Study of 10B by inelastic scattering of 30.3 MeV protons

Autor(en): **Swiniarski, R. de / Resmini, F.G. / Glashausser, Ch.**

Objekttyp: **Article**

Zeitschrift: **Helvetica Physica Acta**

Band (Jahr): **49 (1976)**

Heft 2

PDF erstellt am: **30.06.2024**

Persistenter Link: https://doi.org/10.5169/seals-114764

Study of ^{10}B by Inelastic Scattering of 30.3 MeV Protons[1])

by **R. de Swiniarski**[2]), **F. G. Resmini**[3]), **Ch. Glashausser**[4]) and **A. D. Bacher**[5])

Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

(10. X. 1975)

Abstract. The angular distributions of the differential cross-section for the inelastic scattering of 30.3 MeV protons were measured for excited states in ^{10}B up to 6.57 MeV excitation. Due to the very good energy resolution achieved (25 to 30 keV FWHM), 12 cross-sections have been measured generally with small statistical errors. The elastic scattering cross-section was analyzed with the standard optical model and very good agreement with the data was obtained. This shows the validity of this model even for a target of mass as low as ten. The inelastic cross-sections were analyzed with the collective model DWBA formalism. Very good agreement for several low-lying excited states in ^{10}B was obtained; this may confirm the simple structure of these levels. The deformation parameters extracted are generally in agreement with a recent neutron scattering experiment but not with recently reported ^{3}He results. The 6.57 MeV level appears from our calculations to have negative parity and we therefore tentatively assign a $J^{\pi} = 2^{-}$ character to this state.

1. Introduction

The low-lying excited states in ^{10}B have been investigated recently through inelastic scattering experiments using several types of bombarding particles, mainly ^{3}He particles [1] and neutrons [2, 3], while only low-energy protons have been used [4a, b] in the past. Both the ^{3}He and the neutron experiments led to the conclusion that the collective model, in the framework of the distorted waves Born approximation (DWBA), was able to describe successfully several of the low-lying excited states in this nucleus.

Although the neutron and ^{3}He experiments led to the same conclusions concerning the angular momentum transfer L required for the low-lying states in ^{10}B, considerable variations in the nuclear deformation parameters β_L were found between these two experiments. Compound nucleus contributions in the case of the 32 MeV ^{3}He experiment [1] or the well known inherent difficulties of the time-of-flight experiment [2] may be responsible for the large differences observed.

Moreover, since both experiments were done with poor resolution, a new measurement using high energy, well-analyzed protons appears necessary to resolve these ambiguities and to confirm the conclusions mentioned above. Another goal of this

---

[1]) Work supported in part by the U.S. Atomic Energy Commission.

[2]) Present address: Institut des Sciences Nucléaires, Grenoble, France.
[3]) Present address: University of Milan, Italy.
[4]) Present address: Rutgers University, New Brunswick, New Jersey.
[5]) Present address: Indiana University, Bloomington, Indiana.

experiment was to provide high resolution data with low statistical error, in order to test some of the different microscopic models which have recently appeared in the literature [5].

Indeed the ^{10}B nucleus appears to be a good choice for such calculations using, for instance, the Goldhammer wave functions [6] which give a very good reproduction of the nuclear levels. Such calculations are now in progress. Only coupled-channels or DWBA calculations in the framework of the nuclear collective model will be presented in this paper.

After a brief description of the experimental method in Section 2, the experimental cross-sections are presented in Section 3, while Section 4 presents the optical model and the various DWBA calculations. A short summary of the conclusions is given in Section 5.

2. Experimental Method

The present experimental data were taken with 30.3 MeV protons at the Berkeley 88″ cyclotron. Scattered protons were detected with four 5 mm thick Si(Li) detectors cooled to $-25°C$ by a thermoelectric device. A total resolution (FWHM) of 25 to 35 keV was achieved. The ^{10}B target used was enriched to about 90% and had a thickness of 129 $\mu g/cm^2$. Because of the very good resolution obtained in this experiment, almost all states known up to 7 MeV excitation have been resolved; cross-sections were extracted from $\theta_{lab} = 20°$ to $165°$. The only exception is the 5.17–5.18 MeV doublet which was measured as one state. All the cross-sections have been obtained with a fitting program [7] using a console directly on-line with the CDC 6600 computer at the LBL computer facilities. On Figure 1, which shows the experimental spectrum obtained at $\theta_{lab} = 135°$, the strong excitation of the low-lying excited states is clearly apparent.

3. Experimental Results

From Figure 1 we can see that the 4^+ state at 6.03 MeV is the most strongly excited state; this is true at all angles. All other states are about equally excited with the exception of the $J^\pi = 0^+, T = 1$ state at 1.74 MeV which is about 2–3 times less excited. This is also in agreement with the recent inelastic ^3He scattering results [1]. The 0^+ state presents a particular interest since it can be excited only through a spin and isospin flip mechanism since the ground state is $J^\pi = 3^+$, $T = 0$. The experimental cross-sections[6]) are presented in Figures 2 and 3; the spins and parities assigned were taken from published work [9]. The errors shown are statistical and allow for background subtraction. No particular features are visible from the experimental curves. However, some angular distributions for states of the same spin and parity have very similar shapes, like the 2.15 MeV (1^+) and the 0.717 MeV (1^+) states. Such similarities may suggest a possible single configuration structure for those states. On the other hand, the cross-sections for the 5.92 MeV (2^+) and the 3.59 MeV (2^+) have quite different shapes. Such differences can, of course, not be explained by a simple collective model and will require elaborate microscopic model calculations.

---

[6]) The tabulated cross-sections are available on request at the I.S.N. Grenoble (Information Service – Mme Tur).

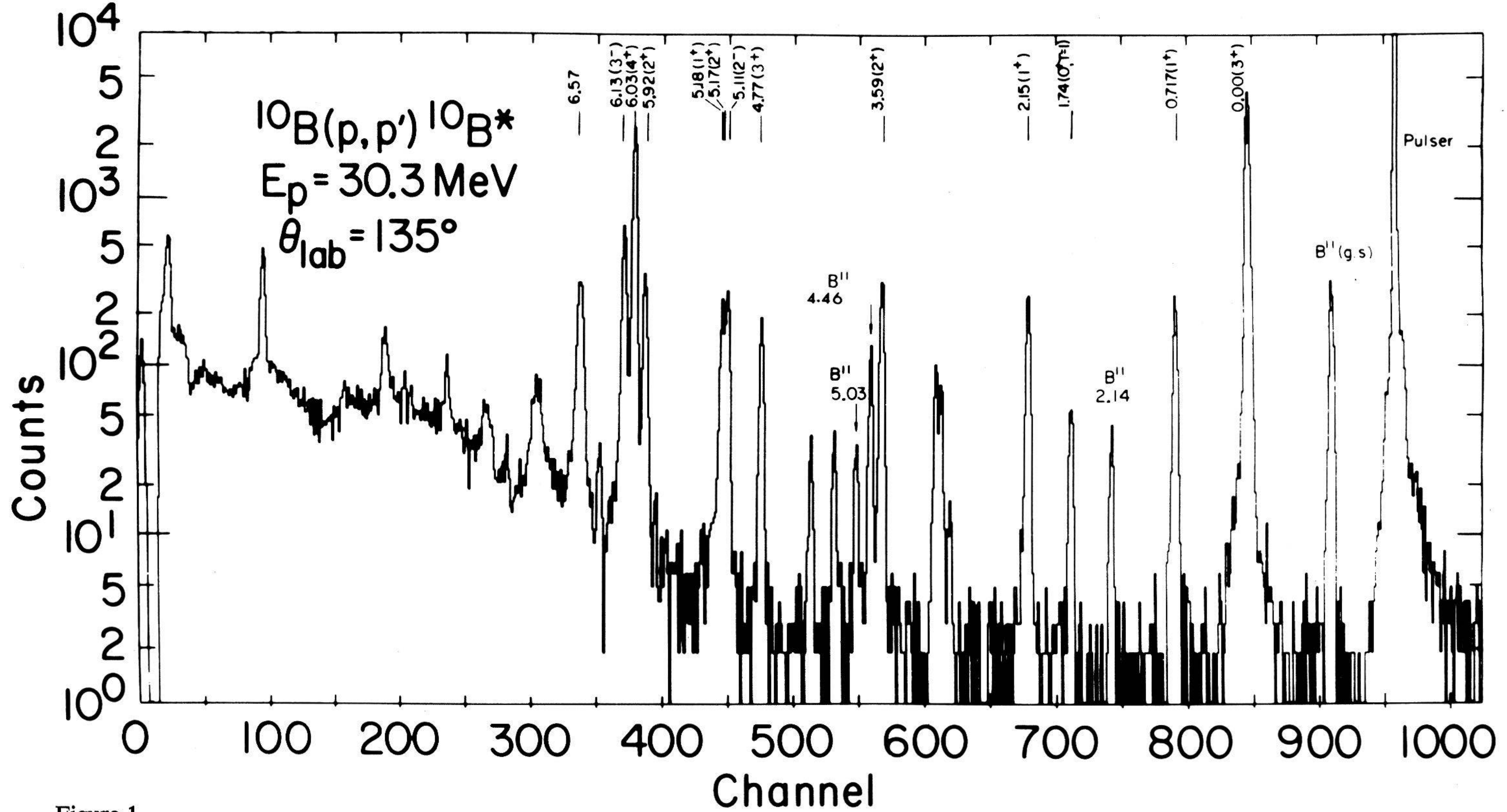

Figure 1
Experimental spectrum for the $^{10}B(p, p')^{10}B^*$ reaction at $\theta_{lab} = 135°$ and $E_p = 30.3$ MeV.

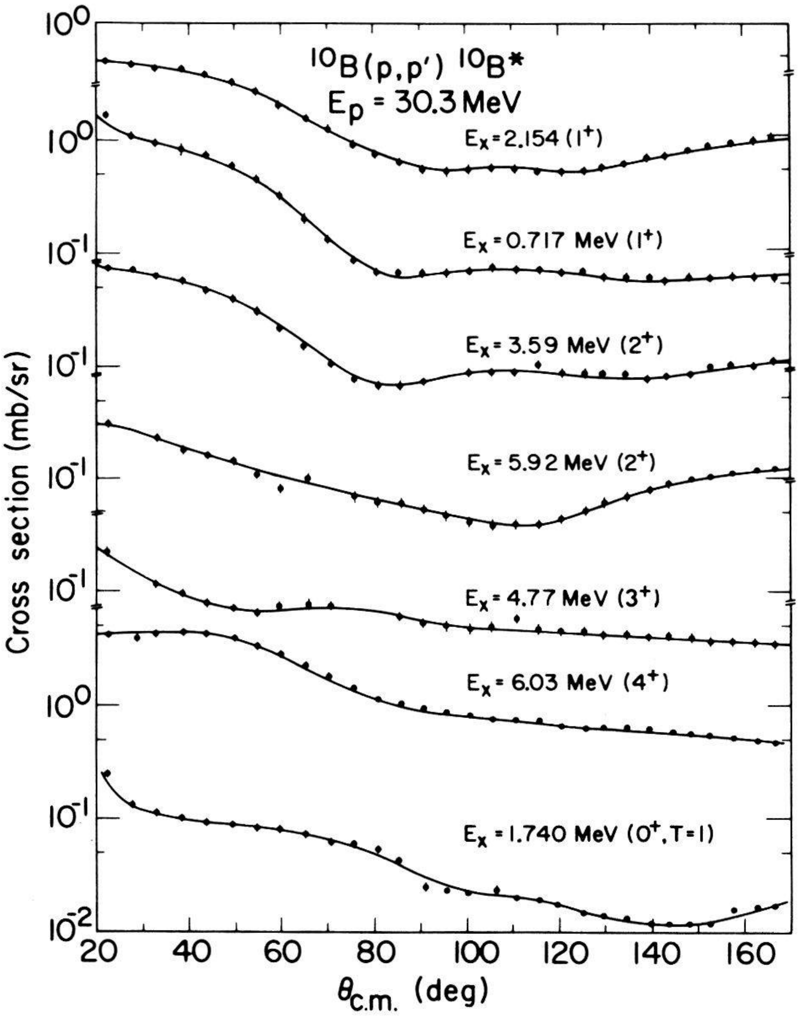

Figure 2
Experimental cross-section for several positive parity states in ^{10}B. A continuous line is drawn through the experimental points as a visual guide.

The presence of a possible complicated band structure in the ^{10}B nucleus [10, 4b] may also explain some of the observed differences among the angular distributions.

4.1. Optical Model Calculations

The elastic scattering was analyzed in terms of the optical model potential using the search code Magali [11]. This potential had the usual definition:

$$U(r) = -V_0 f(r, r_0, a_0) + i\left[W_V f(r, r_I, a_I) - 4a_I W_D\left(\frac{d}{dr}\right) f(r, r_I, a_I)\right]$$
$$+ \left(\frac{\hbar}{m_\pi c}\right)^2 V_{LS} \frac{1}{r}\frac{1}{dr} f(r, r_{LS}, a_{LS}) \mathbf{l}\cdot\boldsymbol{\sigma}$$

to which is added the Coulomb potential V_c of a uniformly charged sphere of radius $r_0 A^{1/3}$. The functions $f(r, r_0, a_0)$, $f(r, r_I, a_I)$ and $f(r, r_{LS}, a_{LS})$ are the Woods–Saxon form factors

$$f(r, r_0, a_0) = \left\{1 + \exp\left[\frac{r - r_0 A^{1/3}}{a_0}\right]\right\}^{-1}.$$

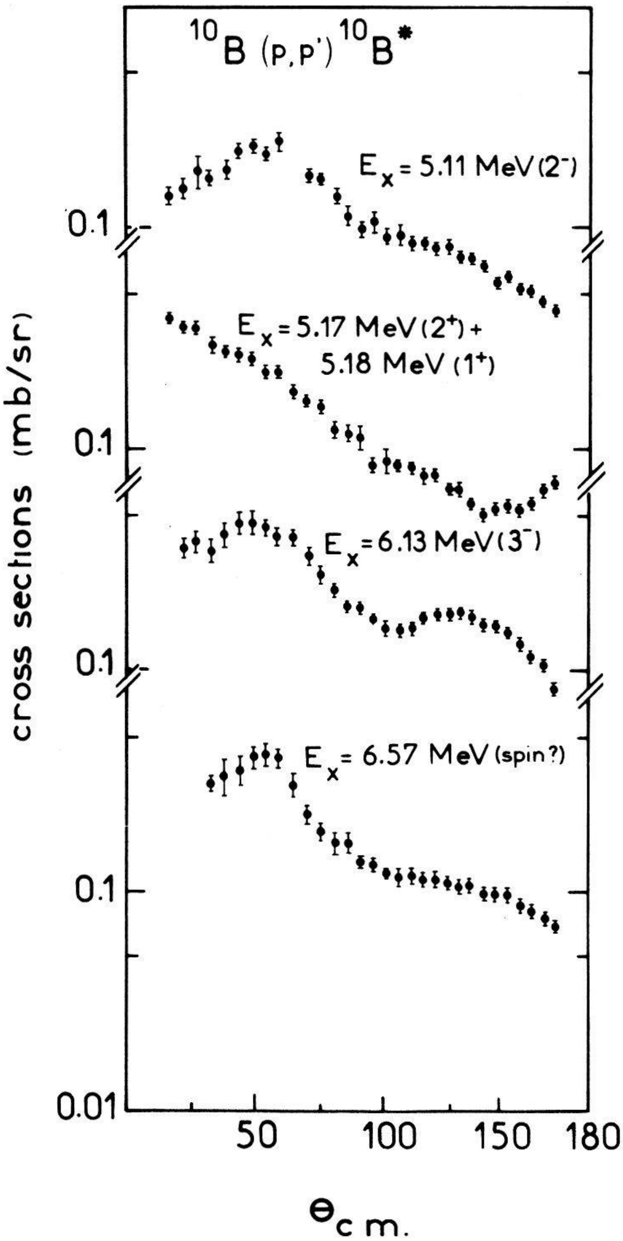

Figure 3
Experimental cross-section for several negative parity states in ^{10}B and for the 5.17 (2^+) + 5.18 (1^+) doublet.

The optical model parameters of reference [12] obtained from a $^{11}B(p, p)^{11}B$ elastic scattering analysis were used as starting parameters in the search. Very good fits to the elastic cross-section were obtained by searching only on the strengths V_0, W_D, V_{LS}, the diffusenesses a_I and a_0, and the spin–orbit radius r_{LS}. Poor fits were obtained by searching on all 9 parameters. The calculations have shown that no volume absorption W_V was needed since the introduction of such a term generally gave poorer fits than with W_D (surface absorption) alone. The best optical model parameters obtained by searching on the elastic cross-section alone are presented on Table I (set A); Figure 4 shows the corresponding excellent fit obtained.

Optical model parameters were also obtained by searching simultaneously on the cross-section and available elastic polarization data [13]. Here the search on all 9 parameters gave spectacular fits but the parameters were not reasonable. The best parameters were obtained by searching on the strengths, the diffusenesses, and the

Table I

[10]B Best optical model parameters deduced from searching on σ only and σ + P for 30.3 MeV incident protons. σ_R and N are the reaction cross-section and the normalisation, respectively, deduced by the calculations.

Search	V_0 (MeV)	r_0 (fm)	a_0 (fm)	W_V (MeV)	W_D (MeV)	r_I (fm)	a_I (fm)	V_{LS} (MeV)	r_{LS} (fm)	a_{LS} (fm)	χ^2_σ	χ^2_P	χ^2/N	σ_R	N	Set
σ	51.75	1.10	0.55	0.0	5.17	1.30	0.68	9.79	1.01	0.57	44	—	1.23	459	0.99	(A)
σ + P	46.85	1.10	0.54	0.0	3.88	1.30	0.80	8.70	0.98	0.57	147	250	6.41	453	1.00	(B)
σ + P	47.71	1.10	0.55	0.0	4.33	1.30	0.68	8.25	1.01	0.54	152	287	6.87	404	0.98	(C)

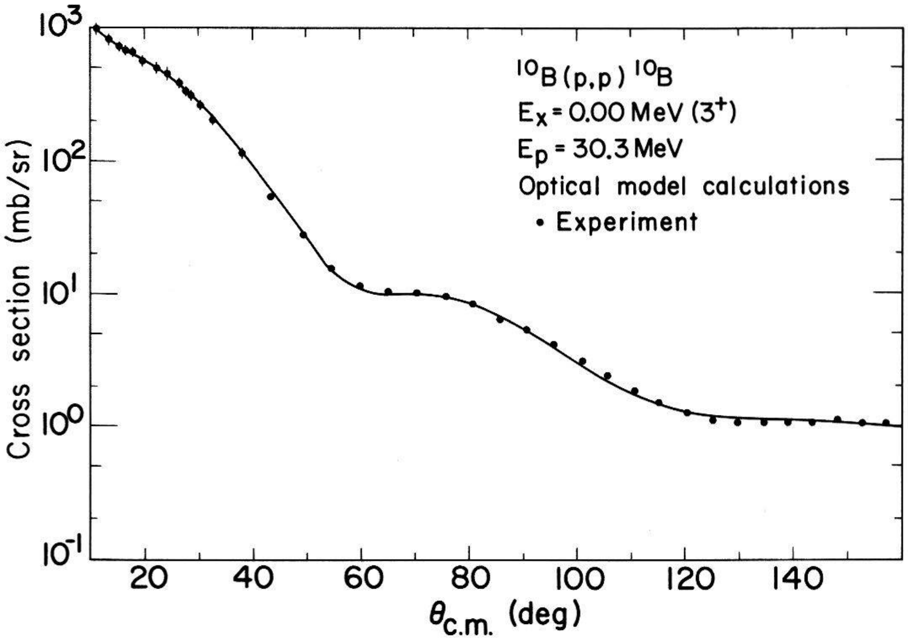

Figure 4
Optical model calculations for the $J^\pi = 3^+$ ground state in ^{10}B. The parameters of Table I (set A) were used.

spin orbit radius together. The final parameters obtained are presented in Table I (set B); Figure 5 presents the corresponding fit to the elastic polarization. The figure also presents the optical model prediction (set A parameters) when only cross-section data were used in the search (dotted line). The main difference between the two sets of parameters appears in V_0, the real well depth, which is lower when polarization data are taken into account. The surface absorption W_D also decreases, from 5.17

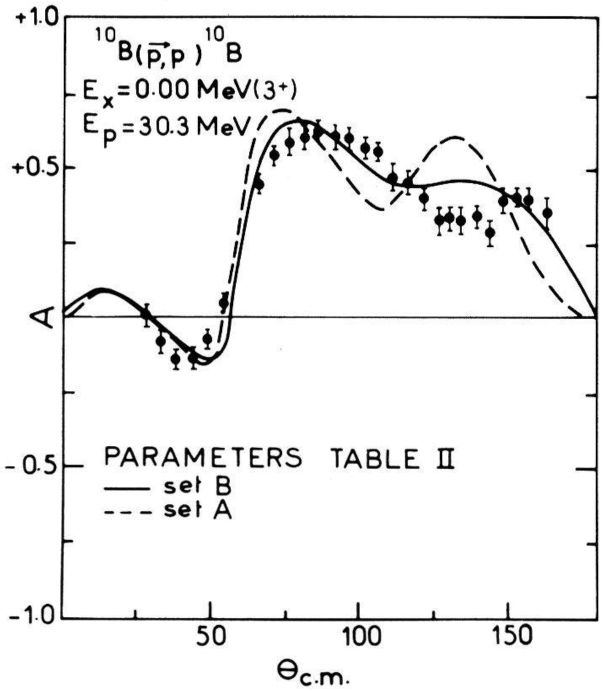

Figure 5
Optical model calculation for the elastic polarization of the ground state in ^{10}B (set A and set B parameters of Table I were used).

MeV to 3.88 MeV. But since the imaginary diffuseness increases from $a_I = 0.68$ to 0.80 fm this change in W_D is not significant; the product $W_D a_I^2$ remains roughly constant.

Good optical model parameters were also obtained by searching on the cross-section and polarization with the geometrical parameters fixed at the values previously obtained by searching on the cross-section alone (set A); V, W_D, V_{LS}, r_{LS}, and a_{LS} were allowed to vary. Although the fits obtained are very similar, the general χ^2 increases slightly from $\chi^2/N = 6.41$ to 6.87.

Therefore several sets of optical model parameters were obtained and used for DWBA or coupled-channels calculations. Nevertheless, since only cross-sections were available for the excited states in ^{10}B (with the exception of the state at 6.03 MeV (4^+) for which polarization data were also available [13]), most of the DWBA calculations were done with set A optical model parameters.

Finally it is worthwhile to point out the excellent fit obtained for both the elastic cross-section and the elastic polarization which is, a priori, quite surprising for such a very light nucleus.

4.2. Analysis of the Inelastic Scattering Cross-section

The inelastic cross-sections were analyzed with the collective model using the DWBA program DWUCK [14]. This code calculates a cross-section $\sigma_L(\theta)$ for a given angular momentum transfer L which is related to the experimental differential cross-section by:

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{exp}} = \frac{2J_f + 1}{2J_i + 1}\frac{1}{2L + 1}\,\beta_L^2\sigma_L(\theta). \tag{1}$$

Here J_i and J_f are the initial and final nuclear spins, L is the angular momentum transfer, and β_L is the deformation parameter. If the input parameters used for the program DWUCK are the optical model parameters and the transferred angular momentum L, the deformation parameter β_L is therefore obtained from the formula (1) by comparing the experimental and calculated DWBA cross-sections.

A few calculations have also been done with the coupled-channels (C.C.) code ECIS 71 [15] mainly to see the influence of the spin-orbit coupling on the calculations. Indeed the C.C. code contains the spin-orbit deformed optical potential of the full-Thomas form [16] while this potential is absent in the DWBA code. Nevertheless all the calculations done have shown that the spin–orbit coupling has only a small effect on the calculated cross-sections and that differences between DWBA and C.C. calculations (at least, in our case) are completely negligible.

Figure 6 presents the angular distribution for four of the excited states in ^{10}B which are in good agreement (at least up to $\theta_{cm} = 120°$) with the $L = 2$ predictions of DWUCK. The 0.717 MeV state in ^{10}B is a $J^\pi = 1^+$ level which would permit transfers of angular momentum $L = 2$ or $L = 4$. As shown in Figure 6, the $L = 2$ DWBA calculation is in good agreement with the experimental measurements. From our calculations we have extracted a deformation parameter $\beta_2 = 0.67 \pm 0.05$ in disagreement with the (^3He, $^3He'$) experiment by Squier et al. [1] who have obtained a value of $\beta_2 = 0.37 \pm 0.04$ for this state. Our calculations have also shown that adding some $S = 1$ transfer to the $L = 2$ calculations (i.e., $J = 2, L = 2, S = 1$) with the same collective model form factor, improves somewhat the agreement between

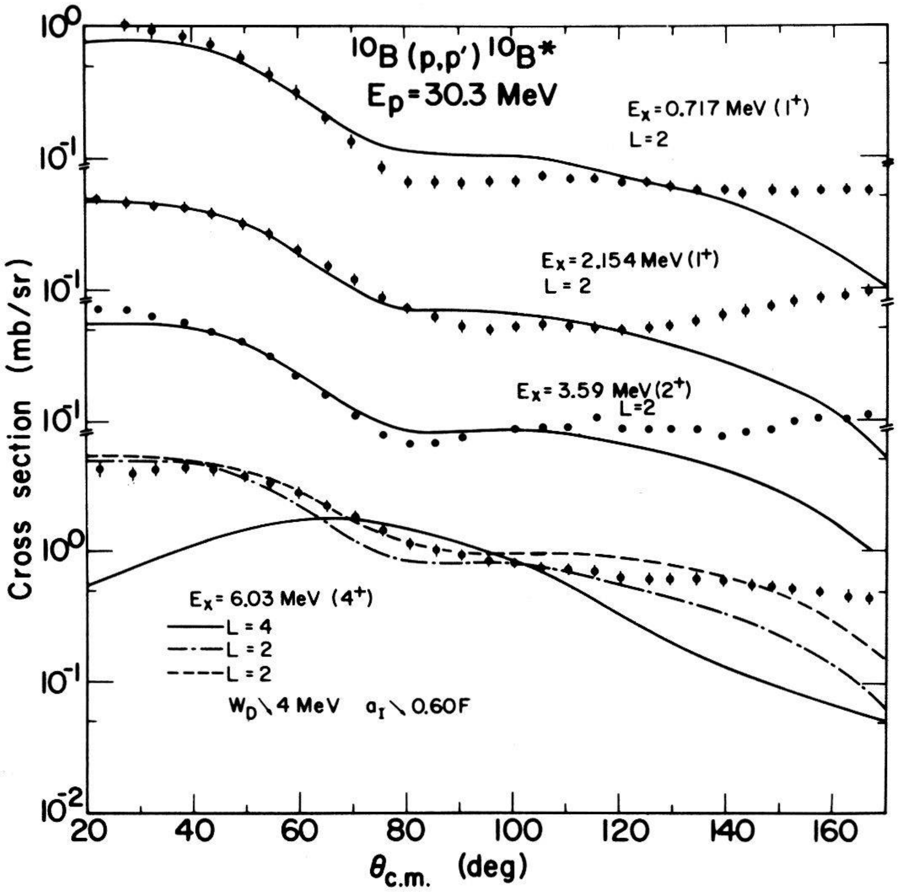

Figure 6
DWBA calculations with $L = 2$ angular momentum transfers for several low-lying positive parity states in ^{10}B.

the calculations and the experimental data at back angles. However, such calculations have only a phenomenological meaning.

The $L = 2$ DWBA predictions for the 2.15 MeV (1^+) and for the 3.59 MeV (2^+) states are in excellent agreement with the experimental results. The extracted deformation parameters are $\beta_2 = 0.49 \pm 0.04$ for the 2.15 MeV (1^+) state and $\beta_2 = 0.45 \pm 0.04$ for the 3.59 MeV (2^+) state; these values are again somewhat higher than the values derived by Squier et al. [1] who have obtained $\beta_2 = 0.36 \pm 0.04$ for both states. On the other hand, these deformation parameters are in excellent agreement with the (n, n') experiment by Vaucher et al. [2] who have obtained for both states $\beta_2 = 0.49$ when using for their DWBA calculations the most realistic optical model parameters. Here also the agreement between the calculations and the experimental data is somewhat improved mainly at back angles by adding some $S = 1$ transfer to the $L = 2$ DWBA calculations with the same collective model form factor.

Figure 6 finally presents the excellent agreement between the $L = 2$ calculations and the experimental measurements for the 6.03 MeV (4^+) state. Although the $J^\pi = 4^+$ character of this state could authorize also an $L = 4$ transition, it is clearly apparent from this figure that the $L = 4$ curve gives a poor fit to the data. This fact is even more clearly evident in Figure 7 where $L = 2$ and $L = 4$ angular momentum transfers calculations are compared to the available [13] analyzing power data for this state. Surprisingly, for such a low mass nucleus, the $L = 2$ calculations give a rather good fit to the analyzing power. The fit to the cross-section of this 6.03 MeV (4^+) state is somewhat improved by changing the optical model parameters; W_D was decreased

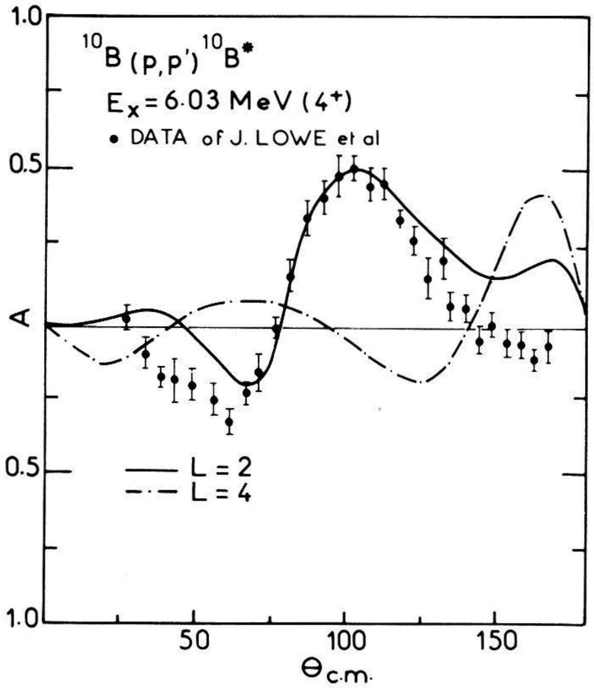

Figure 7
DWBA calculations with $L = 2$ or $L = 4$ angular momentum transfers for the analyzing power of the 6.03 MeV (4^+) state in ^{10}B.

from 5.17 MeV to 4.00 MeV, and a_I from 0.68 fm to 0.60 fm. This procedure is often useful for calculations concerning highly excited states [17]. The deformation parameter extracted by our DWBA calculations is $\beta_2 = 0.95 \pm 0.04$, again in good agreement with the (n, n') results [2] but not with the (^{3}He, ^{3}He') calculations [1]. The very large value of this deformation parameter can be explained by the fact that this state probably belongs to a rotational band [10], and therefore realistic calculations should require elaborate coupled-channels calculations including perhaps several intermediate states (like a 2^+ state which could be the 5.92 MeV level). Such calculations are obviously difficult to do at the present moment since the exact situation of the rotational levels in ^{10}B has still be be investigated. The agreement between the β_2 extracted from this work ($\beta_2 = 0.95 \pm 0.04$) and the (n, n') experiment ($\beta_2 = 0.82$) is quite surprising since in this last experiment the cross-sections of three close states, namely the 5.92 MeV (2^+), the 6.03 MeV (4^+) and the 6.13 MeV (3^-), have been measured together as one single state, due to lack of resolution. This could confirm also that the 6.03 MeV (4^+) state is the most strongly excited state in inelastic scattering experiments even when different particles are used as probes.

The DWBA calculations with $L = 3$ angular momentum transfers for several negative parity states in ^{10}B are presented in Figure 8. The cross-section of the 5.11 MeV (2^-) state is very well fitted (at forward angles); a deformation parameter of $\beta_3 = 0.45 \pm 0.04$ is extracted from these calculations. Since this state is a 2^- state, $L = 1$, 3 and 5 are allowed, but only $L = 3$ DWBA calculations give a reasonable fit to the data. Similarly, the 6.13 MeV (3^-) is also well reproduced (at least at forward angles) only with $L = 3$; a deformation parameter $\beta_3 = 0.53 \pm 0.03$ is derived from these calculations.

Figure 8 also presents the DWBA calculations for the 6.57 MeV state for which the spin and parity are still unknown. The best (and unique) fit for this state could be obtained with $L = 3$ angular momentum transfer; this implies a negative parity for

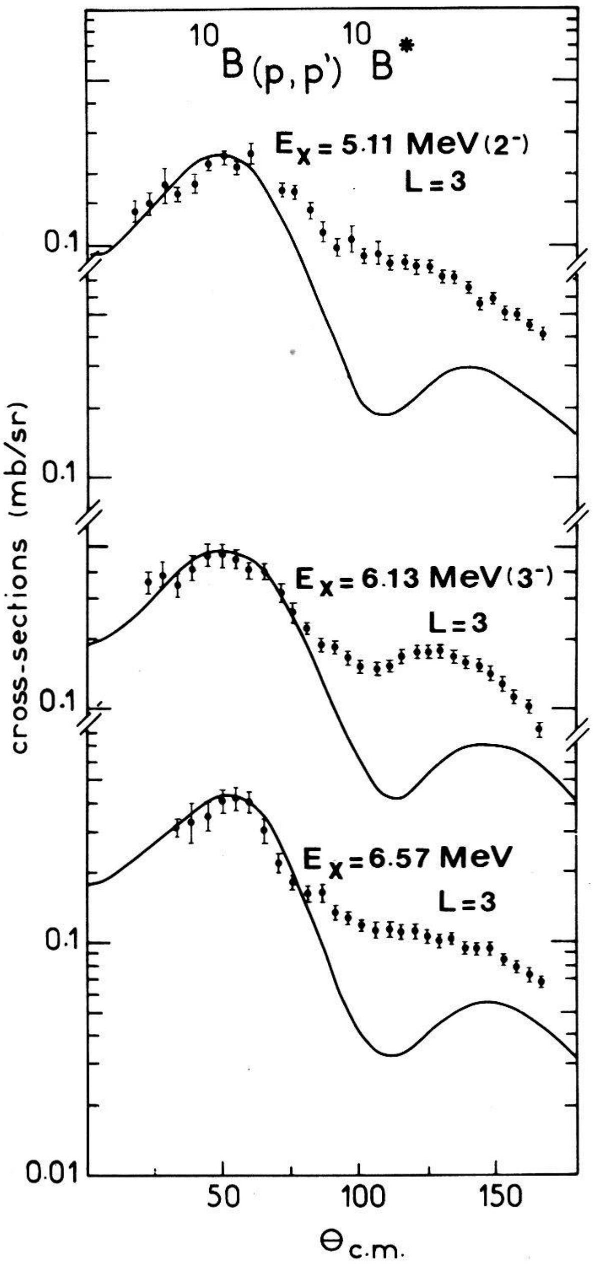

Figure 8
DWBA calculations with $L = 3$ angular momentum transfers for several negative parity states in ^{10}B.

this level. We are therefore in agreement with the recent (n, n') result [2] and also with the recently proposed negative parity character for this state by Meyer et al. [18] and Balakrishnan et al. [19] who suggested that J^{π} is 2^- or 4^-. A deformation parameter $\beta_3 = 0.59 \pm 0.03$ is extracted for this state if it is 2^- while β_3 equals 0.46 ± 0.04 if this level is 4^-. These deformation parameters are lower than the values extracted from the (n, n') work by Vaucher et al. [2] who extracted $\beta_3 = 0.83$ if J^{π} is 2^- and 0.62 if it is 4^-. Since it has been suggested from several recent experiments [20, 21] that this state should have spin $J = 2$, we favor a 2^- assignment for the 6.57 MeV level, although $J^{\pi} = 4^-$ is also possible. We are in definite disagreement with the proposed [21] positive parity for this state.

The various deformation parameters obtained from this work are presented in Table II and compared to the recent ^3He and neutron scattering experiments. Several

Table II
Energy levels in ^{10}B and deformation parameters

E_x (MeV) Ref. [9]	J^π Ref. [9]	L	(^3He, $^3He'$) Ref. [1]	(n, n') Ref. [2][a])	(p, p') This work
0.0	3^+	—	—	—	—
0.71	1^+	2	0.37 ± 0.04	—	0.67 ± 0.05
1.74	$0^+, T = 1$	(3)?	(0.69 ± 0.09) as $L = 3$	—	—
2.15	1^+	2	0.36 ± 0.04	0.49	0.49 ± 0.04
3.59	2^+	2	0.36 ± 0.04	0.49	0.45 ± 0.04
4.77	3^+	—	—	—	—
5.11	2^-	3	—	—	0.45 ± 0.04
5.17	$2^+, T = 1$	2	—	0.49[b])	—
5.18	$1^+, T = 0$	—	—	—	—
5.92	2^+	2	—	—	0.28 ± 0.03
6.03	4^+	2	0.62 ± 0.03	0.82[c])	0.95 ± 0.04
6.13	3^-	3	—	—	0.58 ± 0.03
6.57	2^-	3	—	{0.83 if $J^\pi = 2^-$ {0.62 if $J^\pi = 4^-$	{0.59 ± 0.03 if $J^\pi = 2^-$ {0.46 ± 0.04 if $J^\pi = 4^-$

[a]) The deformation parameters presented are those obtained by the authors with 'realistic optical model parameters'.
[b]) Calculations for the 5.17 MeV (2^+) state are for the three levels together, namely, the 5.11 (2^-) and 5.17 (2^+), the 5 18 (1^+) states.
[c]) Calculations for the 6.03 MeV (4^+) state are for the three levels together, the 5.92 (2^+), 6.03 (4^+) and 6.13 (3^-) states.

cross-sections could not be fitted by any DWBA calculations. Among these, the 4.77 MeV (3^+) and the 5.17 MeV (2^+) are typical. They appear to have a complicated structure [22]. Indeed the cross-sections for these states are very different from all the various cross-sections presented in this paper and only elaborate microscopic model calculations are likely to explain these states. A similar situation arises for the interesting 1.74 MeV state ($J^\pi = 0^+, T = 1$) which can be excited only through a spin and isospin-flip mechanism. It should be a good candidate for the various microscopic model calculations now under way [5]. Finally the cross-section for the 5.92 MeV (2^+) state is only poorly reproduced with an $L = 2$ DWBA curve leading to a deformation parameter of $\beta_2 = 0.28 \pm 0.03$, although here also the fit is slightly improved by adding some $S = 1$ admixture to the $L = 2$ angular momentum transfers. As has already been pointed out in the beginning of this paper, the cross-section for this 5.92 MeV (2^+) state is very different from the cross-section of the 2^+ state at 3.58 MeV. Such a situation confirms also the more complicated structure of the 5.92 MeV (2^+) level which belongs perhaps to a rotational band.

5. Conclusion

We have measured, by inelastic scattering of 30.3 MeV protons, several differential cross-sections in ^{10}B up to the 6.57 MeV state. Due to the excellent resolution achieved (25 to 30 keV FWHM) the cross-sections for about 12 states in ^{10}B have been measured with high precision and low statistical errors. Large variations in the shape of the cross-sections among several states having the same spins and parities were observed. The elastic scattering cross-section has been analyzed by a standard optical model calculation and several sets of optical model parameters have been obtained which give excellent fits to the elastic cross-section; this is surprising for such a low mass nucleus. The inelastic cross-sections for several excited states in ^{10}B were analyzed in the DWBA collective model formalism. Very good agreement between the $L = 2$ DWBA calculations and the cross-sections for the 0.717 MeV (1^+), the 2.15 MeV (1^+), the 3.59 MeV (2^+) and the 6.03 MeV (4^+) states was obtained. The $L = 3$ DWBA calculations reproduced the 5.11 MeV (2^-), the 6.13 MeV (3^-) and the 6.57 MeV angular distributions. It is interesting, also to point out that the behavior of the analyzing power of the 6.03 MeV (4^+) state is remarkably well reproduced by the collective model $L = 2$ calculation.

The deformation parameters extracted by the calculations presented in this paper are generally in very good agreement with the recent (n, n') experiment by Vaucher et al. [2] but in complete disagreement with the inelastic ^{3}He experiment by Squier et al. [1]. The 6.57 MeV state is well reproduced by an $L = 3$ DWBA calculation which implies a negative parity for this state. We tentatively propose for this state a 2^- assignment in agreement with a recent suggestion [19, 2], but a 4^- assignment cannot be completely excluded; we are in definite disagreement with the recently proposed positive parity for this state [21].

Several higher excited states in ^{10}B are not reproduced at all by the various DWBA calculations attempted and are therefore probably of a more complicated structure. A recent ^{9}Be (α, t)^{10}B experiment has shown, indeed, that there is possibly an f-wave component in ^{10}B [24].

In conclusion, it can be said that it is quite interesting to point out that the simple collective model gives a good description for several low-lying excited states in a light nucleus like ^{10}B, which are therefore probably of a simple configuration. The ^{10}B data should be a good test for further microscopic model calculations which will hopefully explain the structure of the other higher excited states.

We would like to thank Drs. E. A. McClatchie, J. Sherman for assistance in taking data and Dr. R. Ascuitto for constant interest in the theoretical interpretation.

REFERENCES

[1] G. T. A. Squier, E. A. McClatchie, A. R. Johnston, R. J. Batten, J. B. A. England and F. G. Kingston, Nucl. Phys. *A119*, 369 (1968).
[2] B. Vaucher, J. C. Alder and C. Joseph, Helv. Phys. Acta, *43*, 237 (1970); B. Vaucher, Thesis, Université de Lausanne, unpublished (1969).
[3] K. Tesh, Nucl. Phys. *37*, 1962 (1962); A. J. Frasca, R. W. Finlay, R. D. Koshel, R. L. Cassola, Phys. Rev. *144*, 854 (1966).
[4] (a) B. A. Watson, R. E. Segel, J. J. Kroepfl, and P. P. Singh, Phys. Rev. *187*, 1351 (1969) and references therein. (b) G. Schrank, E. K. Warbuton and W. W. Daehnick, Phys. Rev. *127*, 2159 (1962).
[5] F. Petrovich, R. Schaeffer, H. McManus, G. R. Gruhn, T. Y. T. Kuo, B. M. Preedom and C. J. Maggiore, Phys. Lett. *46B*, 141 (1973); R. A. Hinricks, D. Larson, B. M. Preedom, W. G. Love and F. Petrovich, Phys. Rev. *C7*, 1981 (1973); R. Ascuitto, private communication; H. V. Geramb, private communication.
[6] P. Goldhammer, J. R. Hill, J. Nachamkin, University of Kansas, Technical Report COO-1120-67 and private communication.
[7] Program 'Seefit', University of California, Berkeley, unpublished.
[8] R. E. Hintz, F. B. Selph, W. S. Flood, B. G. Harvey, F. G. Resmini and E. A. McClatchie, Nucl. Instr. Meth. *72*, 61 (1969).
[9] F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. *A227*, 148 (1974).
[10] D. Kurath, *Proc. Rehovoth Conference on Nuclear Structure* (1958) p. 54.
[11] Program 'MAGALI' by J. Raynal, CEN-Saclay, DPhT/69.42.
[12] O. Karban, J. Lowe, P. D. Greaves and V. Hnizdo, Nucl. Phys. *A133*, 255 (1969).
[13] J. Lowe, private communication, unpublished work.
[14] Program 'DWUCK' by P. D. Kuntz, University of Colorado, unpublished.
[15] Program 'ECIS 71' by J. Raynal, CEN-Saclay, unpublished. The mathematical formulations included in this program are described in *Symposium of Nuclear Reactions Mechanisms and Polarization Phenomena*, Québec (1969) (Les Presses de l'Université, Laval), J. Raynal, p. 75.
[16] J. S. Blair and H. Sherif, Phys. Lett. *B26*, 317 (1968).
[17] T. Tamura, Rev. Mod. Phys. *37*, 679 (1965).
[18] V. Meyer, R. E. Pixley, P. Truol, Nucl. Phys. *A101*, 321 (1967).
[19] M. Balakrishnan, M. K. Mehta and A. S. Divitia, Nuov. Cim. *1A*, 205 (1971).
[20] P. D. Forsyth, A. R. Knudson and F. C. Young, Nucl. Phys. *85*, 153 (1966); P. D. Forsyth, H. T. Tu and W. F. Hornyak, Nucl. Phys. *82*, 33 (1966).
[21] A. J. Sierk and T. A. Tombrello, Nucl. Phys. *A210*, 34 (1973).
[22] D. E. Alburger, P. D. Parker, D. J. Bredin, D. H. Wilkinson, P. F. Donovan, A. Gallmann, R. E. Pixley, L. F. Chase, R. E. McDonald, Phys. Rev. *143*, 692 (1966).
[23] L. A. Kull and E. Kashy, Phys. Rev. *167*, 963 (1968).
[24] K. W. Kemper, S. Cotanch, G. E. Moore, A. W. Obst, R. J. Puigh and R. J. White, Nucl. Phys. *A222*, 173 (1974).