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Production of Californium-252 by Using Reverse Reaction Technology

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Abstract

In the current work, Calculate cross sections for ^{252}Cf (α,3n)^{253}Fm reaction Use of interpolation and cross-section sampling published in the international literature to select the appropriate interaction of ground-level energies in a computer-based program (MATALAB-17.0) , in steps of energies (0.2 Million electron volts). Given the importance of the ^{252}Cf isotope and its entry into the industrial and medical fields, there was a need to determine the energy of the incident neutron to produce this isotope, relying on the masses of the entering and leaving particles and the values of angular momentum to obtain an equation and according to the theory of the opposite reaction. The reaction cross sections (^{253}Fm (3n,α) ^{252}Cf) were calculated using the opposite reaction theory for the energy range (3.9789-14.538)MeV. The results show that the probability values increase with the neutron's energy smoothly. The results show that cross-section values are almost constant for the energy range limited to (8.5-14)MeV. The results were plotted and tabulated using MATLAB 17.0. Also, the values obtained for the reaction cross sections ^{253}Fm (3n,α) ^{252}Cf through which the CF is produced. Semi-empirical equations were obtained for the relationship between energy and cross-section.

Keywords: Cross-sections, nuclear reactions, radioisotopes, energy, reverse reaction.

1. Introduction

Californium is a radioactive, trivalent chemical element.(1) A synthetic chemical element in the periodic table. Its chemical symbol is Cf and the number of protons is 98. It was discovered by bombarding the element curium with alpha particles. It has a few uses. ^{252}Cf has a half-life of 2.6 years and is highly radioactive. It is considered a source of neutrons (1 microgram radiates about 170 million neutrons per minute). Nine radioactive isotopes have been discovered, the most stable of which are ^{251}Cf with a half-life of 898 days, ^{249}Cf with a half-life of 351 years, and ^{250}Cf with a half-life of 13 years. The rest of the radioactive isotopes have a half-life of less than 2.7 years, most of which are about twenty minutes, and the atomic weight of the isotopes ranges between 237.062 (^{237}Cf) to 256.093 (^{256}Cf).

2. Materials and Methods

2.1. Radioisotope Production

Isotopes are substances with nuclei that have an equal number of protons and a varying number of neutrons. The physical characteristics of an element's isotopes differ from their chemical counterparts but are the same in the number of nucleons. Because of this, each isotope is distinguished by its mass number. In addition, some isotopes are unstable and are liable to radioactive decay. Radioactive isotopes are the name given to these isotopes (2) **Figure 1.** shows two groups of elements, the elements with the same number of neutrons (isotones) and elements with the same mass number (isobars). The lines in the figure show how the number of nucleons changes in the different types of radioactive decay, where the coordinate represents the number of neutrons N and the coordinate represents the atomic number Z. All radioactive elements have a half-life, Where the half-life is the time during which half of the nuclei of the current radioactive isotope decay and it can vary from 10^{-8} seconds for short-lived radioisotopes and up to 10^{14} years for long-lived radioisotopes. The different radioactive isotopes of some elements also have multiple types of half-life, decay pathways, and decay types. Naturally or as a result of artificially modifying the atom unstable nucleation of radioactive isotopes can occur. In some cases, a cyclotron is used. In other instances, a nuclear reactor produces radioactive isotopes used in the medical field in diagnosis, treatment, and other industrial fields. A nuclear reactor is the best way to produce neutron-rich radioactive isotopes used in technological advances such as molybdenum-99., while cyclotrons are the most appropriate way to produce proton-rich radio-isotopes like fluorine(3,4).

practical releasing radiation is called radioactive decades. The process of radioactive decay for each radioactive isotope is unique and is measured by a period called the half-life (5-7).

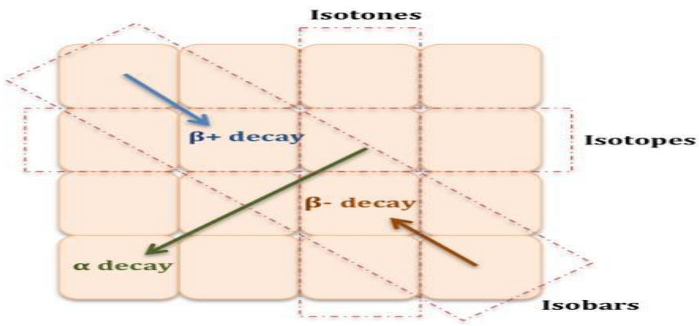

Figure 1. Describes groups of elements and the path of decay(7).

2.2. Cross Sections

The interaction of the neutron with the target nucleus in a reaction does not depend on the type of nucleus, but rather on the energy for neutrons. Therefore, the absorption of thermal neutrons in some materials is much greater than the absorption of fast neutrons. In addition to the type of interactions (7). This probability of an interaction between neutrons is called a microscopic cross-section σ. The values of these cross-sections change with changes in neutron energies(8,9). Cross sections have several types:

- Microscopic cross sections.
- Macroscopic cross sections.

Microscopic cross sections (σ) are the target and effective areas presented by a single nucleus of the bombardment particle. Microscopic cross-sections can also be defined as follows (10):

$$\sigma = R/I \qquad (1)$$

σ : Microscopic cross- section-section (cm^2)(11,12).

R: Numbers of reactions per unit time per nucleus.

I: Numbers incident particles per unit times per unit area.

While the macroscopic cross sections (∑) are the effective target areas represented by the cores containing cm^2 of material, another meaning is that these are microscopic and macroscopic cross sections and expressed in cm^2 or pens (1 barn = 10^{-24} cm^2). A neutron will interact with a given volume of matter, and this depends on the microscopic cross sections on the number of nuclei within that volume. In other words, all macroscopic cross sections are the probability of certain interactions occurring / units travel of the neutron. (∑) where this microscopic cross section (σ) is related to the following relationship (11).

$$\Sigma = N * \sigma \qquad (2)$$

∑ : Macroscopic section (cm^{-1}).

N: Atoms densities of material(atoms/cm^3).

This neutron interacts with an atom of matter by scattering first and absorbing second. Microscopic absorption cross sections, σ_a, is the probability that a particular atom will absorb a neutron. The scattering probability of neutrons from the nucleus is the microscopic scattering cross section, σ_s. So the total cross section's σ_T is given by the following relationship(12,13):

$$\sigma T = \sigma a + \sigma s \qquad (3)\ (14,15)$$

$$\sigma\, a = \sigma\, c + \sigma\, f \qquad (4)\ (16)$$

The reaction cross sections B(n,α)A can be calculated from reaction cross sections. If reaction cross sections A(α,n)B are measured by the opposite reaction method:

$$\frac{\sigma(\alpha,n)}{g\,\alpha,n\ \lambda\!\!\!^{-}\alpha 2} = \frac{\sigma\,(n,\alpha)}{g\,n,\alpha\lambda\!\!\!^{-} n2} \qquad (5)$$

σ(α,n) and σ(n,α) are the cross sections of (α,n) and (n,α) interactions, respectively, g and the statistical factor which is the de-Broglie wavelength divided by 2π and (20) are given by:

$$\lambda\!\!\!^{-} = \frac{\hbar}{MV} \qquad (6)$$

Where ħ= h /2π is Dirac- constant, h is plank-constant, M is mass and V is velocity.

3. Results and Discussion

In the current study, cross sections were measured by the inverse reaction method ^{252}Cf (α,3n)^{253}Fm This is to obtain the production of chloronium from the reaction^{253}Fm (3n,α) ^{252}Cf This is due to the status that CF enjoys and its great importance, as californium is a radioactive, trivalent chemical element that contains 98 protons. CF is used as an important neutron source that helps in detecting natural ores and minerals such as gold and silver through the neutron activation technique. It is also used in neutron radiography of aircraft and weapon components to detect corrosion.

Table 1. Cross section of alpha particle incident by step 0.2MeV for ^{252}Cf (α,3n)^{253}Fm reaction(p.work).

Alpha Energy (MeV)	X- Sections (mb) p.w.	Alpha Energy (MeV)	X- Sections (mb) p.w.	Alpha Energy (MeV)	X- Sections (mb) p.w.
29.5	0.7462	33.3	1.8279	37.1	3.2571
29.7	0.7953	33.5	1.9796	37.3	3.2472
29.9	0.8444	33.7	2.1313	37.5	3.2373
30.1	0.8935	33.9	2.283	37.7	3.2275
30.3	0.9426	34.1	2.4346	37.9	3.2176
30.5	0.9917	34.3	2.5863	38.1	3.2078
30.7	1.0408	34.5	2.738	38.3	3.1979
30.9	1.0899	34.7	2.8897	38.5	3.1881
31.1	1.139	34.9	3.0341	38.7	3.1782
31.3	1.1882	35.1	3.0547	38.9	3.1683
31.5	1.2373	35.3	3.0752	39.1	3.1585
31.7	1.2864	35.5	3.0957	39.3	3.1486
31.9	1.3355	35.7	3.1162	39.5	3.1388
32.1	1.3846	35.9	3.1368	39.7	3.4316
32.3	1.4337	36.1	3.1573	39.9	3.7908
32.5	1.4828	36.3	3.1778	40.1	4.1501
32.7	1.5319	36.5	3.1984	----------	----------
32.9	1.581	36.7	3.2189	----------	----------
33.1	1.6763	36.9	3.2394	----------	----------

Table 1. shows the range of alpha energy incident on the target nucleus, ^{252}Cf, between 29.5 and 40.1 (MeV). It is shown that the behavior of the cross sections begins to increase until it reaches a cross-section of 4.1501 mbarn as shown in fig.1 by using MATLAB program The evaluation of cross sections recalculated by spline(22,23), fitting and interpolate. The percentage was calculated from the appropriate equation for the distribution of cross sections of the alpha energy range, as follows: $y = 1.1e\text{-}5*x_\alpha^7 - 0.0028*x_\alpha^6 + 0.3*x_\alpha^5 - 17*x_\alpha^4 + 6.1e{+}2*x_\alpha^3 - 1.3e{+}4*x_\alpha^2 + 1.5e{+}5*x_\alpha - 7.5e{+}5$
where y is the cross sections, x_α is the neutron energy.

Table 2. Cross sections of neutron Incident of ^{253}Fm (3n,α) ^{252}Cf reaction(p.work).

Neutron energy (MeV)	X- Sections (mb) p.w.	Neutron energy (MeV)	X- Sections (mb) p.w.	Neutron energy (MeV)	X- Sections (mb)p.w.
3.9789	0.2838	7.565	0.6375	11.1511	1.2241
4.1782	0.3024	7.7643	0.6951	11.3504	1.2319
4.3774	0.3211	7.9635	0.7528	11.5496	1.2386
4.5766	0.3398	8.1627	0.8105	11.7488	1.2349
4.7758	0.3585	8.3619	0.8682	11.948	1.2311
4.9751	0.3771	8.5612	0.9259	12.1473	1.2274
5.1743	0.3958	8.7604	0.9835	12.3465	1.2236
5.3735	0.4145	8.9596	1.0412	12.5457	1.2199
5.5728	0.4332	9.1589	1.0989	12.745	1.2161
5.772	0.4518	9.3581	1.1538	12.9442	1.2124
5.9712	0.4705	9.5573	1.1617	13.1434	1.2086
6.1704	0.4892	9.7565	1.1695	13.3426	1.2049
6.3697	0.5079	9.9558	1.1773	13.5419	1.2011
6.5689	0.5265	10.155	1.1851	13.7411	1.1974
6.7681	0.5452	10.3542	1.1929	13.9403	1.1936
6.9673	0.5639	10.5534	1.2007	14.1396	1.305

7.1666	0.5826	10.7527	1.2085	14.3388	1.4416
7.3658	0.6012	10.9519	1.2163	14.538	1.5782

In **Table 2.,** the cross sections for the reaction (3n, a) were calculated using the reverse reaction technique and according to the following equation:

$X_{(n,\alpha)} = 0.33068487\frac{T\alpha}{Tn} X_{(\alpha,n)}$

Which depends on the atomic masses of each of the products and reactants(24-26), by calculating Q-value and E_{th}, and by relying on the spin and parity values of each of the products, reactants (27,28), and the complex nucleus to calculate the g-factor(29,30).

Where $g_{\alpha,n}=1$ and $g_{n,\alpha}=1/4$

These data are listed in **Table 2.** and plotted in **Figure 2.** In addition to the sixth-order semi-empirical formula, using the program (MATLAB version R (2017). From the data, we noticed the increase in cross sections from (0.2838 mbarn) to (1.5782 mbarn) and this increase is smooth. We deduced that the greatest potential for production ^{252}Cf by bombarding ^{253}Fm by Resonance neutrons (Its power ranges from 1-100 MeV).

In **Table 2**; It was found that the values of the cross sections increase with the increase in the energy of the neutron incident on the target material ^{253}Fm as shown in **Figure 2**. From Figure 2 a sixth-order semi-empirical equation is obtained for the relationship between neutron energy with cross sections and the following

$y = - 7.5e\text{-}06*x_n^6 + 0.00071*x_n^5 - 0.022*x_n^4 + 0.31*x_n^3 - 2.2*x_n^2 + 7.8*x_n – 10$

where y is the cross sections, x_n is the neutron energy.

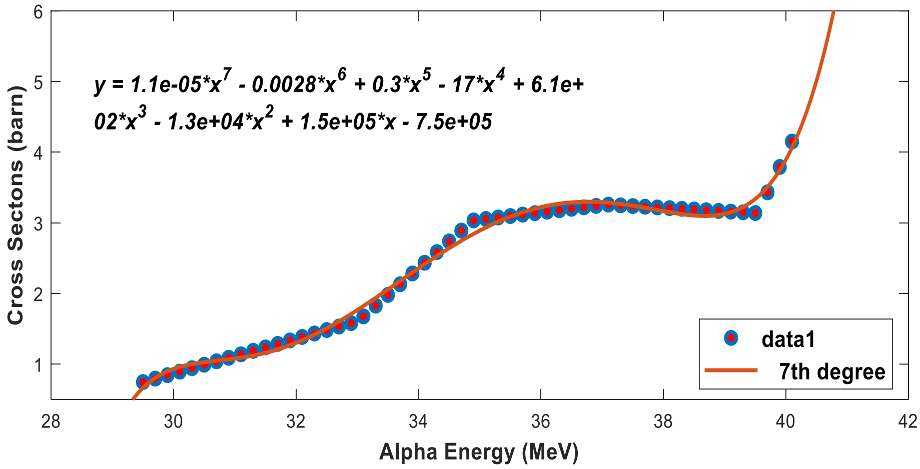

Figure 2. The cross sections as a function of alpha energy for ^{252}Cf (α,3n)^{253}Fm reaction.

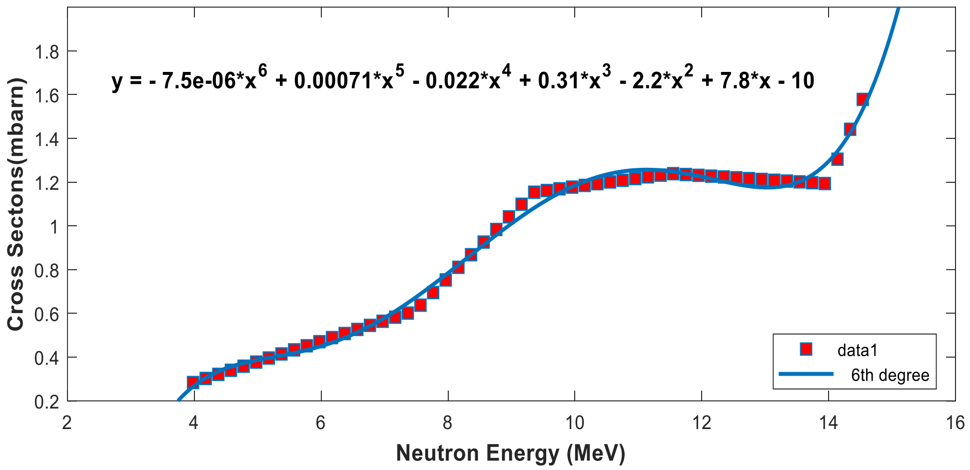

Figure 3. The cross sections as a function of neutron energy for ^{253}Fm (3n,α) ^{252}Cf reaction.

4. Conclusion

It was found from this study that the values of probability increase with the increase of neutron until it reaches a constant stage and for the energy range that ranges between 9.3581-14.3388 MeV. In other words, the probability of obtaining a CF isotope is higher with an increase in the energy of neutrons, as CF is used for diagnosis and treatment.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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Ethical Clearance

The local ethical committee at the University of Baghdad approved the project.

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