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Measurement of the Average Cross-Section Values for Neutron Reaction with the Elements (Mg , Al, Fe, Ni, Zn , Cu) from the Neutron Source ^{241}Am/Be.

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Abstract

The average cross- section for fast neutron reactions with the elements (Mg , Al, Fe, Ni, Zn , Cu) in ^{65}Cu(n, p)^{65}Ni, ^{64}Zn(n, p)^{64}Cu, ^{58}Ni(n, p)^{58}Co, ^{56}Fe(n, p)^{56}Mn, ^{57}Al(n, p)^{57}Mg and ^{24}Mg(n, p)^{24}Na reactions has been calculated by using the numerical – graphical method for ^{241}Am/Be neutron source according to the intensity distribution of the source as a function of neutron energy. The corresponding neutron cross-section values at certain energies are taken from neutron cross-sections curves.

Furthermore, the average neutron cross-sections for each of these reactions have been measured using the activation method. A $(5'' \times 5'')$ well-type NaI(Tℓ) detector was used for measuring the radiation activity.

The cross-sections for these reaction were measured by using of ^{27}Al(n, p)^{27}Mg reaction as a reference for short-lived activity arising in the different reactions. For long - lived activities the ^{27}Al(n, α)^{24}Na, and ^{56}Fe (n, p)^{56}Mn are used. It is found that the cross – section for the ^{65}Cu isotope is σ =826.29±62 mb while the standard value is σ =962±60 mb for the same.We have found the relative neutron activation method is more accurate than the absolute neutron activation method to stabilize the value of neutron flux through the use of the monitor reaction.

Keywords: Neutron source, neutron activation , cross-section .

1. Introduction

It is known that the Neutron Activation Analysis technique (NAA) has a great importance in nuclear physics because it is widely used in different scientific applications.

The scientific basis for the analyzing technique by Neutron Activation Analysis (NAA) is based on the concept of making reactions inside the nuclei of radioactive elements by bombardment these with flux of neutrons which can be taken from the available neutron sources so as to make these nuclei activated isotopes which it can these decay according to the half-life for each one by gamma radiation. Analyzing the spectrum of gamma radiation is made by measuring the radioactivity for these isotopes by using the nuclear detectors for gamma ray like high purity germanium

detector (HPGe) which has the ability of high resolving power or by using scintillation detector like NaI(Tℓl) with high efficiency in measuring [1].

The studying of cross-section of fast neutron reaction with the elements is done for its applications in the fields of reactors, academic studies designing breast plate protectors, and producing radioactive isotopes [2].

2. Theoretical Part:

This study used the neutron activation method for measuring the cross section of neutron interaction with elements.

When irradiating a sample that contains stable isotope (A) for time (t_{irr}) and the stable isotope will be radioactive isotope with activity (A_1) thus this falls down into (A_2) after that it falls during delay time (t_d) , then it falls during measuring into (A_3) as follows in the diagrams [3,4]:

$$A(Isotope) \xrightarrow{t_{irr}} A_1 \xrightarrow{t_d} A_2 \xrightarrow{t_c} A_3$$

Where (t_c) is a counting time where as the part which can be measured of radial activation can be represented as :

$$A' = A_2 - A_3$$

(A_1) is related to radiating time of the following relation:

$$A_1 = A_O(1 - e^{-\lambda t_{irr}}) \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where is A_o in the equation represents the number of radio active nuclei.

(A_2) is take the form :

$$A_2 = A_O(1 - e^{-\lambda t_{irr}})e^{-\lambda t_d} \quad \ldots\ldots\ldots\ldots \quad (2)$$

and (A_3) has the form :

$$A_3 = A_O(1 - e^{-\lambda t_{irr}})e^{-\lambda t_d}\, e^{-\lambda t_c} \quad \ldots\ldots\ldots \quad (3)$$

so (A') becomes :

$$A' = A_O(1 - e^{-\lambda t_{irr\ t}})e^{-\lambda t_d}\ (1 - e^{-\lambda t_c}) \quad \ldots\ldots\ldots \quad (4)$$

Equation (4) represents the analysis by neutron activation .

In considering group of affecting factors represented by neutron flux , cross sections relative of the isotopes and the intensity of the radiation sent from the sample and the adequacy of the used detector in measuring .

We can write equation (4) as follows [1,5,6]:

$$A = (WN_{av}K / \lambda A_w)\sigma\,\xi\, I\gamma\phi_n(1 - e^{-\lambda t_{irr}})(1 - e^{-\lambda t_c})e^{-\lambda t_d} \ldots\ldots\ldots (5)$$

Where:

(A) is the radioactivity measured during the counting time (t_c) through is the net area under the photo peak of gamma radiation .

$N=N_{av}$ wK/A_w is nuclei number of the target atoms.

N_{av} is Avogadro number (atom , mole)= 6.023×10^{23} for each gram of the material.

(w) is mass of the sample in (g).

(A_w) is the atomic weight of the sample in (g/mole).

(K) is the isotope abundance in nature by percentage (%).

(λ) is the decay constant $\lambda = 0.693/T_{1/2}$

$T_{1/2}$ is the half life of the produced nucleus [in seconds (s)].

(σ) is the cross section of interaction in (barn).

(ϕ_n) is the neutron flux ($n.cm^{-2}.s^{-1}$).

(ξ) is the efficiency of the used detector in the measuring [percentage (%)].

(I_γ) is the percentage of gamma radiation submitted from radioactive nucleus (%).

(t_d) is the time delay between the end of irradiation and the beginning of measurement

When the irradiating time is quite long in comparison with the half life of the nucleus produced from interaction then:

$$t_{irr} \rightarrow \infty \ and \quad e^{-\lambda t_{irr}} \cong 0 \quad with \quad (1-e^{-\lambda t_{irr}}) \cong 1$$

The radioactivity reaches the saturation value when the average radioactivity produced equals the average of decay and this happens when (t_{irr}> 6 $T_{1/2}$) and the last equation becomes [2] :

$$A = \left(\frac{N\sigma\xi I_\gamma \phi_n}{\lambda} \right)(1-e^{-\lambda t_c})e^{-\lambda t_d} \quad \ldots\ldots\ldots \quad (6)$$

The equation can be written as :

$$A = \alpha\beta\phi_n\sigma \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

where $\left\{ \begin{array}{l} \alpha = \left(\frac{N\xi I_\gamma}{\lambda} \right), \\ \beta = (1-e^{-\lambda t_c})e^{-\lambda t_d} \end{array} \right\}$

If the process of irradiating the sample is achieved through irradiate the sample and standard together, the neutron flux of the sample keeps stability and measuring of cross section can be done using the formula

$$\sigma_u = \frac{A_u \alpha_r \beta_r}{A_r \alpha_u \beta_u}\sigma_r \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

where the suffixes

r and u denote the standard and measured values respectively.

3. Average Cross – section Calculation:

We have calculated the average cross – section of the elements in this paper because the neutron source ^{241}Am/Be has uniform intensity and multi- energies. The cross-section values are taken from the curves which describe the relation between the cross-section ( ) and neutron energy (E_n) [7].

The average cross-section for any reaction in continuous neutron spectra is defined by the following relation [8]:

$$\sigma_{av} = \frac{\int_0^{E\max} \sigma(E)N(E)dE}{\int_0^{E\max} N(E)dE} \quad \text{..... (9)}$$

Where:-

$\sigma(E)$ is the cross-section of reaction as a function of energy and $N(E)$ is the energy distribution of neutrons.

Equation (9) can be approximated to the following formula for discrete values of energy [8]:

$$\sigma_{av} = \frac{\sum_{j=1}^{n} \sigma_j N_j}{\sum_{j=1}^{n} N_j} \quad \text{..... (10)}$$

Where:-

σ_j is the cross-section at a given neutron energy and N_j is the relative intensity of neutron at the same energy.

Moreover, the relative intensity of neutrons is taken from energy spectra of the radioisotope neutron source ^{241}Am/Be as shown in figures (7) and (8).

4. Preparation of Samples:

Samples of the elements (Cu, Zn, Ni, Fe, Al, Mg) have been taken in the form of foils and powder. The powder samples were compressed in the form of pellets. Diameter (2-3 cm). Were put inside smooth nylon bags for irradiating to avoid polluting the samples and losing part of their weight before and after irradiating.

The following is an explanation of radioisotope samples irradiated by using the radio isotope neutron source (^{241}Am/Be).

The samples as foils and thicknesses (0.5-1 mm) to isotopes their irradiated from the radioisotope as shown in Table (1).

5. Results and Discussion:

In this research, the technique of neutron activation is used for its accuracy in measuring cross- section. Whereas the vibration in neutron flux was dealt with by using Monitor Reaction and the use of Mixture Powder Method to guarantee irradiating both the studied sample and the standard sample under same conditions.

The reaction $^{27}Al(n, p)^{27}Mg$ is used as standard reaction in finding the cross-sections through interactions having results of short half –lifes And for long half life, the reactions $^{27}Al\ (n, \alpha)^{24}Na$ was used as standard reaction, We list the elements studied as follows.

5.1.Aluminum

The reason of the importance of this element is its high purity (99.99%) and its possession of neutron interactions with long and short half-lives and the possession of not overlapped gamma line.

So it is possible to depend on in nuclear research like the calculation of neutron flux and as parallel and standard element for calculating a lot of cross – section.

Aluminum is used in this study as a parallel and standard element for the reasons mentioned

As Fig (1) illustrates the photo peak of gamma radiation for the reaction $^{27}Al\ (n, p)^{27}Mg$ (E_γ = 843.8 keV, 1014.4 keV) and the reaction $^{27}Al\ (n, \alpha)^{24}Na$ (E_γ = 1368.6 keV, 2754 keV)

The average of cross- section value of reaction $^{27}Al\ (n,p)\ ^{24}Mg$ was (20± 4) mb and this value is in agreement with the value reported by (Rieppo) [8].

The average of cross section value for the interaction $^{27}Al\ (n,\alpha)\ ^{24}Mg$ which is calculated as a rate for interaction $^{27}Al\ (n,p)\ ^{24}Mg$ with a flow (100%) and gamma line (843.8 keV) with intensity (72%) and half life (9.45 min) and the 286rradiation in time (24 h) calculated with NaI(Tℓl) a flow delay time (55 s) was σ_{av} = (5.21 ± 1.4) mb.

5.2. Magnesium

The average value of cross – section for the interaction $^{24}Mg\ (n,p)\ ^{24}Na$ with flux (78.99%) gamma line (1368.6 keV) and with high intensity(100%) and half life (15.02 h) which is measured as a rate for interaction $^{27}Al\ (n, \alpha)^{24}Na$ ($E\gamma$ = 1363.6 keV) and the result was (26.29 ± 3.41 mb) and which is measured value in this study as shown in Table (3).the values of are $^{24}Mg\ (n, p)^{24}Na$ comparison with ref [1] and we get a good agreement and matching .

Fig. (2) the spectrum of gamma radiation for the interaction $^{24}Mg\ (n, p)^{24}Na$ which is produced by irradiating (MgO) during the irradiation time (6.78 d) and measured by detector NaI(Tℓ) after delay time (75 s) .

5.3. Iron

The average value of cross section for the interaction $^{56}Fe\ (n, p)^{56}Mn$ with a flow (91.7%) and gamma line (846.6 keV) with intensity (99%) and half life (2.582 h) as a rate of interaction(843.8 keV) $^{27}Al\ (n, p)^{27}Mg$ which is measured by the detector NaI(Tℓ) after irradiating time (5.01 d) and delay time (60 sec) was (10.3 ± 2.29) mb) and which is the calculated value in this study and the mentioned value (46) as in

Table (3) the values of are ^{56}Fe (n, p)^{56}Mn comparison with ref [1] and we get a good agreement and matching .

Fig.(3) the spectrum of gamma line produced from irradiating (Fe_2O_3) as we notice the photo peaks of gamma radiation for the interaction above is (E_γ = 846.6 keV, 1811.2 keV, 2112.6 keV).

5.4. Nickel

The average value of cross section for the interaction ^{58}Ni (n, p)^{58}Co with a flow (67.88%) and gamma line (810.6 keV) with intensity (99.4%) as a rate of interaction $^{27}Al(n, \alpha)^{24}Na$ (E_γ = 1368.6 keV) and the result was (112.74 ± 2.64) mb and which is the calculated value in this study as shown in Table(3), the values of are ^{58}Ni (n, p)^{58}Cocomparison with ref [1] and we get a good agreement and matching.

Fig. (4) the spectrum of gamma radiation for the interaction of ($NiCl_2$) time (3.953 d) and the photo peaks of gamma radiation for the interaction above are (Eγ = 810.6 keV, 1636 keV).

5.5. Zinc

The average value of cross – section for the interaction $^{64}Zn(n, p)^{64}Cu$ with a flow (48.9%) and gamma line (511 keV) of intensity (37%) and half life (12.74 h) was calculated as a rate of interaction $^{27}Al(n, \alpha)^{24}Na$ and the result was (43.7 ± 4.54) mb and which is measured value in this study as shown in Table (3).

Fig. (5) the spectrum of gamma line produced from irradiating zinc power (Zn) for (22 h). (NaI(Tℓ) detector was used to measure the activity for zinc radioisotope (^{64}Zn) after delaying time (50 s). The photo peaks E_γ = 511 keV belong to reaction $^{64}Zn(n, p)^{64}Cu$ and the energy is E_γ = 1039 keV for reaction $^{66}Zn(n, p)^{66}Cu$ energy is E_γ = 366.5 keV for the reaction $^{68}Zn(n, \alpha)^{65}Ni$.

5.6. Copper

The average value of cross section for the interaction of $^{65}Cu(n, p)^{65}Ni$ with a flow (30.9%) and gamma line (1481.7 keV) of intensity (25.4%) and half life (2.520 h) was calculated as a rate of interaction (1368.6 keV) $^{27}Al(n, \alpha)^{24}Na$ and the result was (5.59 ± 1.17) mb and result was close to the calculated value in this study as shown in Table (3).

Fig. (6) the spectrum of gamma line produced from irradiating thin plate of copper in for (4 d) where the radio activity was measured by the detector NaI(Tℓ) after decay time (120 s), and photo peaks of gamma line calculated were (E_γ = 511 keV) that belongs to interaction $^{65}Cu(n, 2n)^{64}Cu$ whereas the energies (E_γ = 1115.5 keV, 1481.7 keV) belong to interaction $^{65}Cu(n, p)^{65}Ni$.

6. Conclusions:

1- (Numerical – Graphical) technique was used and it is found that the obtained results are measured by neutron activation technique.

2- The measured values in this study are measured values reported by other studies [8].

3- The analyzing technique by relative neutron activation is more accurate than the technique of analyzing by using the absolute neutron activation because of the stability value of neutron flow through using (Monitor Reaction)

4- (Numerical – Graphical) technique is good method for identifying the average of cross – section practically.

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قياس متوسط قيم المقاطع العرضية لتفاعل النيوترون مع العناصر (Mg، Al، Fe، Ni، Zn، Cu) من المصدر النيوتروني $^{241}Am/Be$

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الخلاصة

تم حساب قيم متوسط المقاطع العرضية لتفاعل النيوترونات السريعة مع العناصر (Cu, Zn, Ni, Fe, Al, Mg) في التفاعلات $^{65}Cu(n, p)^{65}Ni$ ، $^{64}Zn(n, p)^{64}Cu$ ، $^{58}Ni(n, p)^{58}Co$ ، $^{56}Fe(n, p)^{56}Mn$ ، $^{27}Al(n, p)^{27}Mg$ ، $^{24}Mg(n, p)^{24}Na$ باستخدام الطريقة العددية التخطيطية لطيف المصدر النيوتروني $^{241}Am/Be$ طبقاً إلى توزيع الشدة للمصدر كونها دالة لطاقة النيوترون وكذلك على قيم المقاطع العرضية المناظرة لتلك الطاقة المأخوذة من منحنيات المقاطع العرضية.

تم قياس متوسط المقاطع العرضية لتلك التفاعلات باستخدام طريقة التنشيط النيوتروني. واستخدم كاشف أيوديد الصوديوم البئري ($5" \times 5"$) لقياس النشاط الشعاعي.

تم قياس المقطع العرضي للتفاعلات الآنفة الذكر نسبة إلى التفاعل $^{27}Al(n, p)^{27}Mg$ للنواتج ذات عمر النصف القصير ونسبة للتفاعلين $^{27}Al(n, \alpha)^{24}Na$، $^{56}Fe(n, p)^{56}Mn$ للنواتج ذات عمر النصف الأطول. فعلى سبيل المثال تم اخذ نظير النحاس (^{65}Cu) ووجد أن المقطع العرضي $\sigma = (826.29 \pm 62)mb$ مقارنة مع المقطع العرضي القياسي للنحاس (^{65}Cu) $\sigma = (926 \pm 60)mb$. وقد وجدنا ان طريقة التحليل بالتنشيط النيوتروني النسبية هي أكثر دقة من طريقة التحليل بالتنشيط النيوتروني المطلقة وذلك لثبات قيمة الفيض النيوتروني خلال استخدام تفاعل مرقاب.

الكلمات المفتاحية : *المصدر النيوتروني ، التنشيط النيوتروني ، المقطع العرضي.*

Appendices

Table(1): Data of studying for compound material for the neutron source.

Chemical Compound	Compound Weight (gm)	Compound Purity (%)	Weight of Investigated Element (gm)
Mgo	1.0268	99.80	0.61919
Fe_2O_3	5.0	98.0	3.4784
$NiCl_2$	1.7111	99.98	0.7751

Table(2) Data of studying for average cross-sections values measured by (Numerical - Graphical)method according to the spectra of the neutron source^{241}Am/Be

Reaction	This Work			Ref [8]			
	σ_{av1}[9] (mb)	σ_{av2}[10] (mb)	$\sigma_{av}^{mean}{}_1$ (mb)	σ_{av3}[9] (mb)	σ_{av5}[10] (mb)	σ_{av4}[11] (mb)	$\sigma_{av}^{mean}{}_2$ (mb)
^{24}Mg (n, p)^{24}Na	26.96	27.23	27.09	-	-	-	-
^{27}Al (n, p)^{27}Mg	30.58	31.85	31.21	35	25	28	29.33
^{56}Fe (n, p)^{56}Mn	14.10	15.82	14.96	11	8.9	9.0	9.63
^{58}Ni (n, p)^{58}Co	159.56	163.29	161.42	-	-	-	-
^{64}Zn (n, p)^{64}Cu	39.76	41.26	40.50	-	-	-	-
^{65}Cu (n, p)^{65}Ni	4.11	4.38	4.24	-	-	-	-

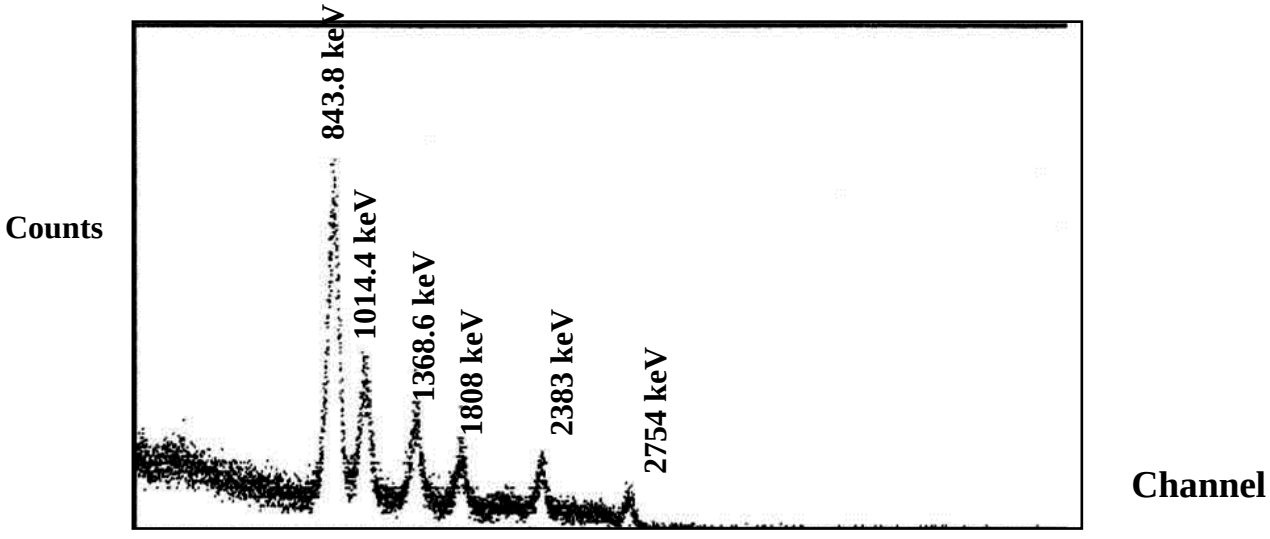


Fig (1) Spectrum of gamma ray for two reactions $^{27}Al(n,\alpha)^{24}Na$, $^{27}Al(n,P)^{27}Mg$ after collection time (15 minutes).

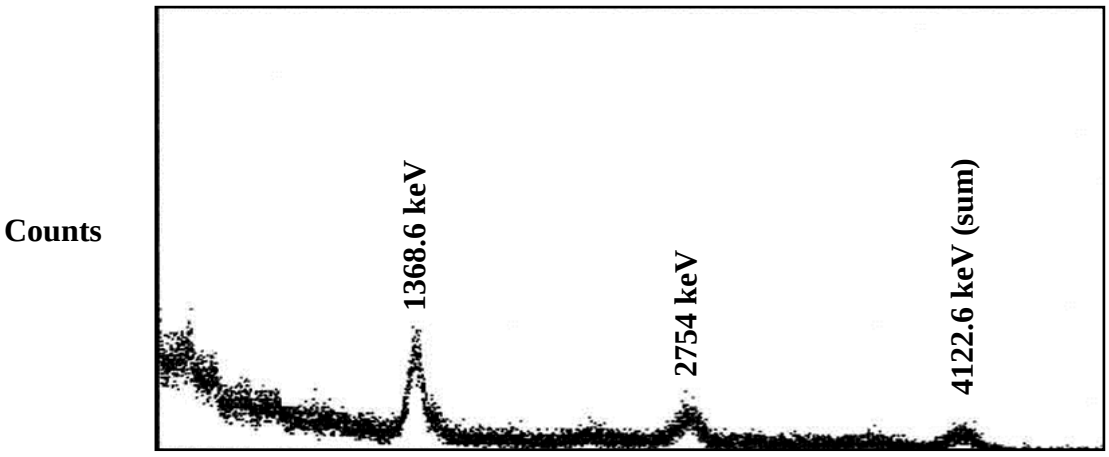


Fig (2) Spectrum of gamma ray for reaction $^{24}Mg\ (n,p)^{24}Na$ after collection time (60 minutes).

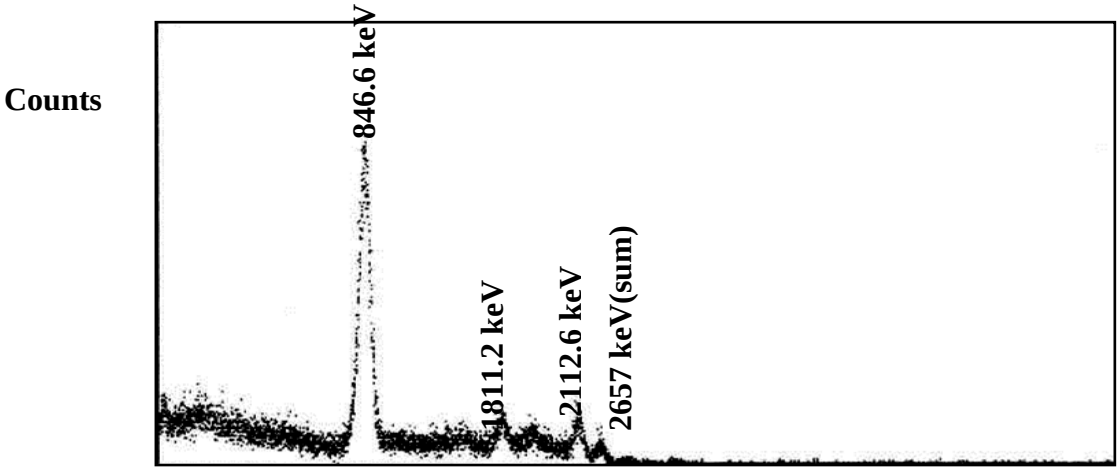
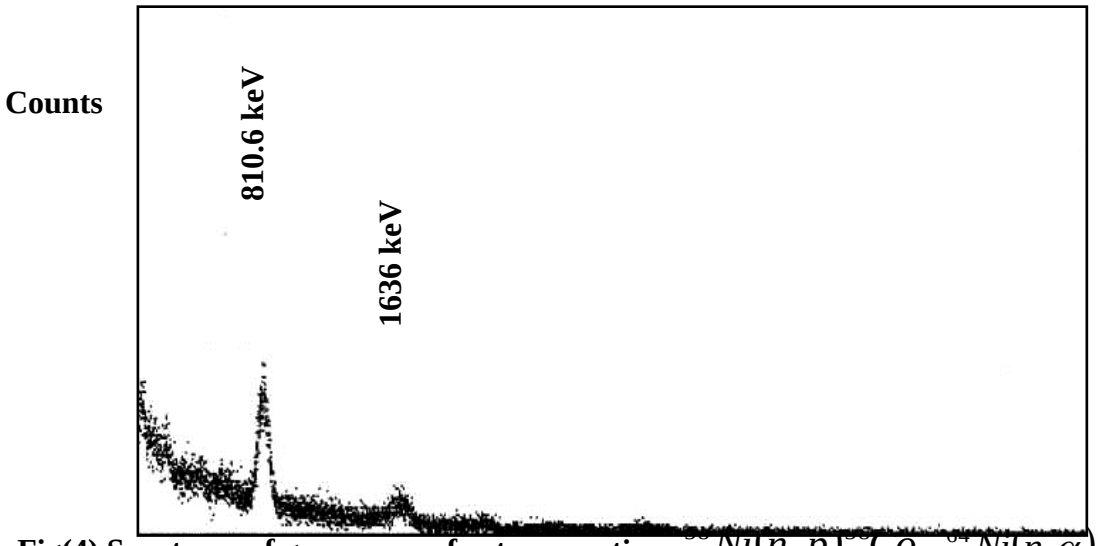


Fig (3) Spectrum of gamma ray for reaction $^{56}Fe\ (n,p)^{56}Mn$after collection time (16 minutes).



Fig(4) Spectrum of gamma ray for two reactions $^{58}Ni(n,p)^{58}Co$, $^{64}Ni(n,\alpha)^{61}Fe$ after collection time (60 minutes).

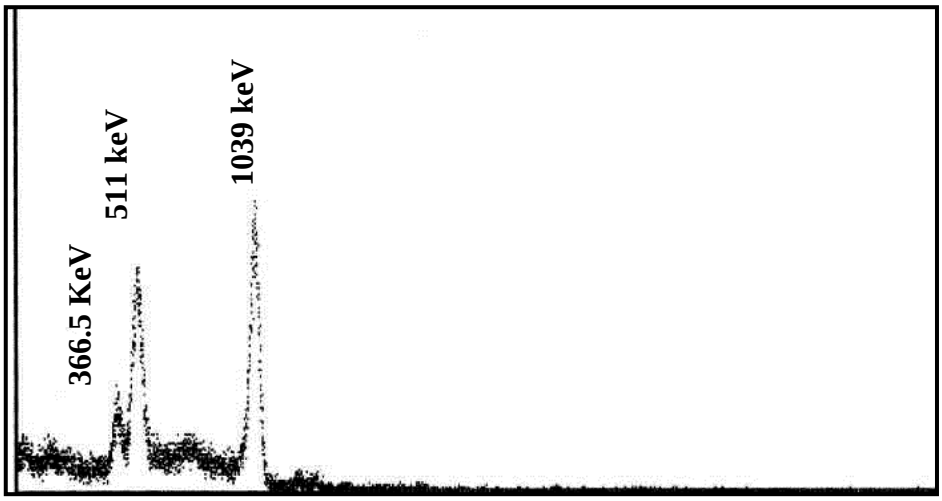


Fig (5) Spectrum of gamma ray for reactions $^{68}Zn(n,\alpha)^{65}Ni$, $^{64}Zn(n,p)^{64}Cu$ ، $^{66}Zn(n,p)^{66}Cu$ **after collection time (10 minutes).**

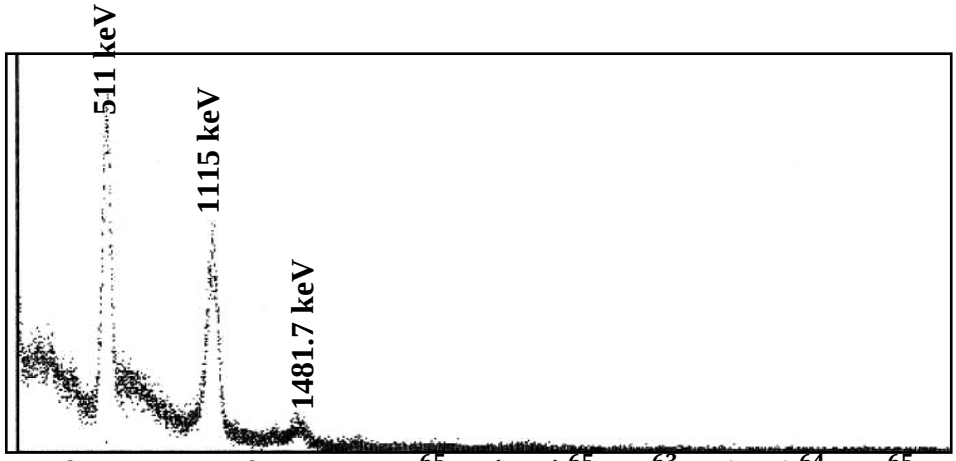


Fig (6) Spectrum of gamma ray for reactions $^{65}Cu(n,p)^{65}Ni$, $^{63}Cu(n,\gamma)^{64}Cu$, $^{65}Cu\ (n,\gamma)^{66}Cu$**after collection time (60 minutes).**

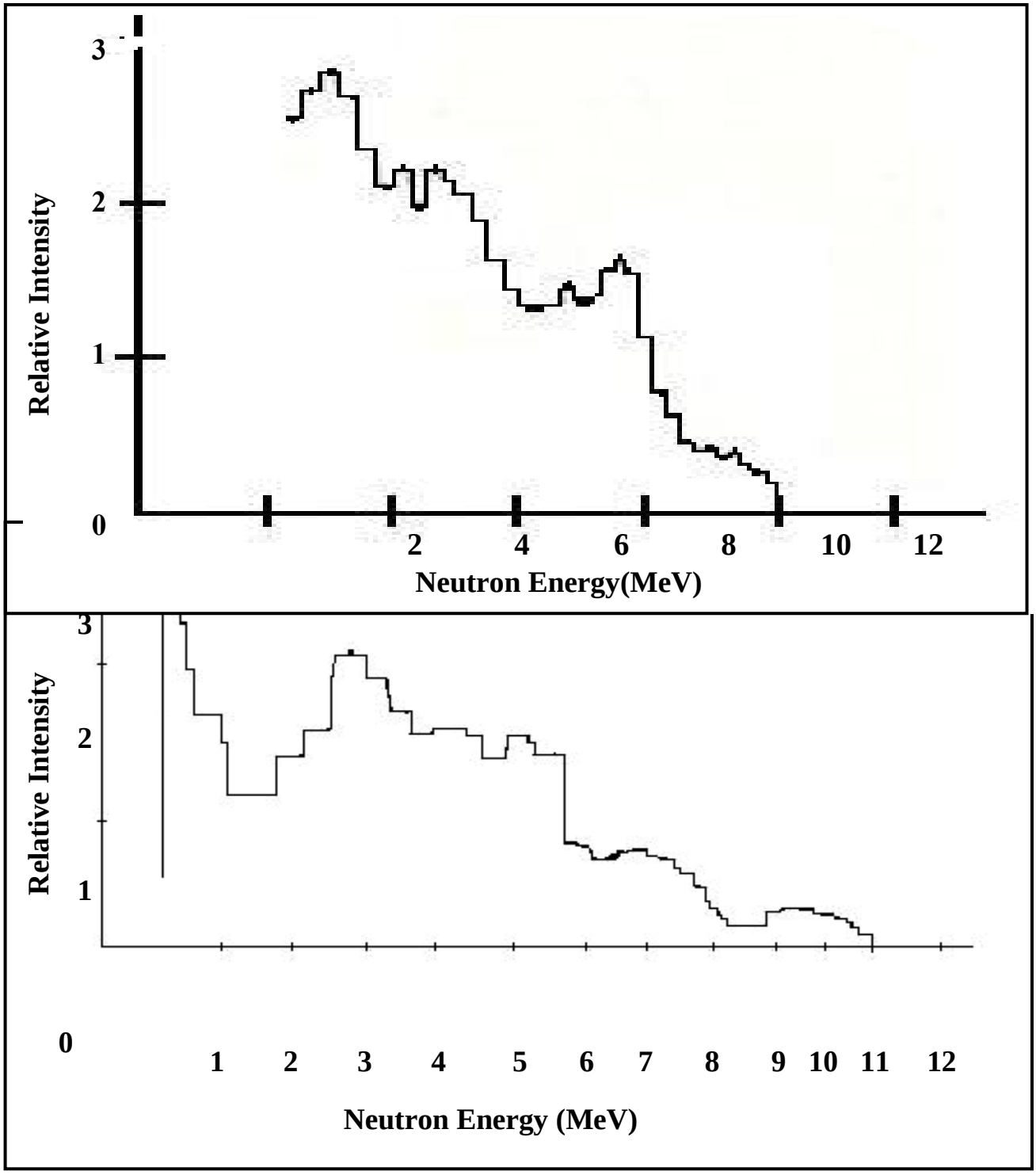


Fig.(8): The spectrum of the neutron source $^{241}Am/Be$ [10]