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Production of Fluorine and Its Role in the Diagnosis of Cancer 15N (α, n)18F and 18F (n, α)15N

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Production of Fluorine and its Role in the Diagnosis of Cancer ^{15}N (α, n)^{18}F and ^{18}F (n, α)^{15}N

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Abstract. In this study, the cross sections for the reaction ^{15}N (α, n)^{18}F were calculated due to the great importance of fluorine 18, as it is one of the radioactive isotopes used in the medical field, as it is used in diagnosing cancer (pet), and because fluorine is distinguished by a property, which is its strong ability to attract electrons, as it has an electronegative property, as it contains five electrons in its outer 2p shell. The cross sections for the reverse reaction ^{18}F(n, α)^{15}N were also calculated, and the highest probability of producing a fluorine isotope was determined in an energy range of 8.7 to 15 MeV, with energy steps of 0.15 MeV. With a threshold energy of 1.05117 MeV. Semi-empirical equations for the cross sections of the reverse reaction were also derived by deriving equations that depend on the mass of the bombarding particle, the mass of the exiting particle, the masses of the target nucleus, the daughter nucleus, the spin, and the parity. We note that the highest probability of a reaction occurring is 16.3444 MeV when the neutron energy is 9.3736 MeV. We note that the cross-section values fluctuate to several peaks, including when the incident neutron energy is 11.3736 MeV, where the cross-section is 8.2743 MeV. As for the neutron energy values calculated by the reverse reaction of the ^{18}F (n, α)^{15}N reaction, the cross-section values range between (16.3444 - 0.4879) mbarn and the energy values range between (11.6236 - 6.3738) MeV.

Keywords: cross sections, attract electrons, particle and reaction

INTRODUCTION

When two charged nuclei, overcoming their Coulomb repulsion, a rearrangement of the constituents of the nucleus may occur. Similar to the rearrangement of atoms in reacting molecules during a chemical reaction, this may result in a nuclear reaction. Nuclear reactions are usually produced by bombarding a target nucleus with a nuclear projectile, in most cases a nucleon (neutron or proton) or a light nucleus such as a deuteron or an α-particle [1]. At low excitation energies (< 10 MeV), the majority of nuclear reactions involve the formation of two nuclei, one nearly equal in charge and mass number to the target nucleus. An equation of the type represents such reactions [2]:

$$X + a \rightarrow Y + b \tag{1}$$

The Q– value of the reaction is defined as the difference between the final and initial kinetic energies:

$$Q = Tb + Ty - Ta \tag{2}$$

$$Q = [\, Ma + Mx - Mb - My \,]\, C^2 \tag{3}$$

If Q is positive, the reaction is said to be an exo-ergic process; if Q is negative, it is endo-ergic process [3]. So, the Q < 0 process cannot occur spontaneously, which means that there is a threshold energy $Ta_{(thr)}$ given by [1]:

$$\mathrm{Ta}_{(\mathrm{thr})} = \mathrm{E}_{\mathrm{thr}} = -\mathrm{Q}\,(1 + \mathrm{Ma}/\mathrm{Mx}) \tag{4}$$

The reaction cross section is a physical term calculated through a specific area [4]. The larger the area, the higher the likelihood of the reaction occurring. [5,6]. The cross section, a unit of area, is used to calculate the cross section of a nuclear reaction, as its incidence is within the square of the nuclear radius, since barn = 10-24 cm^2, Bombardment of particles causes multiple reactions, producing various elements. The cross section of reaction products and the entire reaction cross section are calculated through the relationship [7]:

$$\sigma_{tot} = \Sigma i\, \sigma i \tag{5}$$

The cross section of each reaction within the main reaction is denoted by σi.

The kinetic energies of the reaction products can be used to study any specific reaction. Devices designed for sensing radiation and particles classify their energy. Cross-section calculations are crucial for obtaining basic and essential information [8]. Quantum mechanics can be utilized to calculate the cross section of any reaction by utilizing mathematical models of nuclei. The expected and observed values of different cross sections can be calculated and compared. The nuclear models' hypotheses can be confirmed [8]. The cross-section provides a description of the interaction between particles and the substance as defined above.

The cross-section is the probability of a specific nuclear reaction occurring by determining the actual size of the nucleus [9]. The study of cross-sections of reactions is a crucial aspect of understanding Nuclear Systems [4]:

$$\sigma = R / I \tag{6}$$

The cross section of the nuclear reaction is denoted by σ. The number of interactions per unit time is denoted by R.

RECIPROCITY THEOREM

The cross sections A (α, n) B can be measured as a function of kinetic energy Kα (Kα = Kinetic energy of α-particle) [9, 10]. The reciprocity theorem is used to calculate cross sections B (n, α) A for the reverse reaction based on the kinetic energy of neutrons. K_n (K_n = Kinetic energy of neutrons) [11]. The reciprocity theorem is based on a specific relationship

$$\sigma_{(\mathbf{n},\boldsymbol{\alpha})} = \frac{g_{\mathbf{n},\boldsymbol{\alpha}} M_{\boldsymbol{\alpha}}\ T_{\boldsymbol{\alpha}}}{g_{\boldsymbol{\alpha},\mathbf{n}} M_{\mathbf{n}}\ T_{\mathbf{n}}} \quad \sigma_{(\alpha,n)} \tag{7}$$

The cross-sections of (α, n) and (n, α) reactions are represented by σ (α, n) and σ (n, α, respectively.
g is a statistical factor.
Δ is the De–Broglie Wave Length divided by 2π and is given by:

$$\lambda\!\!\!^{-} = \hbar / MV \tag{8}$$

Where ħ is Dirac constant (h /2π), h is plank constant, *M* and *V* are mass and velocity of α or n particle. The statistical g-factors are givens by

$$g_{\alpha,n} = \frac{2Jc + 1}{(2IA + 1)(2I\alpha + 1)} \tag{9}$$

$$g_{\alpha,n} = \frac{2Jc + 1}{(2IA + 1)(2I\alpha + 1)} \tag{10}$$

The conservation low of momentum and parity implies that [11]: $I_A + I_\alpha = J_c = I_B + I_n$

$$\pi A\,.\,\pi\alpha\,(-1)\ell\alpha = \pi c = \pi B\,.\,\pi n\,(-1)\,\ell n \tag{11}$$

J_c and π_c are the total angular momentum and parity of the compound nucleus are crucial factors to consider. I_A and π_A the total angular momentum and parity of nucleus A are crucial factors to consider. I_B and π_B. The total angular momentum and parity of nucleus B are crucial factors to consider. I_α and π_α the total angular momentum and parity of the α-particle are crucial factors to consider. I_n and π_n the total angular momentum and parity of a neutron are crucial factors to consider [12].

Fluorine-18 is the most commonly utilized isotope in positron emission tomography scans. The isotope is a fluorescent one with a half-life of approximately 110 minutes. This isotope is highly beneficial due to its extended half-life and its emission of positrons with the lowest energy [1], The process of obtaining high-resolution images is significantly facilitated by this. Positron Emission Tomography PET is crucial in tutor diagnosis and staging due to its ability to provide functional information synchronized with anatomical details when combined with computed tomography (CT). Fluoride-18-Fluoride is a valuable PET tracer for pure radiotracers, as it is sub hydroxylated in bone crystals by fluorapatite, enhancing diffusion rates [2].

PET scans reveal an increase in 18-fluoride levels in bone lesions, indicating a boost in bone and blood growth. A PET scan using 18F-FDG labelled the brain, kidneys, bladder, and FDG breakdown, revealing radioactive urine and a large colon cancer tumour mass in the liver. PET is a crucial medical and research tool in imaging tumours, detecting metastases, and diagnosing diffuse brain diseases. It enhances understanding of the human brain, heart function, and supports drug development, and is used in pre-clinical studies [13].

RESULTS AND DISCUSSIONS

In Table No. 1, the cross sections of an incidental alpha particle with an energy ranging between 8.7 and 15 MeV are 0.9017-6.219 mbarn, respectively, and the values of the cross sections fluctuate according to the incident energy of the alpha particle, as shown in Figure 1. We note that the highest value for the probability of a nuclear reaction occurring when the alpha energy is 12.3 MeV is 9.3934 mbarn, as this is the best energy for producing an isotope of fluorine from the response of nitrogen-15 with the alpha particle, which is used in the medical field to diagnose cancer tumors using a PET camera.

The cross-section of the reaction ^{18}F (n, α)^{15}N was calculated using the opposite reaction equation No. 3, based on the values of spin and parity for each of the reactants, products, and the complex nucleus, and these values were subjected to testing according to the above-mentioned equations No [14]. The kinetic energy of the neutron was also calculated by determining the interaction energy values Qo (-0.8295 MeV) and the threshold energy Eth (1.051174 MeV) based on the masses of the isotopes [15, 16].

As for the neutron energy values calculated by the opposite reaction of the reaction ^{18}F(n, α)^{15}N, and as shown in Table 1, the cross-section values range between (16.3444 - 0.4879) mbarn and the energies values range between (11.6236 - 6.3738) MeV, we notice that the highest probability of the reaction occurring is 16.3444 m barn when the neutron energy is The drop is 9.3736 MeV, as shown in Figure 2. We notice that the values of the cross sections fluctuate to several peaks, including when the energy of the incident neutron is 11.3736 MeV, where the cross-section is 8.2743 mbarn.

TABLE 1. Cross section as a function of energies alpha and neutron of $^{15}N(\alpha,n)^{18}F$,$^{18}F(n,\alpha)^{15}N$ reactions

Alpha energy (MeV)	X-Sections (mbarn)	Neutron energy (MeV)	X-Sections (mbarn)	Alpha energy (MeV)	X-Sections (mbarn)	Neutron energy (MeV)	X-Sections (mbarn)
8.7	0.9017	6.3738	1.5689	12	0.6068	9.1237	1.0557
8.85	3.7257	6.4988	6.4826	12.15	2.002	9.2487	3.4834
9	2.5745	6.6238	4.4796	12.3	9.3934	9.3736	16.3444
9.15	2.2636	6.7488	3.9386	12.45	4.99	9.4986	8.6825
9.3	1.3041	6.8737	2.2691	12.6	2.5275	9.6236	4.3977
9.45	2.0072	6.9987	3.4926	12.75	1.8976	9.7486	3.3018
9.6	0.8918	7.1237	1.5516	12.9	1.8034	9.8736	3.1379
9.75	0.4525	7.2487	0.7874	13.05	2.0545	9.9986	3.5749
9.9	0.3416	7.3737	0.5945	13.2	2.7135	10.1236	4.7215
10.05	0.2804	7.4987	0.4879	13.35	3.9134	10.2486	6.8093
10.2	0.36	7.6237	0.6263	13.5	5.1728	10.3736	9.0005
10.35	3.5059	7.7487	6.1002	13.65	4.9877	10.4986	8.6785
10.5	1.0813	7.8737	1.8814	13.8	3.6809	10.6236	6.4047
10.65	0.8968	7.9987	1.5604	13.95	2.6359	10.7486	4.5864
10.8	1.3011	8.1237	2.2639	14.1	2.1037	10.8736	3.6604
10.95	2.5425	8.2487	4.4239	14.25	1.9465	10.9986	3.3869
11.1	4.031	8.3737	7.0139	14.4	2.1529	11.1236	3.7459
11.25	3.0643	8.4987	5.3318	14.55	2.9228	11.2486	5.0857
11.4	1.9911	8.6237	3.4644	14.7	4.7554	11.3736	8.2743
11.55	1.9007	8.7487	3.3073	14.85	7.1782	11.4986	12.49
11.7	4.2841	8.8737	7.4543	15	6.219	11.6236	10.821
11.85	3.8527	8.9987	6.7036	------	------	------	------

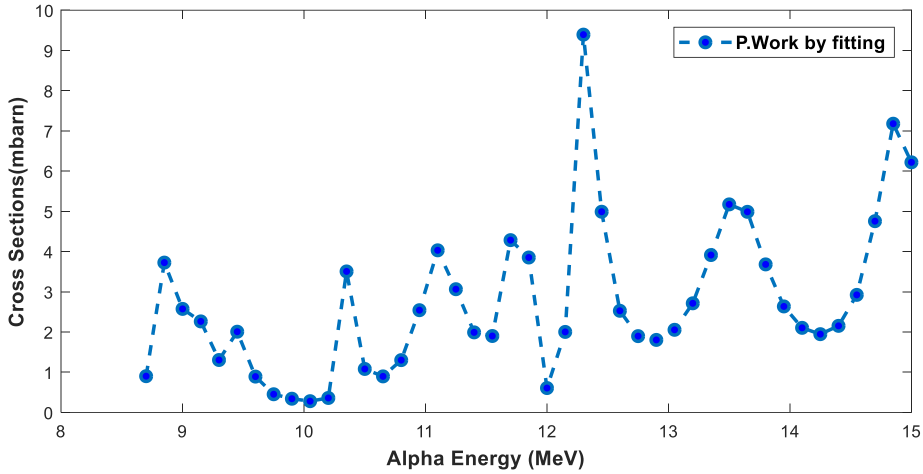

FIGURE 1. Cross Sections as a faction of alpha energy of ^{15}N (α, n)^{18} F

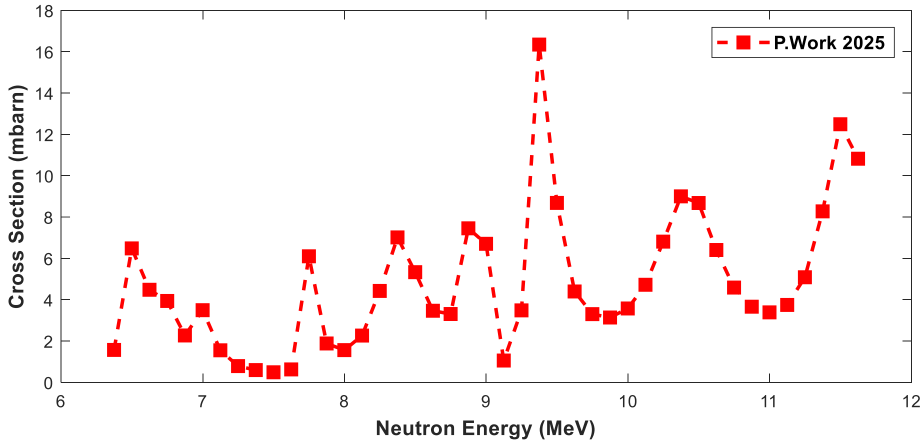

FIGURE 1. Cross Sections as a faction of neutron energy for ^{18}F (n, α)^{15} N

CONCLUSIONS

In reaction ^{15}N(α, n)^{18}F, it is clear from Figure 1 that the cross-section values fluctuate with the incidental alpha energy over the range 8.7-15 MeV, and that the highest probability of the reaction occurring and producing the fluorine isotope is 12.3 MeV is 9.3934 mb. The cross-section values are approximately constant for some values of the incident alpha energies. The highest probability of the reaction occurring and producing the nitrogen isotope from the reverse reaction ^{18}F(n,α)^{15}N occurs when the energy of the incident neutron is 9.3736 MeV. The pattern of the relationship is oscillatory, while the remaining cross-section values fluctuate, and some of them are constant for some values of the incident neutron energy. In the reaction ^{15}N (α, n)^{18}F, it is clear from Figure 1 that the cross-section values fluctuate with the energy of the incident alpha over the range of 8.7-15 MeV. The highest probability for the reaction to occur and produce fluorine isotope is 12.3 MeV (9.3934 mb). The cross sections are almost constant for some values of the incident alpha energies. The highest probability for the reaction to occur and produce the nitrogen isotope from the reverse reaction ^{18}F (n, α)^{15}N is when the incident neutron energy is 9.3736 MeV (16.3444 mb). The pattern of the relationship is oscillatory, while the remaining cross sections are fluctuating, and some of them are constant for some values of the incident neutron energy.

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