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# EXPERIMENTAL INVESTIGATION OF THE ELASTIC SCATTERING OF PROTONS ON $^{10}B$

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*Abstract:* Excitation functions for the elastic scattering of proton on $^{10}B$ were measured at CM angle near 90°, 125° and 150°, in steps of 20 keV, for proton energies between 3 and 10,5 MeV. Angular distributions of elastically scattered protons were measured in steps of 100 keV in the same energy range.

Angular distributions change appreciably with the incident proton energy up to 7.5 MeV. Above this energy small changes and forward peaking of the angular distributions indicate that the direct reaction mechanism prevails.

Resonances in the elastic cross section were found at 3.6, 4.4, 5.3, 5.7, 5.9, 6.4, 6.7, 7.6, and 8.9 MeV incident proton energy. They correspond in all cases to the positions of resonances which appear almost always only in a few reaction channels.

For the state at 12.7 MeV ($E_p$ = 4.4 MeV), 13.4 MeV ($E_p$ = 5.3 MeV) and 16.8 MeV ($E_p$ = 8.9 MeV) tentative assignements of $7/2^+$, $9/2^+$ or $11/2^+$ for the spin and parity are made, and for the last one that it is formed with $l = 0$ or $l = 2$, are given.

## *1. Introduction*

Energy levels of the $^{11}C$ nucleus have been recently reviewed by Ajzenberg—Selove and Lauritsen[1]. Table 11.8 of this review gives the characteristics of the $^{11}C$ energy levels as obtained by considering resonances in $\alpha_0$, $\alpha_1$, $^3He$, $p_0$ and $p_1$ to $p_4$ decay channels from the $^{10}B + p$ reaction.

The elastic scattering of protons from $^{10}B$ was studied between 0,15 and 3.0 MeV by Overley and Whaling[2] and from 1 to 3.5 MeV by Andreev et al[3]. The latter concluded that a strong resonance should exist above 3.5 MeV.

To get some more information on the $^{11}C$ energy levels, proton elastic scattering on $^{10}B$ was studied between 3 and 10.5 MeV incident proton energy. The experiment included the investigation of the excitation functions at 90°, 125° and 150° in the CM system and of the angular distributions in the whole energy range.

## 2. *Experimental procedure*

Thin metallic self-supporting born targets, enriched to about 95% in $^{10}B$, were prepared by vacuum evaporation from a carbon crucible. Such targets contain carbon contamination but are easy to prepare. A well focussed proton beam from the EN Tandem Van de Graaff of the University of Texas was used. To minimize the background counting, the beam was collimated after the 90° analysing and 90° rotating magnets, using only a pair of strong focussing magnetic lenses[4].

A 50 cm. in diameter scattering chamber with four lithium-drifted silicon detectors cooled to dry ice temperature were used. The resolution of the detectors was between 30 and 40 keV and was sufficient to separate the $^{10}B$ elastic peak from the $^{12}C$ elastic peak for scattering angles greater than 55°. A defining aperture placed in front of each detector was covered with a

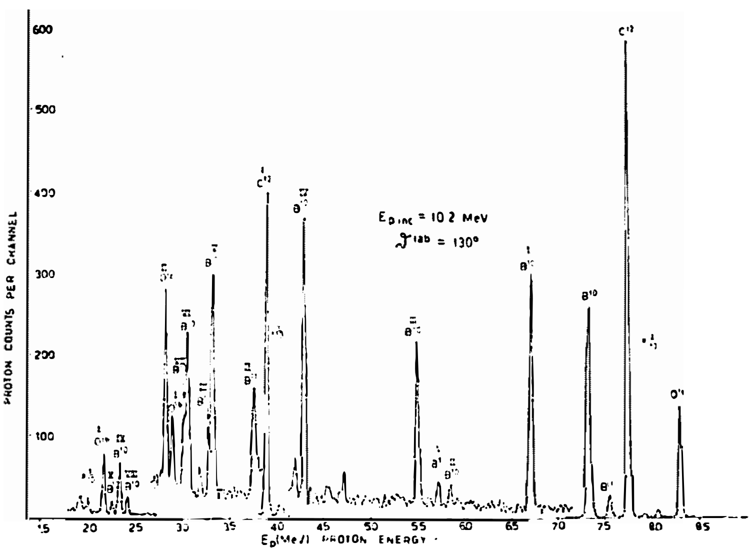


Fig. 1. Pulse height spectrum of the proton groups for the enriched $^{10}B$ target bombarded with protons of 10,2 MeV (lab.) incident energy, at $\vartheta_{lab}$ = 130°.

0,8 mg/cm² mylar polyester film to discriminate protons from $^4He$ and $^3He$ particles. A PDP-7 on line computer was used as a $4 \times 526$ multichannel pulse analyser, that automatically introduced a dead time correction through the current integrator system. The four spectra were printed and then analysed. Fig. 1 and 2 show sample spectra taken at 10.2 MeV incident energy at 130° and 65°. For incident protons above 8 MeV inelastic proton peaks were clearly visible up to that corresponding to the tenth excited state of $^{10}$B. Statistical errors for counting the $^{10}$B elastic peak were about 1%, and for the $p_1$ inelastic peak about 4%.

Excitation curves and angular distributions were taken in steps of 20 and 100 keV, respectively. At each incident proton energy the focussing of the

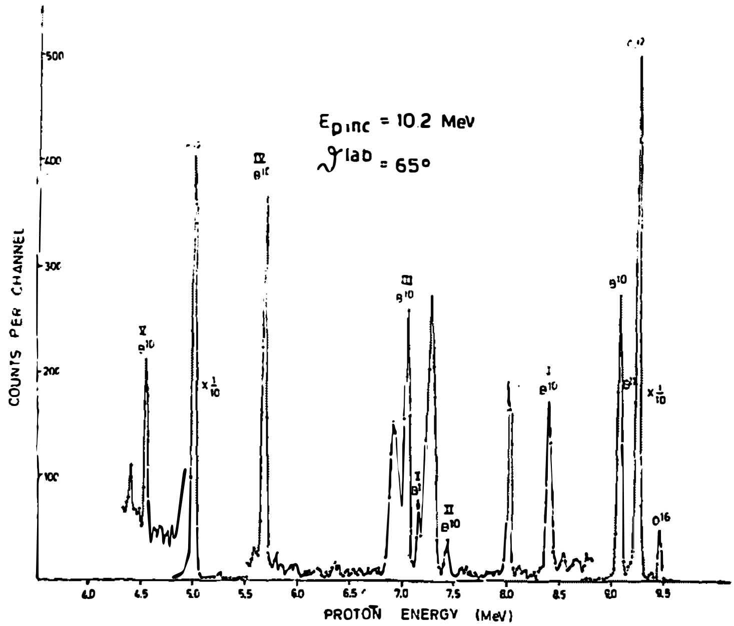


Fig. 2. Pulse height spectrum of the proton groups for the enriched $^{10}$B target bombarded with protons of 10,2 MeV (lab.) incident energy, at $\vartheta_{lab} = 65°$.

beam was checked by allowing the beam to strike a quartz plate placed at the target position. Angular distributions were taken in steps of 10° between 35° and 165°. As the $^{10}$B elastic peak in the spectra could not be well resolved from the $^{12}$C peak below 55°, additional spectra were taken below this angle using a thin $^{12}$C target. Thus by subtracting the $^{12}$C contribution in the proper proportion, that portion of the peak due to $^{10}$B could be determined.

## *3. Results and discussion*

To get the information how the nuclear angular distribution and the total cross section of the elastically scattered protons from $^{10}$B change with the incident proton energy, the Rutherford scattering and the interference effects between the Rutherford and nuclear scattering has to be esteemed[2].

At first, the ratio of the experimental cross sections (transformed to CM system), to Rutherford scattering was calculated. In Fig. 3 the so obtained excitation functions (in CM), taken in steps of 20 keV at 85°, 120° and 145° (lab), are given. Similar excitation functions extracted from the angular distributions taken in energy steps of 100 keV and 10° angular steps between 35° and 160° showed that above 6 MeV this ratio is higher than 5. For forward angles it ranges between 5 and 10 and for backward angles between 15 and 90. Such result could be expected due to the high excitation energy in $^{11}C$, which for the 3 to 10,5 MeV incident proton energy lays between 11,5 and 18,5 MeV.

The results of the angular distributions obtained in such a way are given in Fig. 4. The normalization was done with respect to Overleys and Whaling[2)] data at 3 MeV. Angular distributions change appreciably with the incident proton energy up to 7.5 MeV.

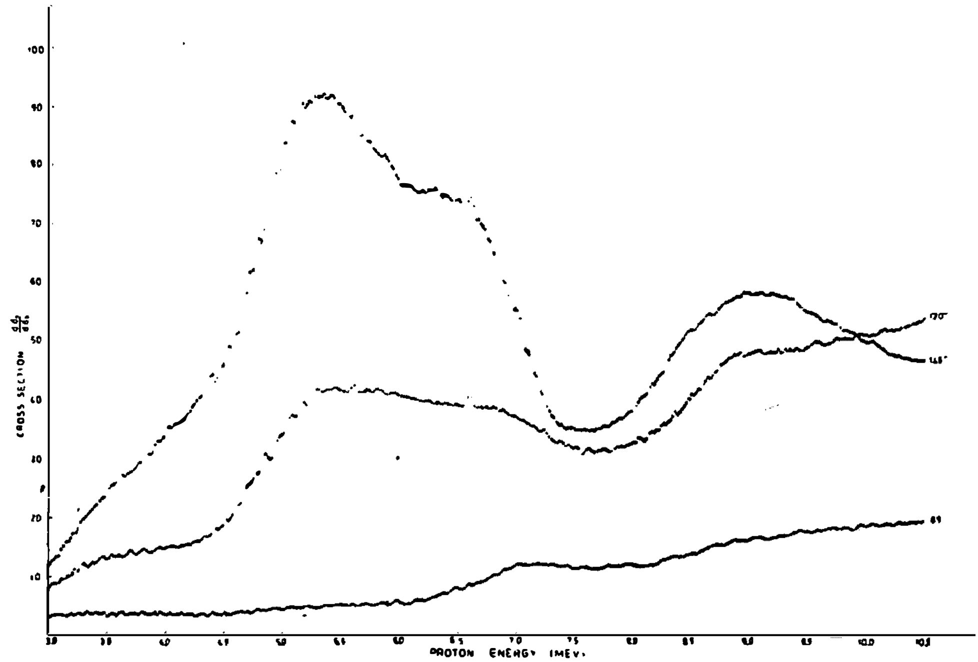

Fig. 3. Excitation functions of the ratio of the experimental cross section (in CM) to Rutherford scattering cross section, for three scattering angles.

From these curves by graphical integration, the total elastic scattering cross section was obtained. The result is given in Fig. 5. Strong resonances are present at 3.6, 5.3, 6.7 and 8.9 MeV, and resonance structures at 4.4, 5.7, 5.9, 6.4 and 7.6 MeV incident proton energy. In the same figure the total nonelastic cross section as a function of incident proton energy is given.

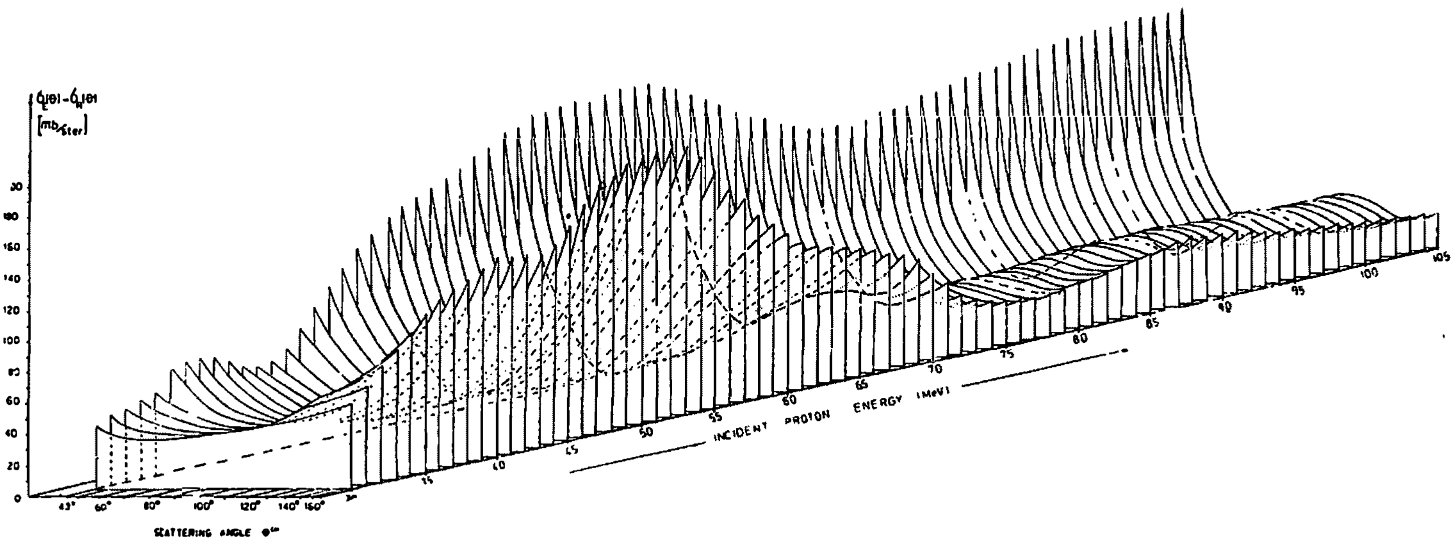


Fig. 4. Angular distributions (in CM) of elastically scattered protons on $^{10}B$ as function of incident proton energy (lab.). The Rutherford scattering cross section was subtracted from the experimental cross section (in CM).

This curve was obtained by summing all the reaction and inelastic cross sections for the $^{10}B + p$ incident channel.

The following cross sections were taken into account:

| | |
|---|---|
| $\sigma(p, \alpha_0)$ and $\sigma(p, \alpha_1)$ | (5), (6) |
| $\sigma(p, {}^3He)$ | (7) |
| $\sigma(p, p_i)$ i = 1, 2, 3 and 4 | (5) |
| $\sigma(p, n_0)$ | (8) |

The energy positions of the known resonances for different decay channels, as taken from ref.[1]), are indicated by arrows.

Considering all these data one can give some tentative level assignement for the $^{11}C$ compound nucleus.

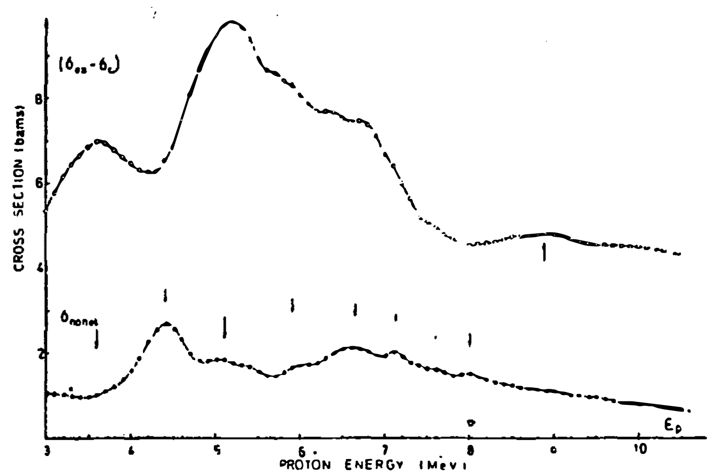


Fig. 5. Total elastic scattering cross section and total nonelastic cross sections for the $^{10}B + p$, as a function of incident proton energy. Total elastic scattering cross section was obtained by integrating the curves given in Fig. 4. Total nonelastic cross section was obtained by summing up all the reaction and inelastic cross sections for the $^{10}B + p$ incident channel [5-8]). The arrows indicate the positions of the resonances in different channels. The arrow pointing upward indicates the resonance which appears only in the elastic channel.

The shapes of excitation functions for the proton elastic scattering arround 4.4 MeV, corresponding to 12.7 MeV excitation energy in $^{11}C$, strongly support the $J^{\pi} = 7/2^+$ as well as $l = 0$[7]) for the incident protons forming the state. A total width of 400 ± 50 keV seems to be reliable.

The same arguments suggest a spin of 9/2 or 11/2 and even parity, for the strongly resonating state formed with $l = 2$ at 5.3 MeV incident proton energy. To the total width of 1.2 ± 0.1 MeV different reactions do not contribute much. Our $p_1$ data do not show resonance structure at this energy.

The resonance at 8.9 MeV, with a width of 900 $\pm$ 100 keV, corresponds only to elastic scattering. Angular distributions in that energy range indicate that the direct reaction mechanism prevails. Excitation functions suggest that it is formed with $l = 0$ or $l = 2$.

Interference effects between the Rutherford and nuclear scattering in the lower energy range[2], as well as between different $^{11}C$ levels complicate a more elaborated theoretical analysis.

Similar situation appears at the higher energy range where the direct reaction mechanism strongly appears.

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# EKSPERIMENTALNO ISPITIVANJE ELASTIČNOG RASEJANJA PROTONA NA $^{10}B$


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## Sadržaj


Overley i Whaling[2] ispitali su elastično rasejanje protona na $^{10}B$ u oblasti upadnih energija protona od 0.15 do 3.0 MeV a Andreev i dr.[3] proširili su energetsku oblast do 3.5 MeV. U višoj energetskoj oblasti upadnih protona izvršeni su eksperimenti (p, alfa)[5,6], (p, $He^3$)[7] i (p, n)[8], koji pored ostalog ukazuju — preko intenzivnih rezonanci u alfa kanalu — na eventualno postojanje klaster strukture u jezgru $^{11}C$ (2).

Ovaj rad daje rezultate ispitivanja elastičnog rasejanja protona na $^{10}$B od 3 do 10.5 MeV upadnih protona. Izmerena je ekscitaciona funkcija na 90°, 125° i 150° (CM) u koracima od po 20 keV-a. Angularne raspodele elastično rasejanih protona su izmerene u istoj energetskoj oblasti, a od 40° do 160° (CM), u koracima od po 100 keV-a.

Eksperimenti su izvršeni na EN Tandem Van de Graaffu Univerziteta u Teksasu, sa komorom za rasejanje prečnika 50 cm. Kao meta je korišćen tanki, samonoseći, metalni film od 99% obogaćenog $^{10}$B, dobiven isparavanjem u vakuumu. Za detekciju protona korišćena su četiri debela silicijumska- litijum driftovana brojača, hlađena na temperaturi čvrstog $CO_2$. Rezolucija u spektru je iznosila između 30 i 40 keV-a. Snimanje spektara i analiza podataka je rađena sa priključenim PDP-7 računarom.

Analiza podataka je omogućila određivanje karakteristika nivoa jezgra $^{11}$C na 12.7 MeV pobude (4.4 MeV upadnih protona) kao $7/2^+$, nivoa na 13.4 MeV pobude (5.3 MeV upadnih protona) kao $9/2^+$ ili $11/2^+$. Za široku jednočestičnu rezonancu na 8.9 MeV upadnih protona, koja se je pokazala samo u elastičnom »p« kanalu, podaci ukazuju da je formirana sa $l = 0$ ili $l = 2$ protonima.

Premda se većina širokih rezonanci u elastičnom »p« kanalu poklapa po energetskom položaju s rezonancama u alfa kanalu, odnosi intenziteta tih rezonanci ne potvrđuju pretpostavku izrazite klaster strukture u $^{11}$C jezgru.