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Calculation the Cross Sections of $^{10}B(n,p)^{10}Be$ Reaction by Using the Reciprocity Theory for the First Excited State

S. A. Ebrahiem, K. H. Mahdi ,A. K.Taki
Department of Physics ,College of Education Ibn Al-Haytham , University of Baghdad
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Abstract

In this study light elements ^{10}B , ^{10}Be for $^{10}B(n,p)^{10}Be$ reaction as well as proton energy from 0.987 MeV to 2.028 MeV with threshold energy (1.04MeV) are used according to the available data of reaction cross sections. The more recent cross sections data of $^{10}Be(p,n)^{10}B$ reaction is reproduced in fin steps in the specified energy range , as well as cross section *(p,n)* values were derived from the published data of *(n,p)* as a function of energy in the same fine energy steps by using the reciprocity theory of principle inverse reaction . This calculation involves only the first excited state of ^{10}B , ^{10}Be in the reactions $^{10}Be(p,n)^{10}B$ and $^{10}B(n,p)^{10}Be$.

Key word: Cross Sections , Reverse Reaction , Stopping Power, Neutron Yield

Introduction

The interaction of particles with matter is described in terms of quantities known as cross sections which is defined in the following way [1]. Consider a thin target of area (a) and thickness (X) containing(N) atoms per unit volume, placed in a uniform mono-directional beam of incident particles (neutrons for example of intensity I_o, which strikes the entire target normal to its surface as shown in fig.(1). It is found that the rate at which interactions occur within the target is proportional to the beam intensity and to the atom density, area and thickness of the target

Summarizing this experimental result by an equation, we define the interaction rate

(in the entire target) = σ I N a X ------ (1)

Where the proportionality constant σ is known as the cross section ,

Thus σ = interaction rate / INaX ------ (2)

As NaX is equal to the total number of atoms in the target, it follow s that σ is the interaction rate per atom in the target per unit intensity of the incident beam [2] .

Reciprocity Theory

If the cross-sections of the reaction *A(p,n)B* are measured as a functions of T_p (T_p = Kinetic energy of proton) the cross –sections of the inverse reaction *B(n,p)A* can be calculated as a function of T_n (T_n = Kinetic energy of neutron) using the reciprocity theorem [3] which states that :

$$\frac{\sigma_{(p,n)}}{g_{p,n}\, Ɗ_p^2} = \frac{\sigma_{(n,p)}}{g_{n,p}\, Ɗ_n^2} \quad \text{---------(3)}$$

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Where $\sigma_{(p,n)}$ and $\sigma_{(n,p)}$ represent cross- sections of *(p,n)* and *(n,p)* reactions respectively , g is a statistical factor and $\bar{\lambda}$ is the de–Broglie wave length divided by 2π and is given by

$$\bar{\lambda} = \frac{\hbar}{Mv} \qquad \text{-----------(4)}$$

Where ħ is Dirac constant (h /2π) , h is plank constant , M and v are mass and velocity of p or n particle .

From eq.(4),we have

$$\bar{\lambda}^2 = \frac{\hbar^2}{2\,MT} \qquad \text{---------(5)}$$

The statistical g-factors are givens by [3]

$$g_{p,n} = \frac{2J_c + 1}{(2I_A + 1)(2I_p + 1)} \qquad \text{---------(6)}$$

And

$$g_{n,p} = \frac{2J_c + 1}{(2I_B + 1)(2I_n + 1)} \qquad \text{----------(7)}$$

The conservation low of the momentum implique that :

$$I_A + I_p = J_c = I_B + I_n \qquad \text{----------(8)}$$

And

$$\pi_A \cdot \pi_p (-1)^{\ell p} = \pi_c = \pi_B \cdot \pi_n (-1)^{\ell n} \qquad \text{----------(9)}$$

J_c and π_c are total angular momentum and parity of the compound nucleus .
I_A and π_A are total angular momentum and parity of nucleus A.
I_B and π_B are total angular momentum and parity of nucleus B.
I_p and π_p are total angular momentum and parity of proton.
I_n and π_n are total angular momentum and parity of neutron .

$$\pi_p = \pi_n = +1 \qquad \text{----------(10)}$$

$I_p = s_p + \ell_p$ ----------(11)

Where I_p is the total angular momentum of proton
S_p is spin of proton = 1\2
ℓ_p is the orbital angular momentum of proton

And

$I_n = s_n + \ell_n$ ----------(12)

Where I_n is the total angular momentum of the neutron
s_n is spin of neutron = 1/2
ℓ_n is the orbital angular momentum of neutron

From eq.(1-8),we have :

$|J_c - I_A| \le I_p \le |J_c + I_A|$ ----------(13)

And

$|J_c - I_B| \le I_n \le |J_c + I_B|$ ----------(14)

The reactions *A(p,n)B* and *B(n,p)A* can be represented with the compound nucleus c as in the following schematic diagram. It is clear that there are some important and useful relations between the kinetic energies of the neutron and proton[4] . One can calculate the separation energies of proton (S_p) and neutron (S_n) using the following relations:
S_p and S_n are separation energies of p and n from c as shown Fig(2)[4]. Then

$$E = S_p + \frac{M_A}{M_A + M_p} T_p \quad \text{----------(15a)}$$

$$E = S_n + \frac{M_B}{M_B + M_n} T_n \quad \text{----------(15b)}$$

With

$S_p = 931.5 [M_A + M_p - M_c]$ --------(16)
$S_n = 931.5 [M_B + M_n - M_c]$ ------(17)

Combining (15a) , (15b) , (16) and (17) and as the Q- value of the reaction *A(p, n)B* is given by :

$Q = 931.5 [M_A + M_p - M_B - M_n]$ ----------(18)

Then

$$Q = \frac{M_B}{M_B + M_n} T_n - \frac{M_A}{M_A + M_p} T_p \quad \text{----------(19)}$$

Or :

$$T_n = \frac{M_B + M_n}{M_B} \left[\frac{M_A}{M_A + M_p} T_p + Q \right] \quad \text{--------(20)}$$

The threshold energy E_{th} is given by :

$$E_{th} = - Q \frac{M_A + M_p}{M_A} \quad \text{------(21a)}$$

$$Q = - \frac{M_A}{} E_{th} \quad \text{------(21b)}$$

$M_A + M_p$

Then

$$T_n = \frac{M_B + M_n}{M_B} * \frac{M_A}{M_A + M_p} (T_p - E_{th}) \text{--------}(22)$$

eq . (3) can be written as follows :

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$$\sigma_{(n,p)} = \frac{g_{n,p}\ M_p\ T_p}{g_{p,n}\ M_n\ T_n}\ \sigma_{(p,n)} \quad \text{--------}(23)$$

It is clear form this equation that the cross sections of reverse reaction are related by a variable parameters which can be calculated if the nuclear characteristics of the reactions are known.

Results and Discussion

The cross section of *(p,n)* reactions for the elements ^{10}B , ^{10}Be for $^{10}B(n,p)^{10}Be$ reaction available in the literature[5] , have been taken and re-plotted for a defined energy level as shown in Fig.(3).These plots were analyzed using the Matlab computer program to obtain the cross sections for the selected energies

The atomic mass of elements and isotopes mentioned in this study have been taken from the latest nuclear wallet cards released by the National Nuclear Data Center(NNDC)[6] and the energy level, parity and spin scheme of isotopes from [7].

By using the reciprocity theory we derive the mathematical formula for $^{10}B(n,p)^{10}Be$ reaction for first excited state :

$$\sigma_{n,p} = 1.664 \frac{T_p}{T_n} \sigma_{p,n}$$

The evaluated cross sections as a function of neutron energy from (0.0320) MeV to (0.9881) MeV of present work are listed in tables (1). These data plotted in Fig.(4) we get mathematical equation representing the cross sections distribution in the indicated range of energy and percentage error ($\pm$0.3164) for every data :

y = 3.3e+4*x^10 - 1.7e+5*x^9 + 3.9e+5*x^8 -4.9e+5*x^7 + 3.8e+5*x^6-1.9e+5*x^5+5.9e+4*x^4 - 1.1e+4*x^3 + 1.1e+3*x^2 - 43*x +0.52

We get the maximum cross section to produced the ^{10}Be by neutron energy (0.357MeV) and (0.9881MeV) are (1.1601 mbarn) and (1.3061mbarn) respectively and ^{10}Be very important in technology field. In Fig.(4) we observed that the high probability(high cross sections) to produced ^{10}Be in intermediate and fast neutrons.

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Table (1):The cross sections of $^{10}B(n,p)^{10}Be$ Reaction as a function of neutron energy present work

neutron - energy (MeV)	X- sections (mbarn) P.Work	neutron - energy (MeV)	X- sections (mbarn) P.Work	neutron - energy (MeV)	X- sections (mbarn) P.Work
0.0320	0.0517	0.2280	0.7492	0.5000	0.5801
0.0530	0.0164	0.2350	0.9339	0.5100	0.5274
0.0670	0.0387	0.2440	0.9996	0.5150	0.4834
0.0760	0.0691	0.2640	1.2036	0.5280	0.4041
0.0780	0.6758	0.2890	0.9068	0.5520	0.3558
0.0840	0.4118	0.2920	0.5685	0.5770	0.3379
0.1040	1.2568	0.3120	0.6081	0.5990	0.3292
0.1280	0.8024	0.3330	0.9112	0.6200	0.3243
0.1310	0.5743	0.3570	1.1601	0.6481	0.3591
0.1400	0.6356	0.3790	0.8667	0.7061	0.5129
0.1590	0.6400	0.3870	0.7787	0.7411	0.4771
0.1690	0.8377	0.4080	0.7260	0.7931	0.8604
0.1810	0.9605	0.4350	0.7081	0.8951	0.8938
0.1910	0.9208	0.4680	0.7120	0.9441	0.9329
0.2170	0.7318	0.4800	0.4969	0.9881	1.3061

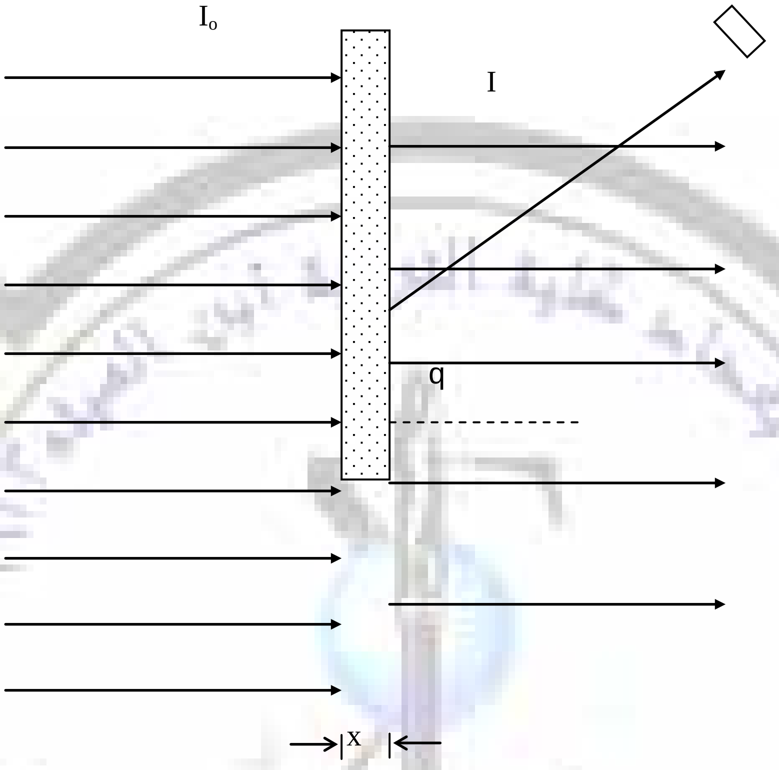
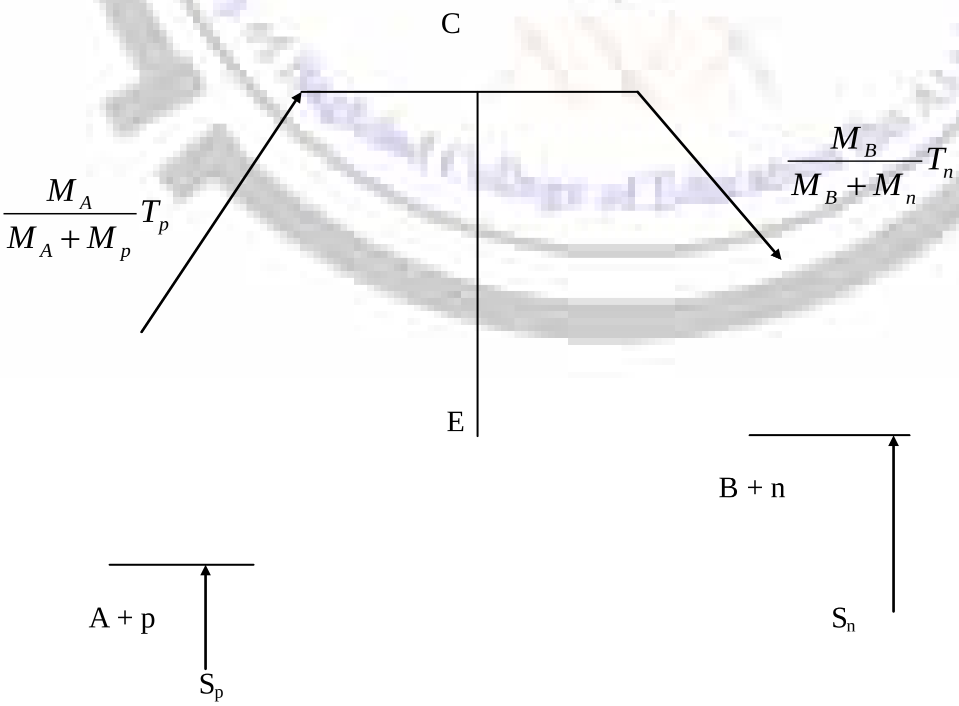


Fig. (1): A schematic diagram illustrating the definition of total cross section in terms of the reduction of intensity[1].



C

Fig. (2):Scematic diagram of the reactions[4]

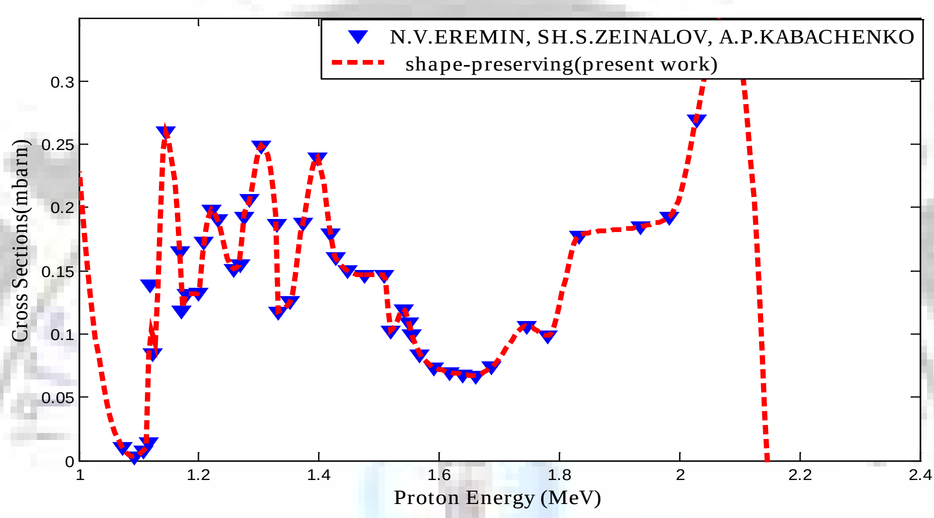


Fig.(3): Cross sections of $^{10}Be(p,n)^{10}B$ Reaction [5]

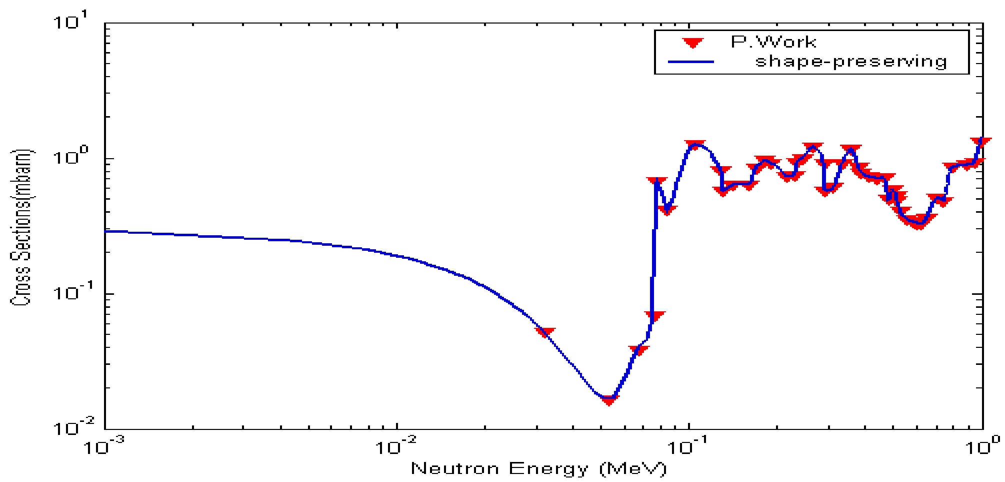


Fig.(4): Cross sections of $^{10}B(n,p)^{10}Be$ Reaction P.Work

حساب المقاطع العرضية لتفاعل $^{10}B(n,p)^{10}Be$ بأستعمال نظرية التعاكس للمستو المتهيج الاول

سميرة احمد ابراهيم ، خالد هادي ، علي كاظم تقي
قسم الفيزياء، كلية التربيه – ابن الهيثم ، جامعة بغداد

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الخلاصة

في هذه الدراسة اعيد حساب المقاطع العرضية للنوى الخفيفة (^{10}B , ^{10}Be) للتفاعل $^{10}B(n,p)^{10}Be$ للبيانات المتوفرة في الادبيات العالمية وللمدى الطاقي من MeV (0.987) الى MeV (2.028) وبطاقة عتبه مقدارها (1.04)MeV دالة للمقاطع العرضية وبخطوات طاقية معينة . بأستعمال نظرية التعاكس اشتقت معادلة لحساب المقاطع العرضية لتفاعل $^{10}B(n,p)^{10}Be$ وللمستو المتهيج الاول وذلك بالاعتماد على المقاطع العرضية لتفاعل $^{10}Be(p,n)^{10}B$ ومن ثم الحصول على معادلة للرسم البياني من خلال استخدام برامج الحاسوب (Matlab-6.5) . تم جدولة ورسم النتائج فضلا عن مناقشة النتائج وتحديد نوع النيوترون لأنتاج ^{10}Be .

الكلمات المفتاحية : المقاطع العرضية، التفاعل المعاكس ، قدرة الايقاف ، الحصيلة النيوترونية