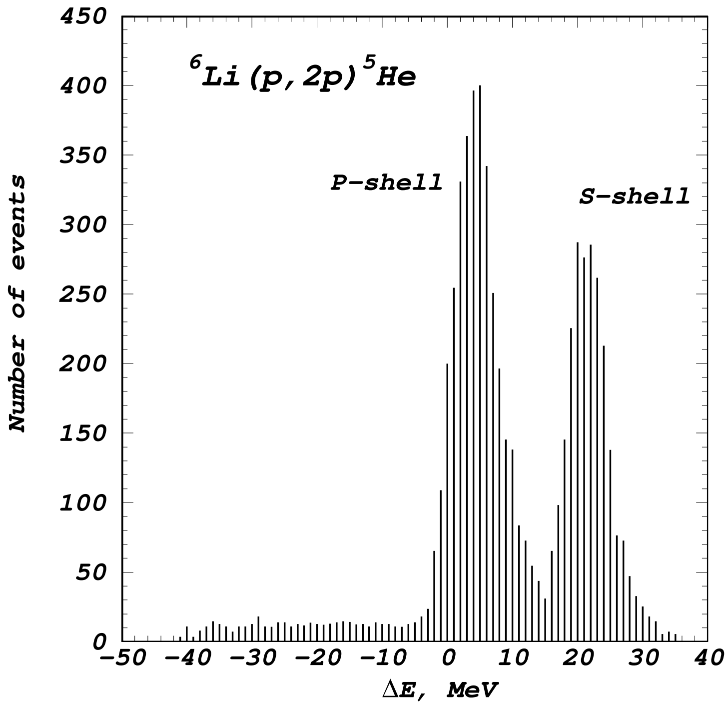

Figure 2: Separation energy spectrum for the reaction ^{6}Li(p,2p)^{5}He.

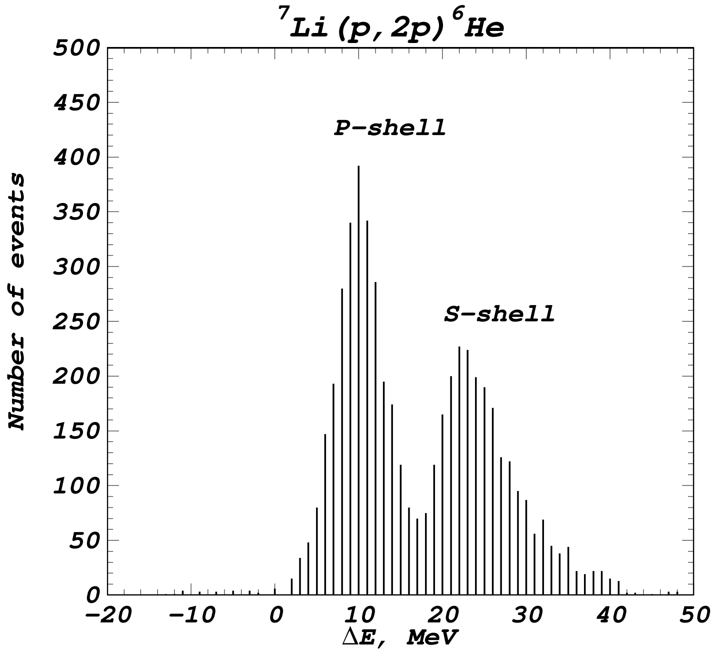

Figure 3: Separation energy spectrum for the reaction ^{7}Li(p,2p)^{6}He.

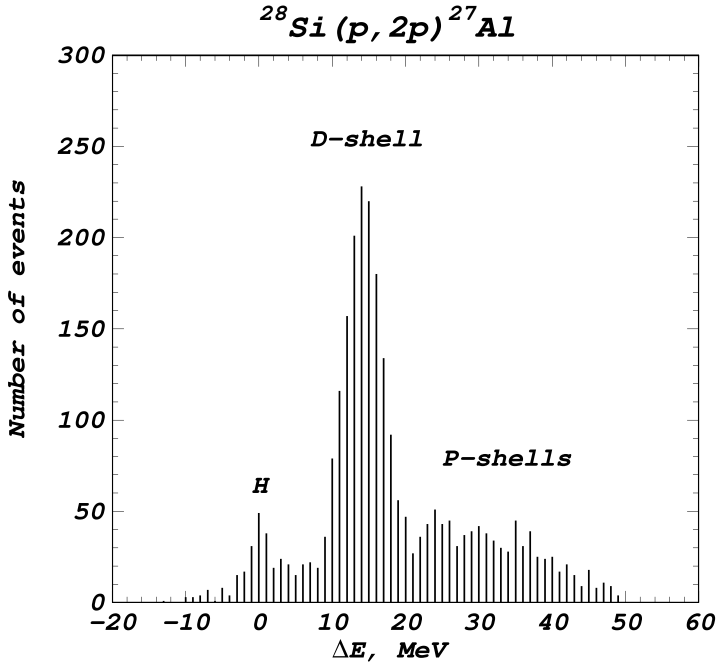

Figure 4: Separation energy spectrum for the reaction ^{28}Si(p,2p)^{27}Al.

3 Experimental results and discussion

The measured polarizations of the recoil protons P_2 and forward-going protons P_1 produced in the reaction A(p,2p)B with P- and S-shell protons of ^{6}Li, ^{7}Li and with D-shell protons of ^{28}Si are shown in Figs. 5÷8, 10 with the results of the theoretical calculations (see also Tables 3÷7). The S-shell data averaged on nuclei ^{6}Li and ^{7}Li are presented in Fig.9. In the figures, the square point is the measured polarization of the recoil protons P_2 in elastic pp-scattering and the solid curve is the result of polarization calculations in the impulse approximation (IA) under the assumption that the target protons are unpolarized (P_{eff}=0).

In the framework of the IA the polarization in the A(p,2p)B reaction is equal to the half-off-energy-shell polarization P for the elastic proton-proton scattering, which has been approximated according to the "initial energy prescription" [12] by its on-shell value $P_{1,2} = P = P(W_l, \Theta_{cm})$. Here W_l is the kinetic energy in the laboratory system and Θ_{cm} is the scattering angle in the center-of-mass system taken respectively as

$$W_l = \frac{s - 4m^2}{2m} \tag{4}$$

and[1]

$$\cos\Theta_{cm} = \frac{t-u}{\sqrt{(s-4m^2)[\frac{(4m^2-t-u)^2}{s} - 4m^2]}} . \tag{5}$$

In (4),(5) m is the proton mass; $s = (k_0 + k)^2$, $t = (k_0 - k_1)^2$ and $u = (k_0 - k_2)^2$ are Mandelstam variables, where k_0, k_1,

[1] Note that, unlike free proton-proton scattering, for off-shell kinematics $s^2 \neq (4m^2 - t - u)^2$.

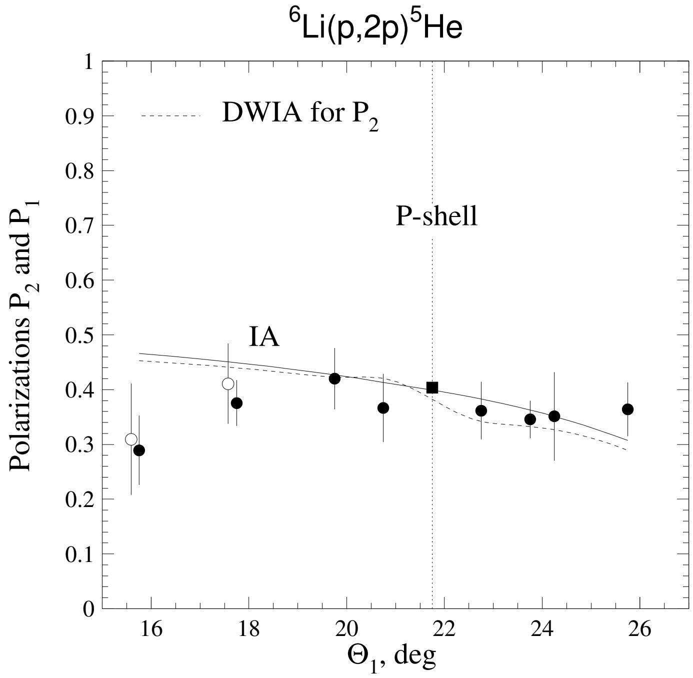

Figure 5: Polarizations of the recoil protons P_2 (•) and forward-going ones P_1 (∘) produced, respectively, at the angles $\Theta_2 = 58.6°$ and Θ_1 in the interaction with the P-shell proton of ^{6}Li. Solid curve represents the result of the calculations in the IA (P_1=P_2). Dashed curve is the result of the DWIA calculations for the recoil protons, the effective polarization of the nuclear proton being taken into account using the single-particle shell model with LS-coupling and the depolarization corrections being made. The measured value of the polarization in elastic pp-scattering at the angle $\Theta_2 = 58.6°$ is shown as a square point at $\Theta_2 = 21.75°$.

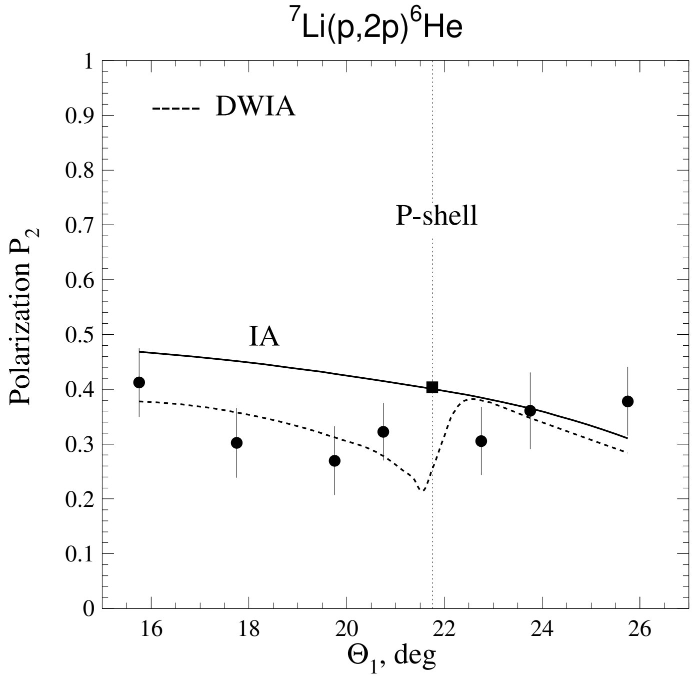

Figure 6: Polarization of the recoil protons P_2 produced at the angle $\Theta_2 = 58.6°$ in the interaction with the P-shell proton of ^{7}Li. Solid curve is the result of the IA calculations. Dashed curve represents the result of the DWIA calculations, the effective polarization of the nuclear proton being taken into account using the single-particle shell model with jj-coupling and the depolarization corrections being made. A square point is the same as in Fig.5.

k_2 and k are the four-momenta of the beam, outgoing protons and nuclear proton before it is knocked out, respectively. The on-shell $P(W_l, \Theta_{cm})$ has been calculated using the Arndt phase-shift analysis [13]. According to our estimations the off-shell uncertainties of the IA calculations of P are less than 0.02 in the kinematic region under investigation (see for instance [14]).

As seen from Figs 5÷10, pure IA fails to reproduce the measured polarizations of the recoil protons P_2 in the investigated kinematic region. A deviation of the the S-shell data for ^{6}Li, ^{7}Li (Figs 7÷9) from the theoretical expectations following from the IA can not be interpreted in terms of the effective polarization of the S-shell nuclear protons because the latter ones have zero orbital momentum. Most probably, the deviation is due to a depolarization of the recoil protons in elastic rescattering on nuclear nucleons. It should be noted that at the recoil proton energy close to 190 MeV one elastic pN-scattering at small angle can drastically decrease its polarization. In the single rescattering approximation the relative depolarization ($\triangle P/P$) can be defined as

$$\frac{\triangle P}{P} = -\frac{L}{L_{free}}\alpha(1-D), \tag{6}$$

where L, L_{free}, α and D are, respectively, a mean path of the secondary protons in nucleus, a mean free path with respect to elastic scattering, a probability for protons to be elastically rescattered in the range of a spectrometer angular acceptance and a depolarization parameter related with the depolarization property of the elastic pN-scattering. The latter in the case of rescattering at the same plane that (p,2p) process is practically equal to the depolarization parameter D_{nn} in the elastic pN-scattering. All variables in the formula (6) in general depend on proton energy and only L can also depend on geometrical

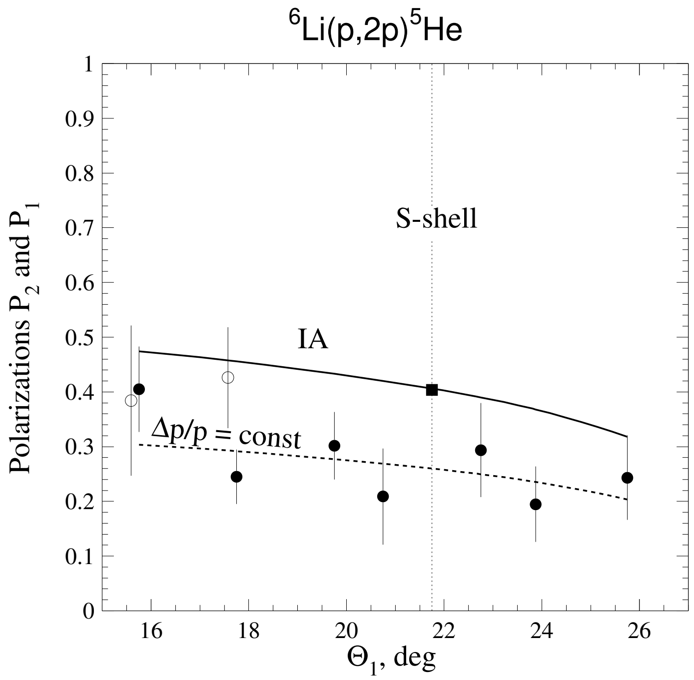

Figure 7: Polarizations of the recoil protons P_2 ($\bullet$) and forward-going ones P_1 ($\circ$) produced, respectively, at the angles $\Theta_2 = 58.6°$ and Θ_1 in the interaction with the S-shell protons of ^{6}Li. Solid curve represents the result of the calculations in the IA (P_1=P_2). Dashed curve is the result of fitting of the values (P^i_{2exp}-P^i_{2IA})/P^i_{2IA} by a function f(Θ_1)=λ^s_{IA}, where λ^s_{IA} is constant. A square point is the same as in Fig.5.

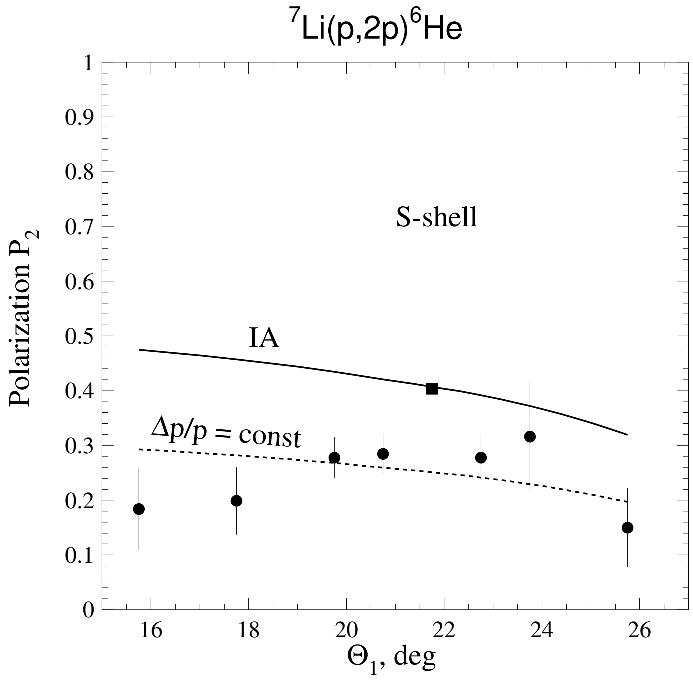

Figure 8: Polarization of the recoil protons P_2 produced at the angles $\Theta_2 = 58.6°$ in the interaction with the S-shell protons of ^{7}Li. Curves and a square point correspond to the same as in Fig.7.

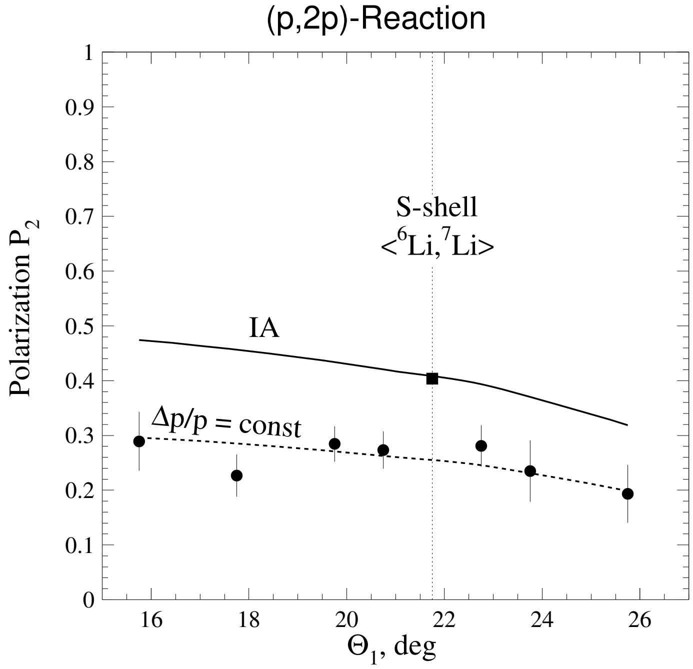

Figure 9: The S-shell recoil proton polarization data averaged on the nuclei ^{6}Li and ^{7}Li. Curves and a square point mean the same as in Figs 6,7.

conditions of the experiment. The DWIA calculations showed that a magnitude of the L (for all shells studied) is practically constant in the angular kinematics under investigation. This fact and the fact that energies of the outgoing protons from the (p,2p) reaction were fixed at present work permit to suppose that a magnitude of the relative depolarization ($\triangle P/P$) was also fixed for the geometry chosen in the experiment. The same result we obtained at the DWIA calculations of the spin-flip amplitude A_{sf} for the polarized protons traversing through the spin-orbit nuclear optical potential [2]. The amplitude is related with the relative depolarization by simple expression $\triangle P/P = 2 \mid A_{sf} \mid^2$.

In Figs 7,8 (see also Fig.9) the dashed lines are the results of fitting of the values (P^i_{2exp}-P^i_{2IA})/P^i_{2IA} for the ^{6}Li and ^{7}Li S-shell data by a function f(Θ_1)=λ^s_{IA}, where λ^s_{IA} is constant. As seen from the figures, a behaviour of the measured polarization P_2 versus the angle Θ_1 follows the theoretical prediction that the relative depolarization ($\triangle P/P$) is constant in the experimental conditions of the given work. The values of the λ^s_{IA} for the S-shells of ^{6}Li and ^{7}Li are equal to -0.360$\pm$0.062 and -0.384$\pm$0.046, respectively.

The P-shell polarization data for ^{6}Li, ^{7}Li (Figs.5,6) and D-shell one for ^{28}Si (Fig.10) can not be explained by only the considered above depolarization effect. We have taken into account the effect from the effective polarization of nuclear protons P_{eff} on the polarization observables using the formulae (1,2). The polarization parameters P, D_{nn}, K_{nn} of the elastic pp-scattering in the formulae were found by the Arndt phase-shift analysis [13]. For instance, a behaviour of the parameters versus the angle Θ_1 for the reaction ^{6}Li(p,2p)^{5}He with the P-shell proton is shown in Fig.11. In the kinematical conditions of the experiment these parameters depend weakly on atomic number of nucleus

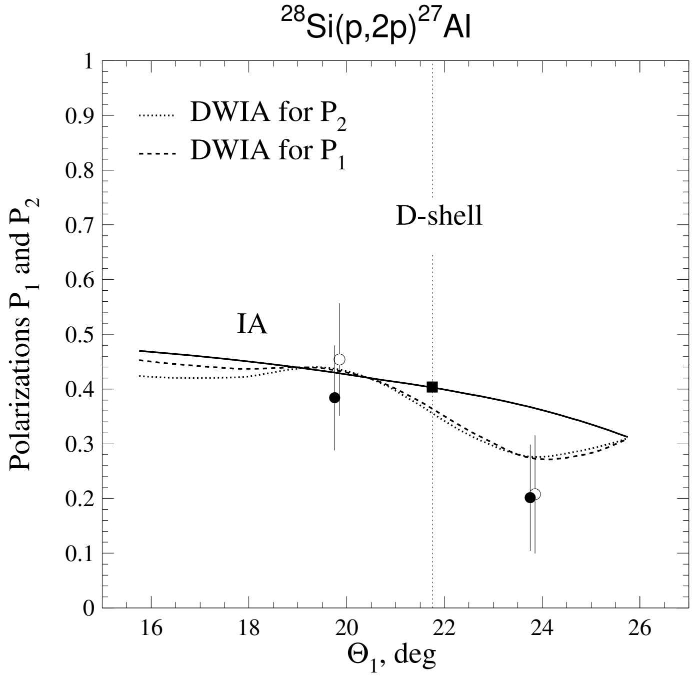

Figure 10: Polarizations of the recoil protons P_2 (•) and forward-going ones P_1 (∘) produced, respectively, at the angles $\Theta_2 = 58.6°$ and Θ_1 in the interaction with the D-shell protons of ^{28}Si. Solid curve is the result of the calculations in the IA (P_1=P_2). Dashed and dotted curves represent the results of the DWIA calculations, respectively, for the recoil and forward-going protons, the effective polarization of the nuclear protons being taken into account using the single-particle shell model with jj-coupling. A square point is the same as in Fig.5

and missing energy of the A(p,2p)B reaction. To calculate the P_{eff}, the DWIA approximation and the single-particle shell wave functions of the nuclei have been used.

In a certain coplanar geometry of the A(p,2p)B reaction the effective polarization is orthogonal to the scattering plane and is given by [3,7]:

$$P_{eff} = \frac{\sum\limits_{m_f m_i} (\mid g'^{(+)}_{m_f m_i}(\vec{k}) \mid^2 - \mid g'^{(-)}_{m_f m_i}(\vec{k}) \mid^2)}{\sum\limits_{m_f m_i} (\mid g'^{(+)}_{m_f m_i}(\vec{k}) \mid^2 + \mid g'^{(-)}_{m_f m_i}(\vec{k}) \mid^2)}. \tag{7}$$

$g'^{(\pm)}_{m_f m_i}(\vec{k})$ is the distorted momentum amplitude which may be written [15]:

$$g'^{(\pm)}_{m_f m_i}(\vec{k}) = (2\pi)^{-3/2} \times$$
$$\times \int e^{-i\vec{k}\vec{r}} \prod_n D_n(\vec{r}) < j_f m_f; B \mid a^{(\pm)}(\vec{r}) \mid j_i m_i; A > d^3\vec{r}, \tag{8}$$

where $\mid j_i m_i; A >$ and $\mid j_f m_f; B >$ denote the initial and final nuclear wave functions characterized by total angular momenta j_i and j_f and projections m_i and m_f; the $a^{(\pm)}(\vec{r})$ are the annihilation operators of a nucleon with position $\vec{r}$ and spin projections $(\pm)$; all angular momenta are quantized in the direction $\vec{K}_2 \times \vec{K}_1$. The distorting functions $D_n(\vec{r})$ (n=0,1,2), which represent the effects of multiple scattering of the incident (n=0) and secondary (n=1,2) protons by the rest of the nucleus, have been calculated using the WKB approximation:

$$D_0(\vec{r}) = exp\left\{ -i\frac{E_0}{h^2 c^2 k_0} \int\limits_{-\infty}^{0} U_0(\vec{r} + s\vec{k}_0) ds \right\}, \tag{9}$$

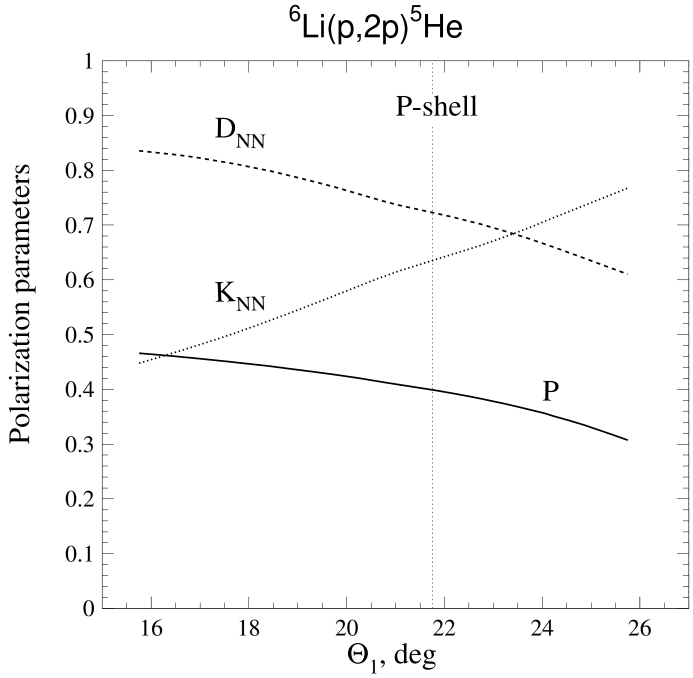

Figure 11: Polarization parameters P, D_{nn}, K_{nn} of elastic pp-scattering calculated under the kinematic conditions in which the (p,2p) reaction with the P-shell proton of ^{6}Li was investigated.

$$D_n(\vec{r}) = exp\left\{ -i\frac{E_n}{h^2c^2k_j}\int\limits_0^\infty U_n(\vec{r}+s\vec{k}_n)ds \right\} \qquad (n=1,2), \quad (10)$$

where E_0 and E_1, E_2 are total energies of the beam and secondary protons from the (p,2p) reaction; $U_n(\vec{r})$=$V_n(\vec{r})$+i$W_n(\vec{r})$ (n=0,1,2) are the complex optical potentials for the protons.

In the shell model calculations for ^{6}Li we have used harmonic oscillator wave functions with a width parameter determinated to reproduce a root mean square radius (R_{rms} = 2.54 fm) [16] measured by electron scattering on the target nucleus. The width parameter for ^{7}Li was supposed to be equal to the one of ^{6}Li [17]. The D-state radial wave function of ^{28}Si have been generated by square well potential with a radius R_w=$\sqrt{5/3}R_{rms}$=3.92 fm (derived from elastic electron scattering [18]) and depth adjusted so as to reproduce the experimental proton separation energy for the state (13.97 MeV [19]). The ground state of ^{6}Li is considered to have a valence neutron and proton with the zero total orbital angular momentum and the total spin equal to unity to give j_i=1 [20]. The residual nucleus in the (p,2p) reaction with the ^{6}Li P-shell proton is ^{5}He (j_f=3/2) having one neutron outside a closed S-shell . In the case of the ^{7}Li nucleus it is assumed that its P-shell nucleons are jj-coupled, and that the total momentum of two P-shell neutrons is zero and spin of the nucleus (j_i = 3/2) is determined by the momentum of the P-shell proton. A clean knocking-out of this proton leads to one j_f=0 state of ^{6}He. In the calculations for the ^{28}Si(p,2p)^{27}Al reaction one supposes that a proton of the ^{28}Si nucleus in $D_{5/2}$ state couples with its core ^{27}Al (j_f=5/2) to give j_i=0.

In the computations we have used the inert-core approximation [7], assuming that the total center-of-mass of the system coincides with the residual nucleus center-of-mass and is not affected by the knock-out process. This approximation results in a strong simplification but causes a error of the order A^{-1} in the squared overlap integrals (8). Here A is the nucleus atomic number. However, for effective polarization calculations this error is considerably reduced as only ratios between momentum distributions enter (see Eq.(7)).

The distorting optical potentials $U_n(\vec{r})=V_n(\vec{r})+\mathrm{i}W_n(\vec{r})$ (n=0,1,2) in (9) and (10) have been taken as spin independent square wells ($V_n(\vec{r})=V_n^0$, $W_n(\vec{r})=W_n^0$) with a radius of R_d ($R_d=\sqrt{5/3}R_{rms}$) 3.28 fm and 3.92 fm for nuclei ^{6}Li, ^{7}Li and ^{28}Si, respectively. The integrations in (8) have been made over the classical paths of the incoming and outgoing protons; these paths were supposed to be straight lines, thus neglecting reflection and refraction. The ^{6}Li and ^{7}Li potential depths for the recoil protons (V_2^0, W_2^0) with kinetic energy T_{K2} close to 190 MeV have been estimated via the potential volumes taking from [3,21÷23]. For the ^{28}Si nucleus these parameters were calculated on the base of data for nuclei ^{16}O and ^{40}Ca [2] using a relation (given by Kerman et al.[24]) between V_n^0 and the real part of the forward nucleon-nucleon scattering amplitude and between W_n^0 and the imaginary one. The optical potentials for the protons produced in the (p,2p) process at the angle Θ_1 with energy T_{K1} close to 800 MeV and for beam protons were assumed to be purely imaginary ones. The potential depths W_1^0, W_0^0 have been estimated via the ones at 190 MeV proton energy using the Kerman relation noted above, the relativistic effect of the finite range of the nucleon-nucleon interaction being partly taken into account [25]. The values of V_n^0, W_n^0 used in the DWIA calculations are presented in Table 2.

The results of the effective polarization calculations are shown

Table 2: The kinematical and optical potential parameters used in the DWIA calculations

	^{6}Li	^{7}Li	^{28}Si
	$1P_{3/2}$	$1P_{3/2}$	$1D_{5/2}$
$T_{K0}(MeV)$	1000	1000	1000
$W_0^0(MeV)$	18.9	21.4	48.6
$T_{K1}(MeV)$	803	798	794
W_1^0 (MeV)	18.2	20.6	46.7
$T_{K2}(MeV)$	191	191	192
W_2^0 (MeV)	6.3	7.5	17.3
V_2^0 (MeV)	6.7	7.8	13.9

in Fig.12. In the calculations for nuclei ^{6}Li, ^{7}Li, the finite range of the angular and momentum acceptances of the spectrometers MAP and NES have been taken into account. We investigated a sensitivity of the polarization to the optical potential depths. It turned out that reasonable changes of the imaginary and real parts of the optical potential for the recoil protons (W_2^0, V_2^0) do not have drastic effect; the relative deviation $\triangle P_{eff}/P_{eff}$ for ^{7}Li is less than 0.1 at changing of W_2^0 or V_2^0 at 20% . The P_{eff} depends more weakly on high-energy potentials W_1^0, W_0^0, being changed in the same proportion; the ratio $\triangle P_{eff}/P_{eff}$ is less 0.1 at changing of W_1^0 and W_0^0 at 30%.

Dashed line in Fig.6 is the result of the DWIA calculations for the reaction ^{7}Li(p,2p)^{6}He with the P-shell proton, a depolarization effect being also taken into account. We supposed that a deviation of the polarizations P^i_{2DWIA} calculated using formula

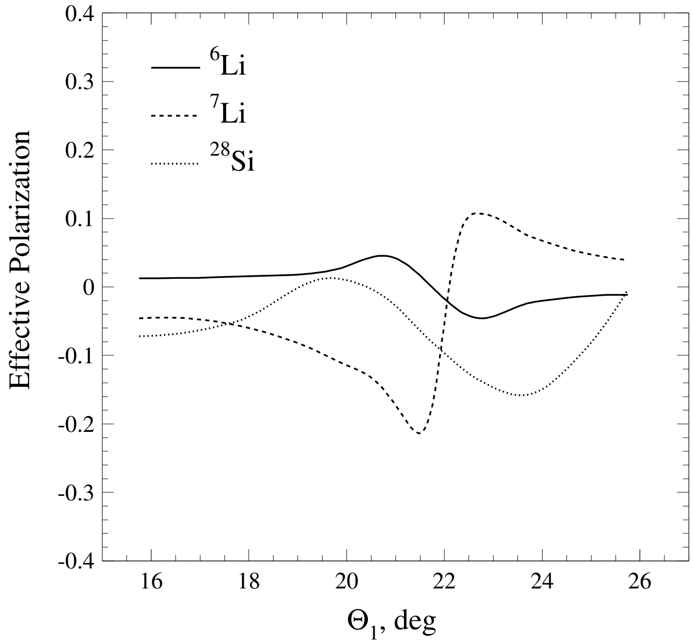

Figure 12: Effective polarizations of the P-shell proton of nuclei ^{6}Li,^{7}Li and D-shell protons of ^{28}Si, calculated in the framework of the DWIA, the single-particle shell wave functions of the nuclei being used.

(2) from the experimental ones P^i_{2exp} is due to a depolarization of the recoil protons. The values $(P^i_{2exp} - P^i_{2DWIA})/P^i_{2DWIA}$ were fitted by a function f(Θ_1)=λ^p_{DWIA} in accordance with the described above depolarization law $\triangle P/P$=constant, a magnitude of λ^p_{DWIA}=-0.1405$\pm$0.0602 being obtained. Fig.6 shows that an assumption about existence of the nuclear proton effective polarization results in a good description of the experimental data. This assumption is also confirmed by the investigations of the (p,2p) reaction with D-shell protons of ^{28}Si (Fig.10). According to the predictions in the framework of the DWIA the effective polarization of the D-shell protons is close to zero at angle of $\Theta_1 = 19.75°$ and achieved a maximal negative magnitude at angle $\Theta_1 = 23.75°$. Besides, it is interesting to note, in the angular region of $\Theta_1 = 22° \div 25°$ a sign of the P_{eff} of the ^{28}Si D-shell protons is opposite to one of the ^{7}Li P-shell proton (see Fig.12). We have performed polarization measurements for both secondary protons produced in the reaction ^{28}Si(p,2p)^{27}Al at the two values of Θ_1 mentioned above ($\Theta_1 = 19.75°$ and $\Theta_1 = 23.75°$). The results of the measurements do not contradict to the DWIA predictions.

The result of the DWIA calculations of the recoil proton polarization P_2 for the reaction ^{6}Li(p,2p)^{5}He with the P-shell proton is presented in Fig.5 (dashed line). A depolarization correction has been made in the same way as for the reaction with ^{7}Li, only values $(P^i_{2exp}$-$P^i_{2DWIA})/P^i_{2DWIA}$ for points in the angular region of $\Theta_1 = 19.75° \div 23.75°$ being fitted. The depolarization parameter for nucleus ^{6}Li λ^p_{DWIA}=-0.0413$\pm$0.0620 have been obtained. As seen from Fig.5 the single-particle shell model of ^{6}Li with LS-coupling, used in the DWIA calculations, fails to reproduce the experimental data in the angular region under investigation. It should be noted that this model reproduces rather good experimental value of the ^{6}Li magnetic moment and gives the ^{6}Li quadrupole moment value (Q_{theory}=0) close to the experimental one [20].

Using the formula (2), the effective polarization P_{eff} of the ^{6}Li P-shell proton as a function of the residual nucleus momentum K_B can be calculated from the measured values of the recoil proton polarization P_2, corrected for the depolarization effect. In the angular region $\Theta_1 = 19.75^\circ \div 23.75^\circ$ (see Fig.5) the P_{eff} seems to be close to zero and a deviation of the experimental values of the recoil proton polarization P_2 from those calculated in the IA is due to the depolarization effect only. In this case the depolarization parameter λ^p_{IA} is equal to -0.0523±0.0612. The results of such calculations with the depolarization parameter λ^p_{IA} are shown in Fig.13. The solid line in the figure corresponds to the result of the DWIA calculations noted above. As seen from Fig.13, a magnitude of the P_{eff} differs from zero at K_B more than $\simeq$ 90 MeV/c. Observation of the non-zero effective polarization on the unclosed shell of ^{6}Li contradicts to the assumption that the ground state of this nucleus may be written as $(2s)^2$ [20], because for the protons with zero orbital momentum P_{eff} must be equal to 0. It is possible that the P_{eff} having finite magnitude at large momenta K_B is related with a presence of the D-component in the ^{6}Li wave function.

In conclusion we should like to discuss the possible reason of the observed considerable difference between depolarization effects for the recoil protons knocked out from P- and S-shells of nuclei ^{6}Li, ^{7}Li; for instance, the ratio $\lambda^s_{IA}/\lambda^p_{DWIA}$ for ^{7}Li is 2.7 (see above). If one supposes that the spin-flip amplitude has a finite value at rescattering of the recoil proton on all nucleons of the residual nucleus then a magnitude of the depolarization should be practically the same for the S- and P- shell recoil pro-

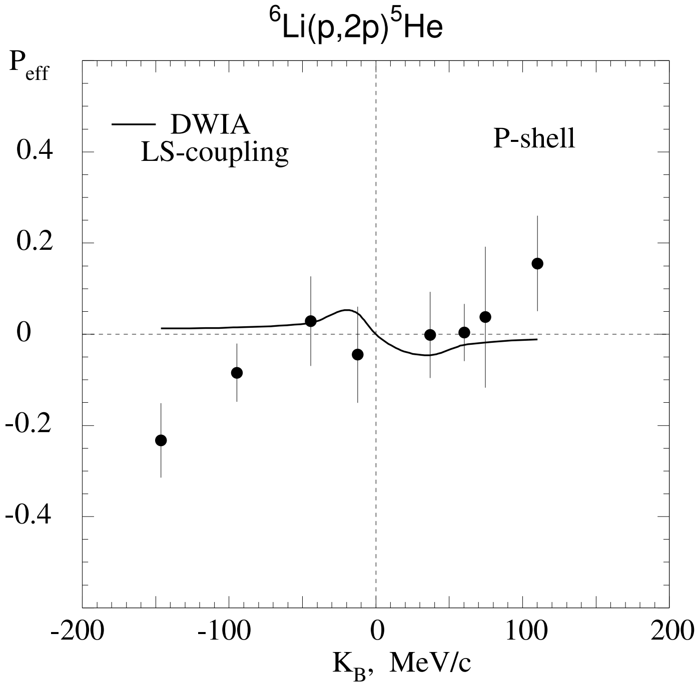

Figure 13: Effective polarization of the P-shell proton of the ^{6}Li nucleus. Sign of the residual nucleus momentum K_B is equal to that of the scalar product $((\vec{K}_0 \cdot \vec{K}_B))$. Solid curve corresponds to the result of the DWIA calculations in the framework of the single-particle shell model of the nucleus with LS-coupling.

tons. There is an argument against the last statement that a path of the S-shell recoil proton in nucleus is bigger than one of the P-shell recoil proton. However, the distortion in nuclear matter emphasizes certain small part of nucleus joined to its boundary. Due to this mean paths of the S- and P-shell recoil protons in nucleus do not differ drastically enough (less than 25% according to our estimations) to explain a big value of the ratio $\lambda^s_{IA}/\lambda^p_{DWIA}$. To a certain extent, the latter can be explained if we assume that the effects of the spin flips at rescattering of the P-shell recoil proton on the S-shell nucleons are forbidden by the Pauli principle and a depolarization of the P-shell recoil proton is determined only by collisions with one (two) neutron(s) of the unclosed P-shell of ^{6}Li (^{7}Li), a depolarization of proton knocked out from S-shell being determined by collisions with one S-proton and all P-shell nucleons of the residual nucleus. It is also possible that the observed significant reduction of the S-shell recoil proton polarization from the prediction in the IA (see Figs 7÷9) is partly caused by a modification of the nucleon-nucleon interaction in nuclear medium [26,27]. Then one may suppose that the kinematic dependence of this medium effect in our experimental conditions is similar to the one of the depolarization effect.

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Table 3: The polarizations of the recoil protons P_2 and forward-going ones P_1 produced, respectively, at angles $\Theta_2 = 58.6^\circ$ and Θ_1 in the reaction ${}^6Li(p,2p)^5He$ at energy 1 GeV with the $P-$shell proton of ${}^6Li$

Θ_1 Deg	K_1 MeV/c	K_2 MeV/c	$K_{\rm B}$ MeV/c	P_2	P_1
15.75	1464.39	630.39	146.52	0.2892±0.0635	0.3093±0.1016
17.75	1466.40	629.76	94.78	0.3753±0.0419	0.4107±0.0733
19.75	1466.76	630.58	44.39	0.4200±0.0564	
20.75	1471.21	624.18	12.49	0.3664±0.0626	
22.75	1469.82	626.06	37.02	0.3616±0.0526	
23.75	1467.94	628.47	60.27	0.3456±0.0340	
24.25	1468.68	626.97	74.57	0.3511±0.0807	
25.75	1465.89	629.94	110.01	0.3638±0.0493	

Table 4: The same as Table 3 for the reaction with the $S-$shell protons of ${}^6Li$

Θ_1 Deg	K_1 MeV/c	K_2 MeV/c	$K_{\rm B}$ MeV/c	P_2	P_1
15.75	1444.82	629.40	146.56	0.4047±0.0781	0.3842±0.1372
17.75	1446.98	628.52	95.58	0.2447±0.0497	0.4260±0.0922
19.75	1447.84	628.56	47.28	0.3016±0.0620	
20.75	1452.58	621.74	20.62	0.2087±0.0880	
22.75	1452.69	621.25	45.26	0.2935±0.0860	
23.87	1452.27	621.27	72.44	0.1948±0.0688	
25.75	1446.73	628.21	113.25	0.2432±0.0773	

Table 5: The polarization of the recoil protons produced at angle $\Theta_2 = 58.6°$ in the reaction $^7Li(p, 2p)^5He$ at energy 1 GeV with the $P-$shell proton of ^7Li

Θ_1 Deg	K_1 MeV/c	K_2 MeV/c	K_B MeV/c	P_2
15.75	1459.24	629.38	145.56	0.4122±0.0628
17.75	1459.89	630.32	95.52	0.3023±0.0635
19.75	1459.93	631.38	45.90	0.2697±0.0625
20.75	1462.52	627.76	17.40	0.3235±0.0525
22.75	1462.38	627.81	35.92	0.3056±0.0619
23.75	1463.89	625.08	63.80	0.3608±0.0700
25.75	1461.03	628.06	111.96	0.3780±0.0625

Table 6: The same as Table 5 for the reaction with the $S-$shell protons of ^7Li

Θ_1 Deg	K_1 MeV/c	K_2 MeV/c	K_B MeV/c	P_2
15.75	1441.73	628.93	146.53	0.1838±0.0747
17.75	1443.00	628.95	96.85	0.1987±0.0613
19.75	1443.34	629.53	50.16	0.2779±0.0377
20.75	1444.68	627.77	29.48	0.2844±0.0366
22.75	1443.91	628.79	42.50	0.2776±0.0420
23.75	1448.90	620.71	70.93	0.3160±0.0980
25.75	1442.25	629.55	112.73	0.1500±0.0720

Table 7: The polarizations of the recoil protons P_2 and forward-going ones P_1 produced, respectively, at angles $\Theta_2 = 58.6°$ and Θ_1 in the reaction $^{28}Si(p,2p)^{27}Al$ at energy 1 GeV with the $D-$shell protons of ^{28}Si

Θ_1 Deg	K_1 MeV/c	K_2 MeV/c	K_B MeV/c	P_2	P_1
19.75	1456.72	629.36	44.78	0.3838±0.0960	0.4541±0.1028
23.75	1455.81	630.68	59.33	0.2012±0.0971	0.2076±0.1079

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