Determining of Cross Sections for $^{16}O(n,\alpha)^{13}C$ reaction from Cross Sections of $^{13}C(\alpha,n)^{16}O$ for the ground state

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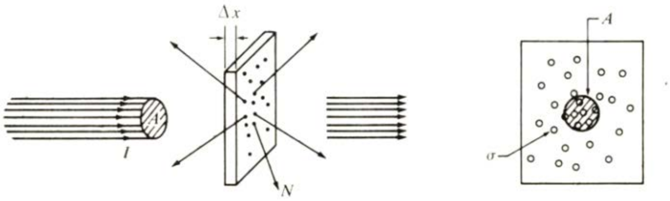
Abstract

In this study, light elements for ^{13}C , ^{16}O for (α,n) and (n,α) reactions as well as α-particle energy from 2.7 MeV to 3.08 MeV are used as far as the data of reaction cross sections are available. The more recent cross sections data of (α,n) and (n,α) reactions are reproduced in fine steps 0.02 MeV for ^{16}O (n,α) ^{13}C in the specified energy range, as well as cross section (α,n) values were derived from the published data of (n,α) as a function of α-energy in the same fine energy steps by using the principle inverse reactions. This calculation involves only the ground state of ^{13}C , ^{16}O in the reactions ^{13}C (α,n) ^{16}O and ^{16}O (n,α) ^{13}C.

Keywords : Cross sections, Inverse reaction ,Statistical factor , Dirac constant

Introduction

Since interactions in a reaction take place with individual target nuclei independently of each other, it is useful to refer the probability of a nuclear reaction to one target nucleus. Assume that in a given experiment a thin slab of target material is struck by a mono energetic beam consisting of I particles per unit time distributed uniformly over an area A, as shown in this schematic [1].



Schematic of Cross-section [1].

If the nuclear reaction produces N light product particles per unit time. It can be pretended that with each target nucleus there is an associated area σ (perpendicular to the incident beam) such that if the center of a bombarding particle strikes inside of σ, there is a hit and a reaction is produced, and if the center of the bombarding particle misses σ , no reaction is produced. The quantity σ is called cross-section and gives a measure of the reaction probability per target nucleus. It is a fictitious area, which need not be related to the cross sectional area (πR^2) of the struck nucleus. The reaction probability can also be described by the ratio N / I , but this quantity depends on the target density as well as its thickness Δx, whereas σ is associated with an individual target nucleus .The probability that any one bombarding particle has a hit is equal to N/I and is also equal to the projected total cross-section of all target nuclei lying within the area A,as seen along the beam direction ,divided by A .

If there are n target nuclei per unit volume in the target material, n A Δx, such nuclei are within reach of any bombarding particle in the beam [1].

Each target nucleus has an associated cross-section σ so that

$$\frac{N}{I} = \frac{nA\Delta x\sigma}{A} \qquad \text{...........(1)}$$

This relation can be used in two ways:

It can serve as a definition of cross-section, by writing

$$\sigma = \frac{N}{(I/A)(nA\Delta x)} =$$

Number of light product particles per unit time, per unit incident flux, and per target nucleus.

The unit of cross-section is cm^2 or barn ($1b = 10^{-24} cm^2$).

Theory

If the cross-sections of the reaction A(α,n)B are measured as a functions of Tα (Kinetic energy of α-particle) the cross –sections of the inverse reaction B(n,α)A can be calculated as a function of T_n (Kinetic energy of neutron) using the reciprocity theorem [2] which states that :

$$\frac{\sigma_{(\alpha,n)}}{g_{\alpha,n}\, \lambda\!\!\!^{-}_{\alpha}{}^{2}} = \frac{\sigma_{(n,\alpha)}}{g_{n,\alpha}\, \lambda\!\!\!^{-}_{n}{}^{2}} \qquad \text{---------(2)}$$

Where $\sigma_{(\alpha,n)}$ and $\sigma_{(n,\alpha)}$ represent cross- sections of (α,n) and (n,α) reactions respectively , g is a statistical factor and ƛ is the de–Broglie wave length divided by 2π .

ħ

$$\lambda = \frac{\hbar}{Mv} \quad \text{-------(a)}$$

Where ħ is Dirac constant (h /2π) , h is plank constant , M and v are mass and velocity of α or n particle .
From eq.(a) ,we have

$$\lambda^2 = \frac{\hbar^2}{2\,MT} \quad \text{---------(b)}$$

The statistical g-factors are givens by [2]

$$g_{\alpha,n} = \frac{2J_c + 1}{(2I_A + 1)(2I_\alpha + 1)} \quad , \quad g_{n,\alpha} = \frac{2J_c + 1}{(2I_B + 1)(2I_n + 1)} \text{------(c)}$$

The reactions A(α,n)B and B(n, α)A can be represented with the compound nucleus. It is clear that there are some important and useful relations between the kinetic energies of the neutron and alpha particle . One can calculate the separation energies of α-particle (S_α) and neutron (S_n) using the following relations:

$$S_\alpha = 931.5\,[\,M_A + M_\alpha - M_c\,] \text{----------(3)}$$

$$S_n = 931.5\,[\,M_B + M_n - M_c\,] \text{----------(4)}$$

S_α and S_n are separation energies of α and n from compound nucleus. Then

$$E = S_\alpha + \frac{M_A}{M_A + M_\alpha}\,T_\alpha \quad \text{----------(5a)}$$

$$E = S_n + \frac{M_B}{M_B + M_n}\,T_n \quad \text{----------(5b)}$$

Where E is reaction energy
Combining (3) , (4) ,(5a) , (5b) and as the Q- value of the reaction A(α , n)B is given by :

$$Q = 931.5\,[\,M_A + M_\alpha - M_B - M_n\,] \quad \text{----------(6)}$$

Then

$$Q = \frac{M_B}{M_B + M_n}\,T_n - \frac{M_A}{M_A + M_\alpha}\,T_\alpha \quad \text{---------(7)}$$

Or :

$$T_n = \frac{M_B + M_n}{M_B}\left[\frac{M_A}{M_A + M_\alpha}\,T_\alpha + Q\right] \quad \text{--------(8)}$$

The threshold energy E_{th} is given by

$$E_{th} = -\,Q\,\frac{M_A + M_\alpha}{M_A} \quad \text{--------(9a)}$$

Or

$$Q = -\frac{M_A}{M_A + M_\alpha}\,E_{th} \quad \text{--------(9b)}$$

Then

$$T_n = \frac{M_B + M_n}{M_B} * \frac{M_A}{M_A + M_\alpha} (T_\alpha - E_{th}) \text{ --------(10)}$$

Thus eq . (2) can be written as follows [2] :

$$\sigma_{(n,\alpha)} = \frac{g_{n,\alpha} \; M_\alpha \; T_\alpha}{g_{\alpha,n} \; M_n \; T_n} \sigma_{(\alpha,n)} \text{ --------(11)}$$

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 $^{16}O(n, \alpha)^{13}C$ cross sections as plotted in fig.(2) and as shown in table (1) was calculated from cross sections for $^{13}C(\alpha,n)^{16}O$ as shown in fig.(1) by using the principle of the inverse reaction [3] by using equ.(11) these calculated on the ground state with parity of ^{13}C , ^{16}O , $1/2^-$, 0^+ respectively[4] and with threshold energy 2.354(MeV) .The cross sections for $^{16}O(n, \alpha)^{13}C$ were measured from $2.7 \leq E_n \geq 3.18$ (MeV) [5]. The atomic mass of these elements is used in the present work [6] . It is clear that our result , especially , when the energy between 2.8 (MeV) to 3.08 (MeV) is close to with author [5] as shown in fig.(3) .

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Table (1) : The Cross Sections of the Reaction $^{16}O(n,\alpha)^{13}C$ as a Function Of Neutron Energy with Thresholds Energy of 2.354 MeV

Neutron Energy(MeV)	Cross section(barn) P.Work	Cross section(barn) by ENDF[5]
2.70	1.81e-10	2.09e-10
2.72	5.29e-10	5.20e-10
2.74	1.33e-9	1.46e-9
2.76	2.78e-9	3.31e-9
2.78	6.27e-9	7.37e-9
2.80	1.44e-8	1.48e-8
2.82	3.04e-8	3.00e-8
2.84	5.96e-8	6.03e-8
2.86	1.09e-7	1.19e-7
2.88	2.01e-7	2.05e-7
2.90	3.72e-7	3.65e-7
2.92	6.66e-7	6.72e-7
2.94	1.14e-6	1.21e-6
2.96	1.85e-6	2.10e-6
2.98	2.99e-6	3.47e-6
3.00	4.90e-6	5.05e-6
3.02	7.95e-6	7.81e-6
3.04	1.26e-5	1.40e-5
3.06	1.96e-5	2.19e-5
3.08	2.98e-5	3.36e-5
3.10	5.20e-5	4.47e-5
3.12	7.64e-5	6.61e-5
3.14	11.1e-5	9.62e-5
3.16	1.55e-4	1.38e-4
3.18	2.16e-4	1.96e-4

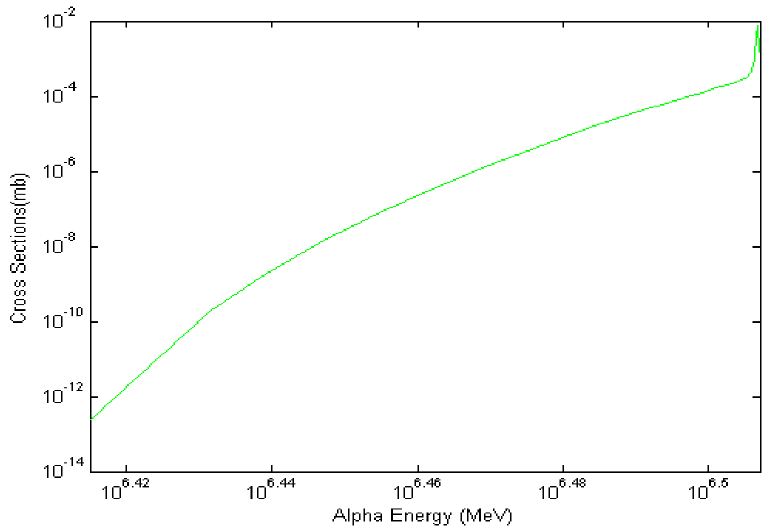

Fig.(1): The cross sections of the reaction $^{13}C(\alpha,n)^{16}O$

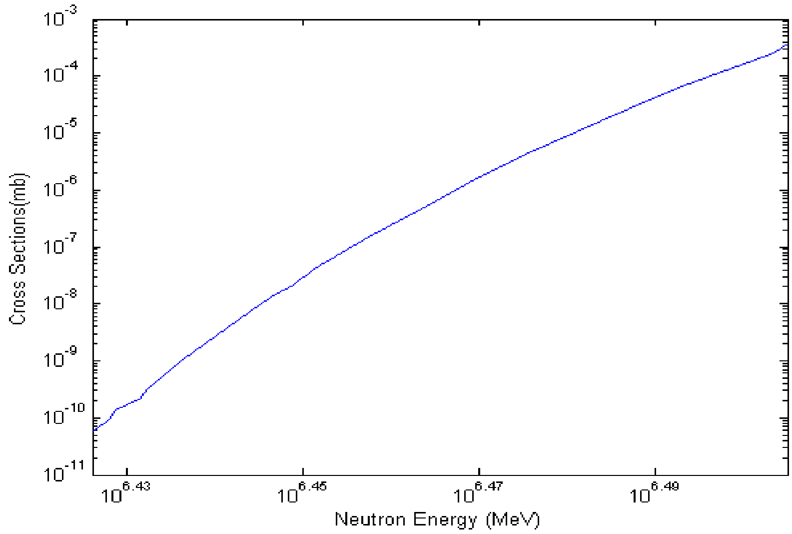

Fig.(2): The cross sections of the reaction $^{16}O(n,\alpha)^{13}C$ as given by P.Work

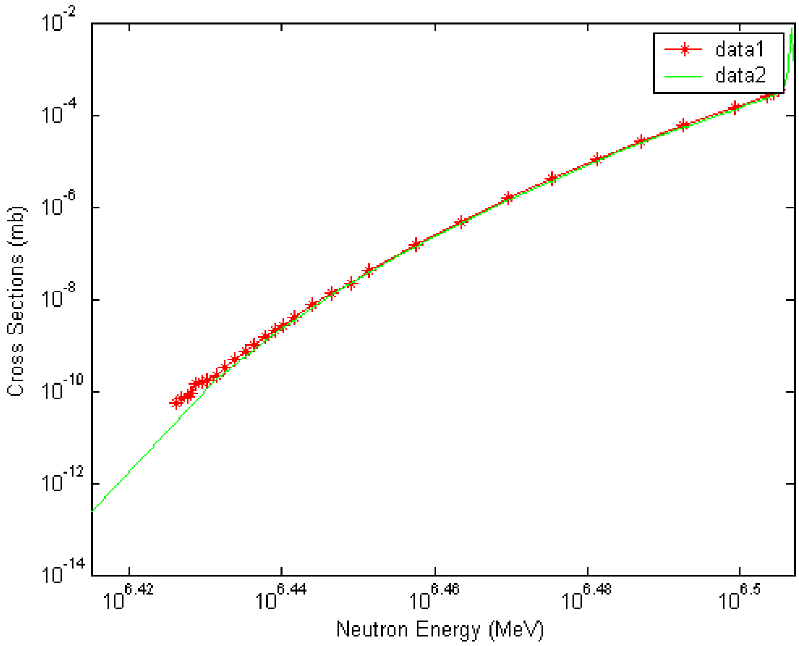

Fig.(4):Cross sections of $O^{16}(n,\alpha)C^{13}$ reaction Data-1 represent of p.workData-2 represent of ENDF-library [5]

حساب المقاطع العرضية لتفاعل $^{16}O(n,\alpha)^{13}C$ من المقاطع العرضية لتفاعل $^{13}C(\alpha,n)^{16}O$ باستعمال نظرية التعاكس في المستوى الارضي

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الخلاصة

في هذه الدراسة ، اعيدت حسابات المقاطع العرضية للتفاعلات النووية (الفا ، نيوترون) و(نيوترون ، الفا) للنوى الخفيفة (^{13}C , ^{16}O) للبيانات المتوافرة و للمدى الطاقي من طاقة العتبة الى (10MeV) لجسيمات الفا والنيوترونات . ان بيانات المقاطع العرضية الاكثر حداثة للتفاعلات (الفا ،نيوترون) و(نيوترون ،الفا) قد استخدثت بخطوات طاقية (0.02 MeV) لتفاعل $^{16}O(n,\alpha)^{13}C$ ، وكذلك حسبت المقاطع العرضية لتفاعل (الفا،نيوترون) من المقاطع العرضية لتفاعل (نيوترون،الفا) المنشورة في الادبيات دالة لطاقة الفا و بالخطوات الطاقية نفسها باستعمال مبدأ التفاعل المعاكس.

تمت هذه الحسابات فقط المستوى الارضي للنوى (^{13}C , ^{16}O) في التفاعلين $^{13}C(\alpha,n)^{16}O$ ، $^{16}O(n,\alpha)^{13}C$.

الكلمات المفتاحية : المقاطع العرضيه ، التفاعل المعاكس ، العامل الاحصائي ,ثابت ديراك