# STUDY OF THE $(d, p)$ REACTION ON $^{48}$Ti and $^{50}$Ti NUCLEI

BY K. GROTOWSKI, A. JASIELSKA*, T. PANEK*, F. PELLEGRINI**
AND S. WIKTOR

Institute of Physics, Jagellonian University***

Institute of Nuclear Physics, Cracow

*(Received March 8, 1968)*

Proton spectra from $^{48}$Ti$(d, p)^{49}$Ti and $^{50}$Ti$(d, p)^{51}$Ti reactions at incident deuteron energy of 12.9 MeV were measured in wide range of angles. Six proton groups leading to: ground, 1.38, 1.72, 2.50, 3.26 and 3.80 MeV states of $^{49}$Ti nucleus and two proton groups leading to: ground and 1.16 MeV states of $^{51}$Ti nucleus were taken for the analysis of angular distributions. The distorted wave, zero range Born approximation method was applied and the $l$-values as well as spectroscopic factors corresponding to different transitions were obtained. Four different sets of parameters of the deuteron optical potential were used in the DWBA analysis and their influence on the shape of angular distributions and the magnitude of spectroscopic factors was investigated. These potentials only which have the depth of the real potential not lower than about 100 MeV appeared to be acceptable. In measured angular distributions noticeable effects due to different coupling of spin and orbital angular momentum of transferred neutron were observed. The differences in shapes of angular distributions caused by that effect were related to the polarization of protons scattered elastically on Ti nuclei.

## 1. *Introduction*

The deuteron stripping reaction was used for many years for the investigation of single particle excitations of atomic nuclei. It is well known that the angular momentum of a nucleon transferred in this reaction influences the shape of the angular distribution of the emitted particle. Recently Lee and Schiffer [1] found a dependence of the shape of angular distribution in the region of large angles on the alternative coupling of spin and orbital angular momentum of the captured nucleon.

---

* Permanent address: High Pedagogical School, Katowice, Poland.
** Permanent address: Instituto di Fisica dell Università, Padova, Italy.
*** Address: Instytut Fizyki Uniwersytetu Jagiellońskiego, Kraków, Reymonta 4, Polska.

In the present experiment energy and angular distributions of protons from the deuteron stripping reaction on $^{48}$Ti and $^{50}$Ti nuclei have beer measured. The DWBA analysis of experimental data have been performed and the Lee and Schiffer rule applied in order to obtain the information about spectroscopic parameters of final states of $^{49}$Ti and $^{51}$Ti nuclei.

Titanium isotopes belong to the region of $A = 50$ nuclei which exhibits distinctly the shell model phenomena. Until now some $(d, p)$ experiments on $^{48}$Ti and $^{50}$Ti nuclei have been performed for rather low [2]—[7] and rather high [8] bombarding deuteron energies. The energy of deuterons in the present work lies in an intermediate energy region.

Parameters of the optical model potentials for the interaction of deuterons with target nuclei and protons with final nuclei must be known for DWBA analysis of the stripping reaction. In the contrary to the very well known parameters of the nucleon optical potential, parameters of the deuteron potential exhibit some ambiguities. In the present work the influence of these ambiguities on the results of the DWBA calculations have been investigated.



## 2. *Experimental procedure*

Experimental data were obtained using the 12.9 MeV deuteron beam from the 120 cm cyclotron of the Institute of Nuclear Physics in Cracow. Well collimated beam bombarded the $TiO_2$ target, placed in the centre of the scattering chamber. Charged reaction products were analysed by means of a broad range magnetic spectrograph and detected on nuclear plates. Because of the high $Q$ — value of the Ti $(d,p)$ reaction and consequently high energy of emitted protons it was possible to eliminate the deuteron background covering nuclear plates by an Al foil of the thickness of 15 mg/cm$^2$. The overall energy resolution of the measurement defined as full width at half maximum of a proton peak in the energy spectrum was estimated to be of about 240 keV.

Targets were prepared by a sedimentation of a very fine $TiO_2$ powder, suspended in water, on a thin gold backing. The $^{48}$Ti isotope was enriched to 98.9 percent and the $^{50}$Ti isotope was enriched to 84 per cent. The thicknesses of targets, determined by weighting and measurements of area were $(1.17 \pm 0.10)$ mg/cm$^2$ and $(1.10 \pm 0.10)$ mg/cm$^2$ for $^{48}TiO_2$ and $^{50}TiO_2$ respectively. The total charge of deuterons collected in the Faraday cup, placed behind the target, was measured by a beam integrator. The intensity of the beam was measured independently by a semiconductor monitor viewing a thin golden foil placed in the front of a mean target. An additional semiconductor counter monitor looking at the $TiO_2$ target was applied in order to check its thickness continuously during the measurements. Angular distributions of protons were measured in 5 degree steps for the range of angles from 20 to 105 degrees (lab).

## 3. *Experimental results*

Typical energy spectra of protons, measured at the reaction angle of 50 degrees are shown in figs 1 and 2. Observed energy groups were identified according to the schemes of levels of $^{49}$Ti and $^{51}$Ti nuclei as reported in the papers [2]—[8]. In the case of the $^{48}$Ti $(d,p)$ $^{49}$Ti

ACTA PHYSICA POLONICA Vol. XXXIV (1968) Fasc. 5

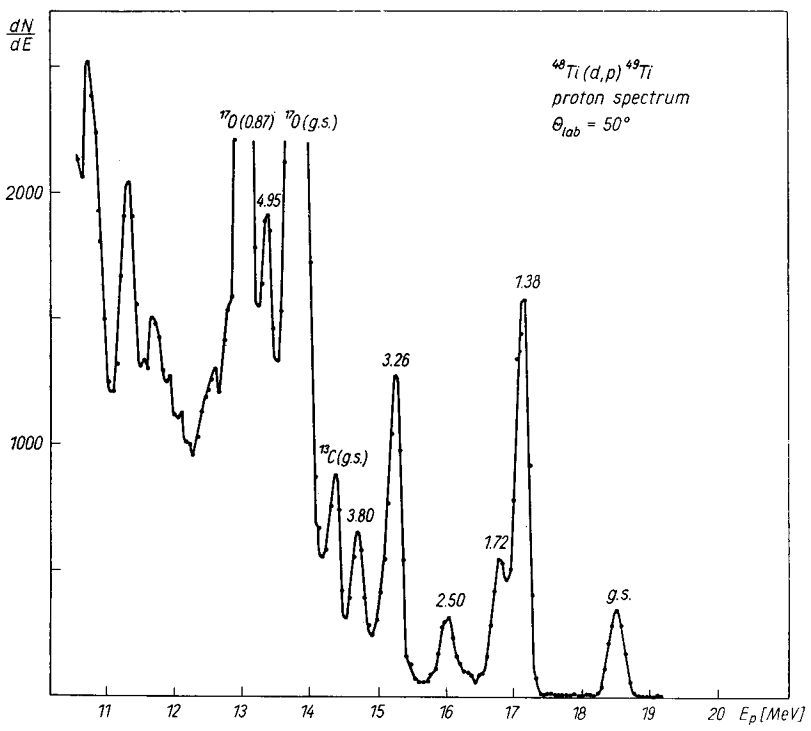


Fig. 1. Energy spectrum of protons from the $^{48}$Ti($d$, $p$)$^{49}$Ti reaction obtained at the angle of 50 degrees

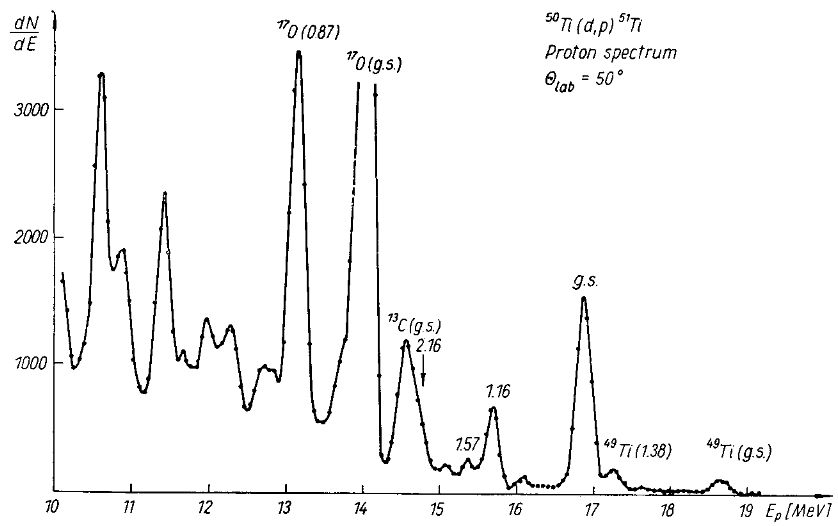


Fig. 2. Energy spectrum of protons from the reaction $^{50}$Ti($d$, $p$)$^{51}$Ti obtained at the angle of 50 degrees

reaction the ground, 1.38, 1.72, 2.25, 2.50, 3.26, 3.46, 3.80, 4.60, 4.90 and 5.10 MeV states of $^{49}$Ti were found. A new highly populated 3.80 MeV state of the $^{49}$Ti nucleus was identified in the present experiment and independently by Alty *et al.* [6] and Barnes *et al.* [7]. Angular distributions of protons have been measured for the transitions leading to the ground, 1.38, 1.72, 2.50, 3.26 and 3.80 states of $^{49}$Ti. Corresponding groups of protons were well

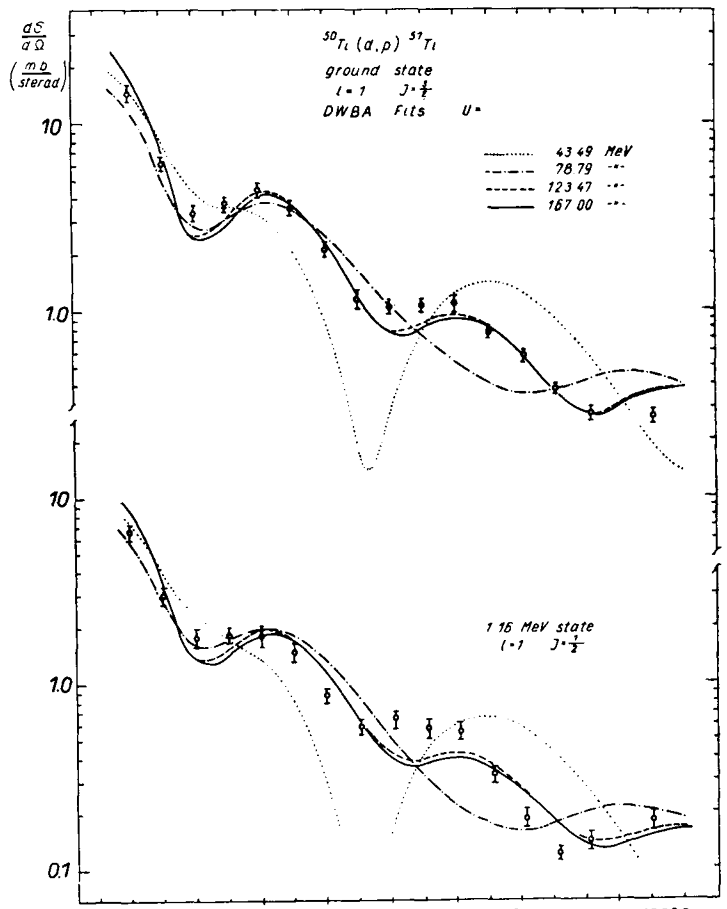


Fig. 3. Angular distributions for the ground and 1.16 MeV transitions in the $^{50}$Ti$(d, p)^{51}$Ti reaction. The curves represent the DWBA calculations with various deuteron optical model parameters

resolved and highly populated. In the case of $^{50}$Ti $(d, p)$ $^{51}$Ti reaction at least 7 energy levels could be resolved. They correspond to the ground, 1.16, 1.57, 2.16, 2.91, 3.12 and 3.94 MeV states of $^{51}$Ti nucleus but only two groups of protons, these corresponding to the ground and 1.16 MeV states were acceptable for measurements of angular distributions. Remaining part of the spectrum was obscured in some angular regions by proton peaks from the $(d, p)$ reaction on $^{12}$C, $^{16}$O and $^{48}$Ti contaminations in the target.

Determination of the number of protons corresponding to the particular peaks in the energy spectrum was carried out by fitting the peaks with curves of the Gaussian shape. A standard program written for the ODRA-1003 computer [9] was employed in order to substract the background and to separate contributions from poorly resolved neighbouring peaks. Contributions of groups of protons belonging to the $(d, p)$ reactions on isotopic im-

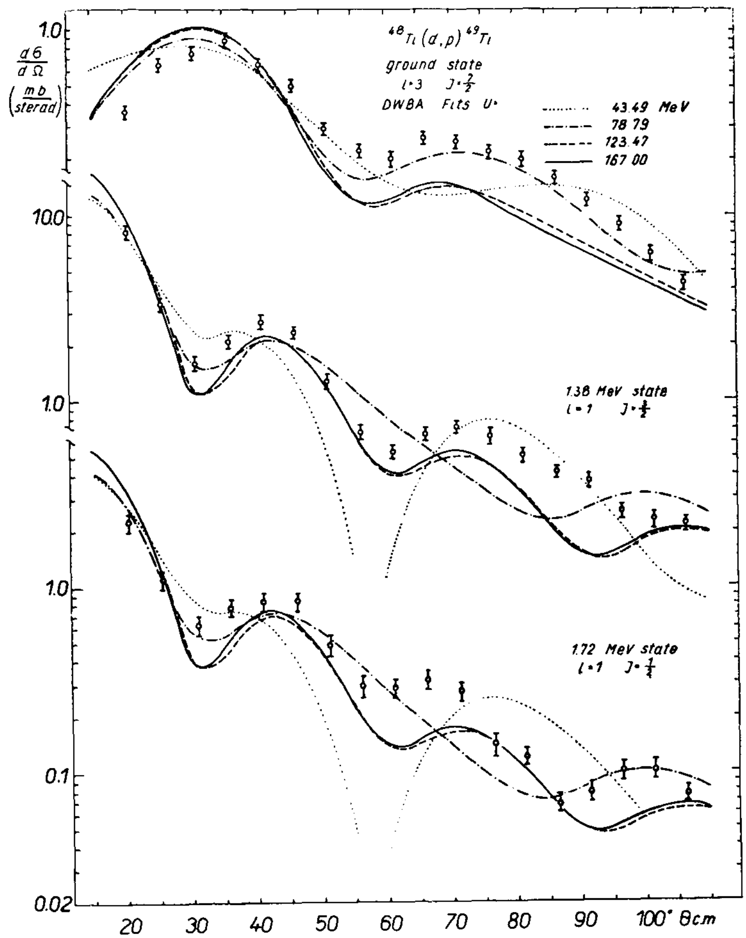


Fig. 4. Angular distributions for the ground, 1.38 and 1.72 MeV transitions in the $^{48}$Ti$(d, p)^{49}$Ti reaction. The curves represent the DWBA calculations with various deuteron optical model parameters

purities which could not be eliminated by the technique described to above because of the complete overlapping of peaks, were estimated from the known cross-sections and substracted. This procedure increasing considerably the error of the determination of the cross-section was necessary at some reaction angles in the case of the $^{50}$Ti target where the $^{48}$Ti admixture was 11 percent. The errors indicated in angular distributions (Figs 3, 4 and 5) include statistical and other errors due to scanning and separation technique. Their values

ACTA PHYSICA POLONICA Vol. XXXIV (1968) Fasc. 5

are spread over the range from 5 to 13 per cent except for the 3.80 MeV state of $^{49}$Ti where the abnormally large errors at some angles of observation are due to the overlapping of proton peaks from the $^{48}$Ti $(d, p)$ $^{49}$Ti and the $^{12}$C $(d, p)$ $^{13}$C reactions. The errors of the absolute value of the cross-sections arising from the measurements of the thicknesses of the targets and of the total charge of deuterons collected in the Faraday cup were estimated to be 20 per cent.

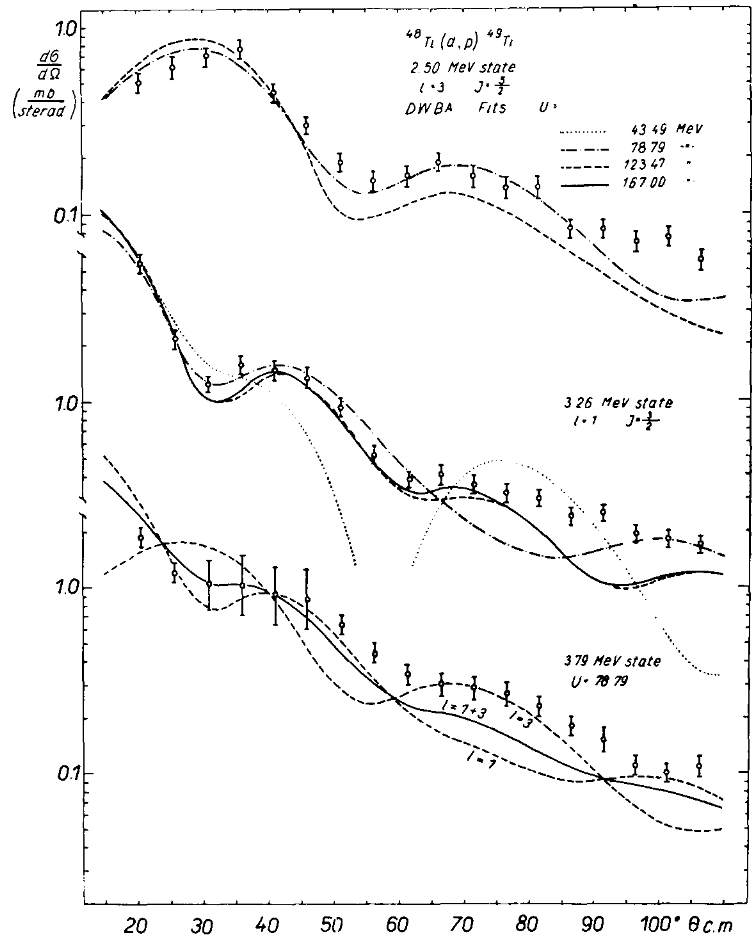


Fig. 5. Angular distribution for the 2.50, 3.26 and 3.79 MeV transitions in the $^{48}$Ti$(d, p)$$^{49}$Ti reaction. The curves represent the DWBA calculations with various deuteron optical model parameters or different values of $l$

## 4. *DWBA analysis*

Measured angular distributions were fitted with curves obtained from the DWBA, zero-range, no cut-off calculations. The calculations were carried out using the GAP-2 program [10] similar to that described by Bassel, Drisko and Satchler [11] but coded in ALGOL for the use on the GIER computer. The surface absorption only was considered in the imaginary parts of the distorting proton and deuteron potentials.

Necessary optical model parameters for deuterons were found from the optical model fits to the deuteron elastic scattering data, obtained in our laboratory [12] for a natural titanium target. An optical model potential of the form:

$$V(r) = V_c(r) + Uf_u(r) + 4iw \frac{df_w(r)}{dr}$$

was used in order to describe the interaction of deuterons with Ti nuclei. In this formula $V_c(r)$ is the Coulomb potential taken to be that due to an uniformly charged sphere of the radius $r_c A^{1/3}$($r_c$ was put 1.3 $fm$), $U$ and $W$ are the real and imaginary depths of the optical potential, $A$ is the mass number of the target nucleus. Both $f_u(r)$ and $f_w(r)$ are the Saxon Woods forms with half value radii $r_u A^{1/3}$ and $r_w A^{1/3}$ and diffusenesses $a_u$ and $a_w$ of the real and imaginary parts of the potential respectively.

An automatic search routine ALA-1 [13] for the optical model, allowing simultaneous adjustment of all six parameters of the potential, to give the best fit to the experimental data, was employed. All calculations were carried out on the GIER computer of the Institute of Nuclear Research in Warsaw.

Various sets of optical model parameters found in our analysis are listed in Table I.

TABLE I

| Deuteron parameter sets | $U$ (MeV) | $4W$ (MeV) | $r_u$ (fm) | $r_w$ (fm) | $a_u$ (fm) | $a_w$ (fm) |
|---|---|---|---|---|---|---|
| $a$ | 43.49 | 52.70 | 1.299 | 1.362 | 0.673 | 0.604 |
| $b$ | 78.79 | 62.60 | 1.259 | 1.273 | 0.691 | 0.705 |
| $c$ | 123.47 | 118.39 | 1.260 | 1.256 | 0.637 | 0.532 |
| $d$ | 167.06 | 167.76 | 1.294 | 1.330 | 0.608 | 0.441 |
| Proton parameter set | 48–51 | 52.00 | 1.25 | 1.25 | 0.650 | 0.470 |

The optical model parameters for the interaction of protons, listed also in the Table I are these found by Perey [14]. The $U$-values for the proton potential were calculated from the formula given by Perey [14] for each state of the residual $^{49}$Ti and $^{51}$Ti nuclei respectively.

Angular distributions of protons from the $(d, p)$ reaction calculated for different deuteron optical potentials are shown in Figs 3, 4 and 5 together with the experimental data. The calculated differential cross-sections were normalized to the experimental ones using the formula

$$\sum_k \sigma(\theta_k)_{\text{exp}} = \frac{2J_f+1}{2J_i+1} S_{lj} \sum_k \sigma(\theta_k)_{\text{calc}}$$

ACTA PHYSICA POLONICA Vol. XXXIV (1968) Fasc. 5

in order to extract the transition strength $\frac{2J_f+1}{2J_i+1} S_{lj}$ and the spectroscopic factor $S_{lj}$. $J$ and $J_f$ are the spins of the target and residual nuclei respectively. In the above formula the summation runs over all measured points.

The goodness of fit of the DWBA curves to the experimental angular distributions can be judged using a $\chi^2$ value defined in the following way

$$\chi^2 = \sum \left[ \frac{\sigma(\theta)_{\text{exp}} - \frac{2J_f+1}{2J_i+1} S_{lj}\sigma(\theta)_{\text{calc}}}{\Delta\sigma(\theta)_{\text{exp}}} \right]^2$$

$\sigma(\theta)_{\text{exp}}$ — measured differential cross-section for protons emitted in the $(d, p)$ reaction

ACTA PHYSICA POLONICA Vol. XXXIV (1968) Fasc. 5

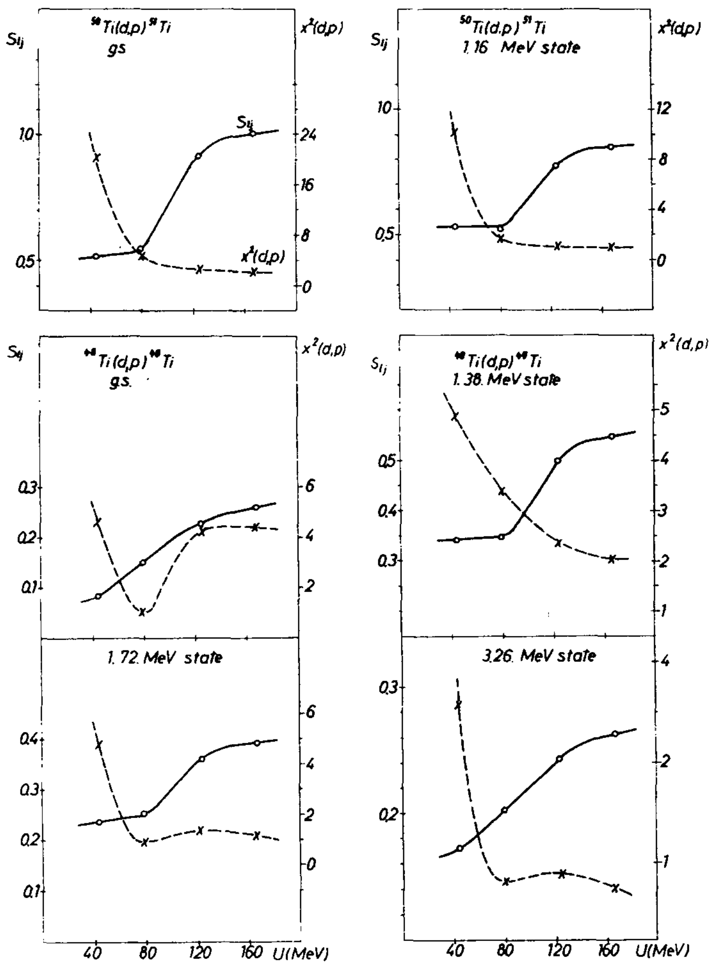


Fig. 6. The dependence of the $\chi^2$ value and the spectroscopic factor $S_{lj}$ on the depths of the real deuteron optica potential. The lines are drawn to connect the points

ACTA PHYSICA POLONICA Vol. XXXIV (1968) Fasc. 5

at the angle $\theta$, $\sigma(\theta)_{calc}$ — calculated differential cross-section, $\Delta\sigma(\theta)_{exp}$ — experimental error of the differential cross-section.

Fig. 6 shows the dependence of the $\chi^2$ value on the depth of the real deuteron optical potential. Looking at Fig. 6 and at the angular distributions shown in Figs 3, 4 and 5 it is obvious that the shallow deuteron potential of the type *a* can not be used in the DWBA analysis of the stripping Ti $(d, p)$ reaction. The calculated angular distributions are in the opposite phase with the experimental data. Acceptable fits can be obtained when using deuteron potentials of the type *c* and *d* with the real part deeper than 100 MeV. The only exception is the case of the $l = 3$ transition to the ground state of $^{49}$Ti where the deuteron potential of the type *b* is the best one. However the DWBA fit to the corresponding angular distribution is generally much worse than these for all other transitions. In all other cases the deuteron potential of the rype *b* can not be accepted because it does not reproduce the shape of the experimental angular distributions in the range of angles between 50 and 80 degrees.

On Fig. 6 the spectroscopic factors $S_{lj}$ are also presented as function of deuteron potentials *a*, *b*, *c*, and *d*. The spectroscopic factor for the transition leading to the ground state of $^{51}$Ti nucleus should be close to unity what will be discussed in the last section of this paper. This value of the spectroscopic factor is given by the deuteron potentials *c* and *d*.

The results of our DWBA analysis of the angular distributions in the Ti$(d, p)$ reaction presented to above suggest the value of about 100 MeV as a lower limit for the real part of the deuteron optical model potential. The analysis can not remove the ambiguity between deuteron potential of the type *c* and *d*. The above conclusions are in agreement with that of the other authors [6], [15].

## 5. *Spin-orbit effects*

It is well known [1] that the shape of the angular distribution of protons from the $(d, p)$ reaction is influenced by the coupling of spin and orbital angular momentum of the captured neutron. This dependence is specially well pronounced in the case of $l = 1$ transitions. In the stripping reaction leading to a $j = l-1/2$ state of the final nucleus a relatively deep minimum in the angular distribution is observed in the region of angles between 120 and 140 degrees. In the case of the transition to a $j = l+1/2$ state such minimum does not appear. It seems that similar spin-orbit effects can be observed also for smaller reaction angles around 80 degrees. In the case of the $^{58}$Ni$(d, p)^{59}$Ni reaction investigated by Rollefson *et al.* [16] beside the minimum at the angle of 120 degrees, another much deeper minimum was found at the angle of about 80 degrees in the angular distribution corresponding to the $j = l-1/2$ transition. The same effect can be observed in the case of $^{50}$Ti$(d, p)\,^{51}$Ti reaction (Fig. 3) where the spin and parity values of the ground and 1.16 MeV states of $^{51}$Ti nucleus were well established by Lee and Schiffer [17] to be $3/2^-$ and $1/2^-$ respectively. If the existence of the minimum in the angular distribution around 80 degrees is really connected with the formation of a $j = l-1/2$ state in the stripping reaction we can use this empirical rule for the determination of spin values of final states of $^{49}$Ti nucleus formed in $^{48}$Ti $(d, p)\,^{49}$Ti reaction. The angular distribution of protons from the $^{48}$Ti$(d, p)^{49}$Ti reaction corresponding to the 1.72 state of the final nucleus presented in Fig. 4 shows a pronounced minimum in the angular region around 85 degrees. The other $l = 1$ transitions leading to the 1.38 and 3.26 MeV states of $^{49}$Ti nucleus do not show such minimum in angular distributions, therefore their spin was identified as 3/2. In Table II are shown the spin assignments made by us and those proposed by other authors.

TABLE II

| Excitation energy (MeV) | $l$ from the DWBA analysis | $J$ values of the states of $^{49}$Ti nucleus proposed from | | | |
|---|---|---|---|---|---|
| | | $(d, p)$ reaction, present experiment | $(d, p)$ reaction investigated by the authors of refs [3], [6], [7] | $(p, d)$ reaction, refs [18], [19] | circular polarization of $\gamma$-rays [20], [21] |
| 0 | 3 | 7/2 | 7/2 | 7/2 | |
| 1.38 | 1 | 3/2 | 3/2 | 3/2 | 3/2 |
| 1.72 | 1 | 1/2 | 1/2, 3/2 | 1/2 | 1/2 |
| 2.50 | 3 | 5/2, 7/2 | 1/2, 5/2, 7/2 | | |
| 3.26 | 1 | 3/2 | 1/2, 3/2 | | |
| 3.80 | 1+3 | | | | |

Following the suggestion of Pearson and Coz [22] we calculated relative differences $W(\theta)$ of measured cross-sections for $j = 1 \pm 1/2 = 1/2$ and 3/2 transitions

$$W(\theta) = \frac{\sigma_{3/2}(\theta) - N\sigma_{1/2}(\theta)}{\sigma_{3/2}(\theta) + \sigma_{1/2}(\theta)}$$

taking into consideration the ground and 1.16 MeV, $l = 1$ transitions in the $^{50}$Ti$(d, p)^{51}$Ti reaction and in addition the 1.38 and 1.72 MeV, $l = 1$ transitions in the $^{48}$Ti$(d, p)^{49}$Ti

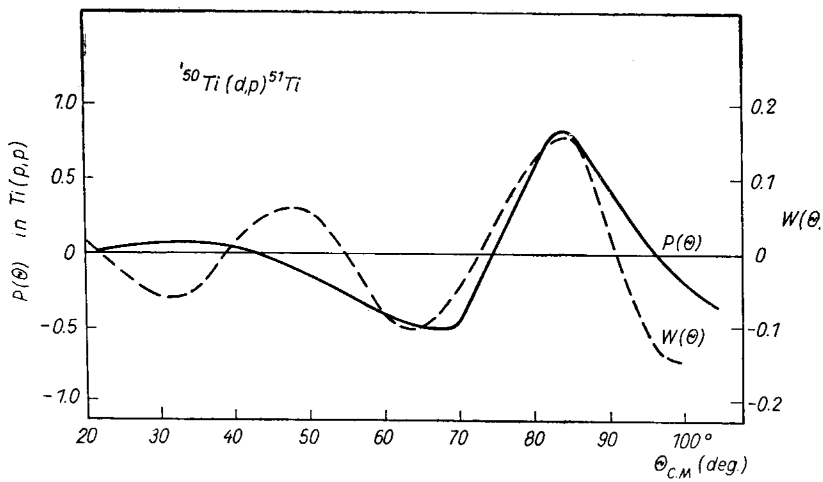


Fig. 7. Relative differences of measured angular distributions $W(\theta)$ for the $J = 3/2$ (ground) and $J = 1/2$ (1.16 MeV) transitions in the $^{50}$Ti$(d, p)$ $^{51}$Ti reaction compared with the polarization of protons of 14.5 MeV elastically scattered on $^{49}$Ti muclei. The curves are drawn to connect the experimental points

ACTA PHYSICA POLONICA Vol. XXXIV (1968) Fasc. 5

ACTA PHYSICA POLONICA Vol. XXXIV (1968) Fasc. 5

reaction. Using an normalizing factor $N$ the magnitudes of both angular distributions have been made equal in the region of the first stripping maximum. Figs 7 and 8 present the curves $W(\theta)$ together with the polarization curves $P(\theta)$ for the elastic scattering of proton on Ti nuclei, obtained by Alty *et al.* [6] at 14.5 MeV and Kossanyi *et al.* [23] at 18.6 MeV. The energies of protons in the above experiments are close to the energies of protons from the Ti$(d, p)$ reactions being investigated by us. The shapes of $W(\theta)$ and $P(\theta)$ curves are similar for angles larger than about 50 degrees in qualitative agreement with the new stripping theory proposed by Pearson and Coz [22], [24].

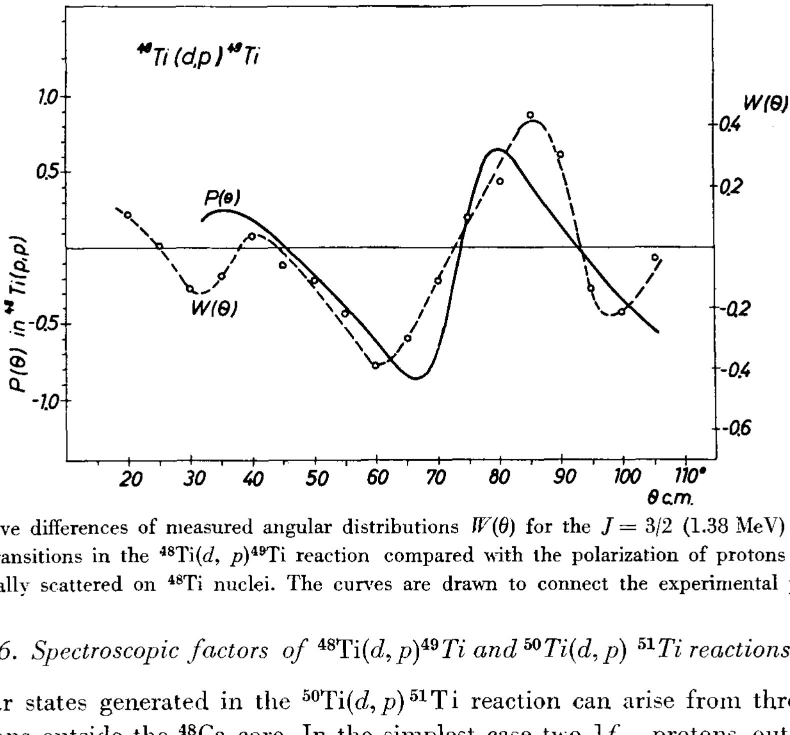


Fig. 8. Relative differences of measured angular distributions $W(\theta)$ for the $J = 3/2$ (1.38 MeV) and $J = 1/2$ (1.72 MeV) transitions in the $^{48}$Ti$(d, p)^{49}$Ti reaction compared with the polarization of protons of 18.6 MeV elastically scattered on $^{48}$Ti nuclei. The curves are drawn to connect the experimental points

## 6. *Spectroscopic factors of* $^{48}$Ti$(d, p)^{49}$*Ti and* $^{50}$*Ti*$(d, p)$ $^{51}$*Ti reactions*

Nuclear states generated in the $^{50}$Ti$(d, p)^{51}$Ti reaction can arise from three nucleon configurations outside the $^{48}$Ca core. In the simplest case two $1f_{7/2}$ protons outside of the core are paired and the neutron is captured on the $2p_{3/2}$, $1f_{5/2}$, $2p_{1/2}$ or higher single particle states of the $^{51}$Ti nucleus. As can be seen from the Table III the spectroscopic factor of the transition leading to the ground $(J = 3/2)$ state of $^{51}$Ti nucleus estimated in the present experiment is close to unity in agreement with theoretical calculations suggesting the domination of single particle character of this level.

TABLE III

| States of $^{51}$Ti (MeV) | $l$ | $J$ | $S_{lj}^*$ | $S_{lj}$ calculated by: Vervier [25] | Ohnuma [26] | Pellegrini [27] |
|---|---|---|---|---|---|---|
| 0 | 1 | 3/2 | 0.96 | 0.880 | 0.88 | 0.895 |
| 1.16 | 1 | 1/2 | 0.81 | 0.563 | 0.60 | — |

* Averaged values from these obtained with deuteron optical model parameters $c$ and $d$.

The value of the spectroscopic factor of the transition leading to the 1.16 MeV ($J = 1/2^-$) state was estimated to be 0.81 being larger than the $S_{lj}$ value calculated by Vervier and Ohnuma.

Table IV presents the values of spectroscopic factors for the considered transitions in the $^{50}$Ti$(d, p)$ $^{51}$Ti reaction obtained at different energies of bombarding deuterons.

TABLE IV

| $E$ (MeV) | $S_{lj}$ for the ground state transition in the $^{50}$Ti$(d, p)$ $^{51}$Ti reaction | $S_{lj}$ for the 1.16 MeV state transition in the $^{50}$Ti$(d, p)$ $^{51}$Ti reaction | Reference |
|---|---|---|---|
| 6.0 | 0.913 | 0.855 | [5] |
| 12.9 | 0.96 | 0.81 | present work |
| 21.4 | 1.2 | 1.2 | [8] |

Although the absolute values of the spectroscopic factors are determined with considerable uncertainty due to the experimental error and the DWBA procedure it seems noteworthy that no significant variation of the spectroscopic factors with the energy can be noticed.

Shell model structure of $^{49}$Ti nucleus is more complicated than that of $^{51}$Ti nucleus. The ground state configuration of $^{49}$Ti can be described as a coupling of the $1f_{7/2}$ neutron hole with the $(1f_{7/2})^2$ $J = 0$ proton pair. A low value of corresponding spectroscopic factor presented in Table V is probably due to the interaction of this hole with remaining neutrons in the $1f_{7/2}$ shell.

TABLE V

| States of $^{49}$Ti (MeV) | $l$ | $J$ | $S^*_{lj}$ | $S_{lj}$ expected from the shell model [28] |
|---|---|---|---|---|
| 0 | 3 | 7/2 | 0.24 | 0.25 |
| 1.38 | 1 | 3/2 | 0.53 | |
| 1.72 | 1 | 1/2 | 0.38 | |
| 2.50 | 3 | 5/2, 7/2 | 0.28, 0.13 | |
| 3.26 | 1 | 3/2 | 0.25 | |
| 3.80 | 1 | 1/2, 3/2 | 0.34, 0.15 | |
| 3.80 | 3 | 5/2, 7/2 | 0.51, 0.24 | |

The formula derived by French and McFarlane [28] taking into account all above interactions gives similar low value of the spectroscopic factor. The higher states of $^{49}$Ti nucleus have much more complicated structure arrising from the interaction of five quasi particles.

Configuration mixing is probably the reason why the energy separation of 340 KeV between $2p_{3/2}$ (1.38 MeV) and $2p_{1/2}$ (1.72 MeV) states is much less than that expected from the shell model. Similar low lying, slightly spaced $2p_{3/2}$—$2p_{1/2}$ doublets were observed also in other nuclei [17] in the region of atomic mass numbers from 50 to 60.

At the excitation energy near to 2.50 MeV there appear few close spaced levels but only one of most intensive transitions could be there separated. An attempt to fit the corresponding angular distribution taking the angular momentum $l = 2$ as proposed by Rietjens *et al.* [3] showed a drastic disagreement with the experiment. The only acceptable fit was obtained assuming the value of angular momentum $l = 3$. Such a state could arise from the single particle $f_{5/2}$ configuration.

The DWBA analysis performed for the transition leading to the 3.80 MeV level or groups of levels at this excitation energy indicates some superposition of $l = 1$ and $l = 3$ transitions.

The authors are deeply indebted to Professor H. Niewodniczański for his advice and encouragement throughout the progress of this work. They wish to express special thanks to Dr A. Budzanowski, Dr P. E. Hodgson and Dr A. Strzałkowski for helpful discussions. They are also indebted to the cyclotron operation staff for running the machine.



REFERENCES

[1] L. L. Lee and J. P. Schiffer, *Phys. Rev. Letters*, **12**, 108 (1964); *Phys. Rev.*, **136** *B*, 405 (1964).
[2] J. H. Bjerregaard, P. F. Dahl and O. Hansen, *Nuclear Phys.* (Netherlands), **51**, 641 (1964).
[3] L. H. Rietjens, O. M. Bilaniuk and McFarlane, *Phys. Rev.*, **120**, 527 (1960).
[4] K. Ramavataram, *Phys. Rev.*, **132**, 2255 (1963).
[5] P. D. Barnes, C. K. Bockelman, O. Hansen and A. Sperduto, *Phys. Rev.*, **136** *B*, 438 (1964).
[6] J. L. Alty, L. L. Green, G. D. Jones and J. P. Scharpey-Schafer, *Nuclear Phys.* (Netherlands), *A* **100**, 191 (1967).
[7] P. D. Barnes, J. R. Comfort, C. K. Bockelman and O. Hansen, *Phys. Rev.*, **159**, 920 (1967).
[8] J. L. Yntema, *Phys. Rev.*, **131**, 811 (1963).
[9] A. Śliżyński, *Report IFJ* No 533/PL (1967).
[10] R. K. Cooper and J. Bang, Niels Bohr Institute, Nordita, GIER program Library.
[11] R. H. Bassel, R. M. Drisko and R. G. Satchler, *ORNL Rep.* 3240 (1962).
[12] A. Strzałkowski, *Phys. Letters*, **2**, 121 (1962).
[13] A. Dudek, *IFJ Report* No 553/PL (1967).
[14] F. G. Perey, *Phys. Rev.*, **131**, 745 (1963).
[15] L. L. Lee, J. P. Schiffer, B. Zeidman, G. R. Satchler, R. M. Drisko and R. H. Bassel, *Phys. Rev.*, **136**, B 971 (1964).
[16] A. A. Rollefson, P. F. Brown, J. A. Burke, P. A. Crowley and J. K. Saladin, *Phys. Rev.*, **154**, 1088 (1967).
[17] L. L. Lee, Jr and J. P. Schiffer, *Phys. Rev.*, **154**, 1097 (1967).
[18] E. Kashy and T. W. Conlon, *Phys. Rev.*, **135**, B 389 (1964).
[19] R. Sherr, B. F. Bayman and E. Rost, *Phys. Rev.*, **139** *B*, 1272 (1965).
[20] J. Vervier, *Nuclear Phys.* (Netherlands), **26**, 10 (1961).
[21] G. Trumpy, *Nuclear Phys.* (Netherlands), **2**, 664 (1957).

[22] S. A. Pearson and M. Coz, *Ann. Phys.* (USA), **39**, 199 (1966).
23] P. Kossanyi-Dewary, R. D. Swinarski and C. Glashhausser, *Nuclear Phys.* (Netherlands), *A* **94**, 513 (1967).
[24] J. M. Bang and C. A. Pearson, *Nuclear Phys.* (Netherlands), *A* **100**, 1 (1967).
[25] J. Vervier, *Nuclear Phys.* (Netherlands), **78**, 497 (1966).
[26] H. Onhuma, *Nuclear Phys.* (Netherlands), **88**, 273 (1966).
[27] H. Onhuma, *Nuclear Phys.* (Netherlands), **88**, 273 (1966).
[28] J. B. French and MacFarlane, *Rev. Mod. Phys.*, **32**, 567 (1960).

ACTA PHYSICA POLONICA Vol. XXXIV (1968) Fasc. 5