Measurement of Cross-Sections of (n, γ) Nuclear Reactions Induced by Thermal Neutrons for Sodium, Copper, Arsenic and Potassium

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Abstract

The cross- sections of nuclear reactions $^{23}Na(n, \gamma)^{24}Na$, $^{63}Cu(n, \gamma)^{64}Cu$, $^{75}As(n, \gamma)^{76}As$ and $^{41}K(n, \gamma)^{42}K$ (Sodium, Copper, Arsenic and Potassium) were measured at thermal neutrons energy 0.025 eV from Cf-252 source. Thermal neutron activation data is important in the development of thermal nuclear reactor. The cross-section data of nuclear reactions induced by different energy neutrons is necessary for several applications in applied nuclear physics such as nuclear models, elemental analysis, advance reactor technology etc. The experimental measured values of cross-sections of the nuclear reactions: $^{23}Na(n, \gamma)^{24}$ Na, $^{63}Cu(n, \gamma)^{64}Cu$, $^{75}As(n, \gamma)^{76}As$, $^{41}K(n, \gamma)^{42}K$ at thermal neutron energy are 0.51b, 4.31b, 4.3b and 2.15b respectively. The accuracy in the measurement of cross-sections is estimated to be about 5 %. The experimental values of cross-sections were measured using the reference nuclear reaction ^{55}Mn (n, γ) ^{56}Mn with the standard value of cross-section 13.3b (Eγ = 0.84 mev, half life = 12.58 h).

Keywords: Thermal neutrons; Neutron flux; Neutron cross-sections; Gamma ray detector; 8 K MCA.

Introduction

During the last few decades considerable work has been carried out in the field of measurement and analysis of cross-sections of nuclear reactions induced by thermal neutrons having energy 0.025 eV. This work includes measurement made to generate new data as well as re-measurement to improve accuracies in the reported values. However, in several cases, values of cross-sections for the nuclear reactions reported by several authors do not match with each other and such a large range exists in the literature values [1, 2]. Looking at the importance of the cross-section data in the field of applied nuclear physics, such as thermal nuclear reactor technology, elemental analysis etc. we have measured the (n, γ) cross-section values at thermal neutron energy 0.025 eV for the Sodium, Copper, Arsenic and Potassium.

The sodium is used as a coolant material in fast nuclear reactors. Therefore its neutron nuclear data is important. The neutron nuclear data of sodium has already been studied by various researchers based on experimental as well as theoretical models. The re-measurement of nuclear data of sodium is still essential to update the various parameters in fast reactors. Potassium is a main component of chemical fertilizer in agriculture sector. It is essential to decide the optimum dose of potassium fertilizer for different crops. It is possible by knowing the uptake rate of potassium by different crops. This needs the nuclear data of potassium; therefore cross-section measurement of potassium is necessary. Similarly, Copper plays an important role in gold ornaments. The strength of the ornaments depends on the concentration of copper in gold. The neutron activation technique can be used to estimate the accurate concentration of copper in gold. This needs the accurate value of nuclear cross section for copper for thermal neutrons. Arsenic is one of the air pollutants. It is hazardous to the lungs and may cause lung diseases. The concentration of Arsenic in air can be estimated accurately with neutron activation technique provided its neutron cross-section value is known accurately. With this intention the re-measurement of thermal neutron cross sections for these elements is of prime importance.

Experimental Work

For the present work, thermal neutron source Cf-252 available in the Department of Chemistry, Savitribai Phule Pune University was used. The induced gamma-ray activities of the thermal neutron irradiated samples were measured with the help of 3” x 3” NaI(Tl) scintillation detector based on gamma ray spectroscopy. The gamma-ray spectrometer was coupled to the computer based 8K M.C.A. NaI(Tl) detector was calibrated using standard gamma ray sources. The measured gamma ray spectrum was analyzed using the computer software.

Material and Methods

Sample preparation and neutron irradiation

In the present work, pure chemical compound of sodium (NaCl powder 99 %), Copper powder (99%), Manganese (MnO_2 powder, 99 %), Arsenic powder (99 %), Potassium (K-powder, 99 %) were used. Each sample was made by packing known weight in range of 500 to 600 mg in polyethylene bag. Along with each sample, 500 mg of MnO_2 powder (99 %) was packed in separate polyethylene bag to calculate the thermal neutron flux as standard. Each sample along with MnO_2 powder was irradiated with neutron flux ~ 10^4 - 10^5 n/cm^{2}sec and neutron of energy 0.025 eV from the Cf-252 neutron source available in the Department of Chemistry, Savitribai Phule Pune University for period of 22.8 hours. After irradiation, each sample was brought to the NaI(Tl) gamma ray detector counting head available in the Department of Physics, of Haribhai V. Desai College, Pune. The induced gamma ray activities of Manganese ^{56}Mn (E_γ = 0.84 MeV) Copper ^{64}Cu (E_γ = 0.511 MeV), Arsenic ^{76}As (E_γ= 0.55 MeV), Sodium ^{24}Na (E_γ = 1.38 MeV) and Potassium ^{42}K (E_γ = 1.53 MeV) were counted separately (Figure 1 to 4). For each sample, irradiation time t_1, cooling time t_2 and counting time, t_3 were noted and used in calculations.

Calculations of neutron flux and cross section

From the induced gamma ray activity of ^{56}Mn, Eγ = 0.84 MeV, thermal neutron flux of Cf - 252 source was calculated using the following activation relation [3]:

$$\Phi = A\lambda/(\sigma N \epsilon f_d (1 - e^{(-\lambda t_1)})(e^{(-\lambda t_2)})(1 - e^{(-\lambda t_3)})) \quad \text{--- (1)}$$

Where,

Σ - cross section for (n, γ) reaction

Φ - neutron flux

A - total count under photo peak

λ - decay constant

f_d - number of disintegration/gamma quanta

N - number of target atoms

Є - detector efficiency for gamma ray

t_1 - irradiation time

t_2 - cooling time (time between end of irradiation and start of counting)

t_3 - counting time

The induced gamma ray activities of the reaction products ^{24}Na, ^{42}K, ^{76}As and ^{64}Cu were calculated from the gamma ray spectra of respective radio nuclide. Using these values of gamma ray photon activities and neutron flux the values of the cross sections were estimated using the relation [3].

$$\sigma = A\lambda/(\Phi N \epsilon f_d (1 - e^{(-\lambda t_1)})(e^{(-\lambda t_2)})(1 - e^{(-\lambda t_3)})) \quad \text{--- (2)}$$

where, parameters involved were for respective nuclear reaction. The details of the nuclear data, which includes gamma ray energies, branching ratio of gamma photons (f_d), half life of generated radioisotopes were taken from the literature [4].

Results and Discussions

Table 1 shows the details of nuclear reactions, decay data used, irradiation time, cooling time and counting time.

Table 1. Nuclear reactions parameters used in the present work

Nuclear reaction	**T (h)**	**Gamma energy (MeV)**	**f_d %**	**t_1 (h)**	**t_2 (h)**	**t_3 (h)**
^{63}Cu(n,γ)^{64}Cu	12.8	0.511	100	23.5	0.5	1
^{23}Na(n,γ)^{24} Na	15.02	1.369	100	45	2.3	1
^{75}As(n,γ)^{76} As	26.4	0.559	45	24	0.5	1
^{41}K(n,γ)^{42} K	12.36	1.53		45	0.7	1
Reference reaction ^{55}Mn(n,γ)^{56} Mn	2.58	0.84	100	-	-	-

[f_d - gamma intensity (%), t_1 - irradiation time, t_2 - cooling time, t_3 - counting time, T - half life of reaction product]

Figure 1 shows the gamma ray spectrum of thermal neutrons irradiated MnO_2 sample counted with NaI(Tl) detector coupled to 8 K M.C.A. Figure 2 shows the gamma ray spectrum of thermal neutrons irradiated sodium sample counted with NaI(Tl) detector coupled to 8 K M.C.A. Figure 3 shows the gamma ray spectrum of thermal neutrons irradiated copper sample counted with NaI(Tl) detector coupled to 8 K M.C.A.

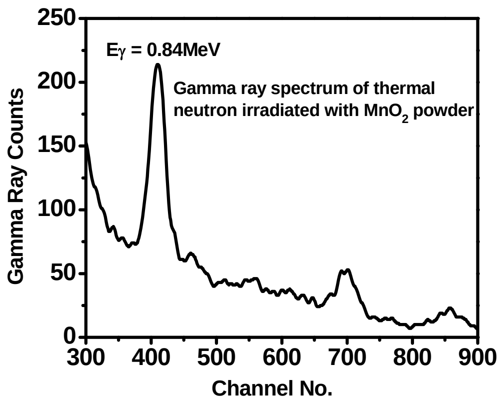

Figure 1. Gamma ray spectrum of thermal neutrons irradiated MnO_2 sample

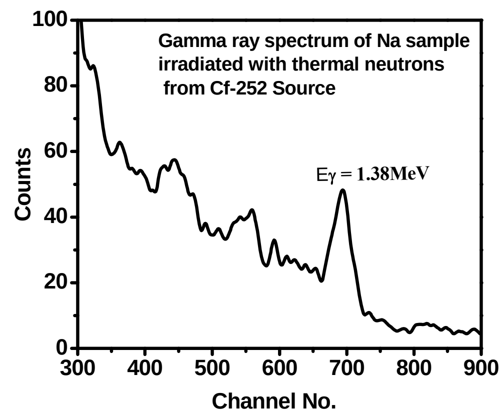

Figure 2. Gamma ray spectrum of Na sample irradiated with thermal neutrons

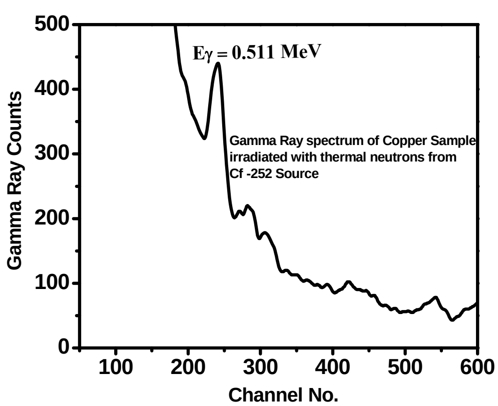

Figure 3. Gamma ray spectrum of copper sample irradiated with thermal neutrons from Cf - 252 source

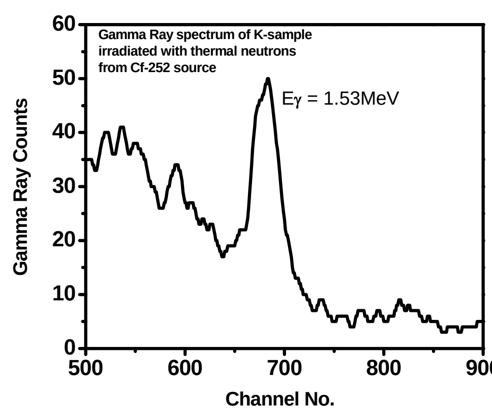

Figure 4. Gamma ray spectrum of potassium sample irradiated with thermal neutrons from Cf-252 source

Figure 4 shows the gamma ray spectrum of thermal neutrons irradiated potassium sample counted with NaI(Tl) detector coupled to 8 K M.C.A. The experimental cross sections for the formation of ^{24}Na, ^{64}Cu, ^{76}As and ^{42}K at thermal neutrons energies are 0.51 b, 4.31 b, 4.3 b and 2.15 b respectively. The experimental values of cross sections in the present work are in good agreement with literature values reported earlier [1, 2, 5, 6].

Conclusions

Figures 2, 3 and 4 indicate that thermal neutrons produce the sufficient measurable gamma ray activities in ^{24}Na, ^{64}Cu, ^{76}As and ^{42}K in samples. Therefore, the thermal neutron activation technique can be used effectively for the analysis of these elements in any sample. The experimentally measured cross sections for the formation of ^{24}Na, ^{64}Cu, ^{76}As and ^{42}K at thermal neutrons energies formed through the nuclear reactions ^{23}Na(n,γ)^{24}Na, ^{63}Cu(n,γ)^{64}Cu, ^{75}As(n,γ)^{76}As, ^{41}K(n,γ)^{42}K are respectively 0.51 barn, 4.31 barn, 4.3 barn and 2.15 barn. These experimental measured values of cross sections in the present work are in good agreement with literature values reported earlier [1, 2, 5, 6]. These cross section values can be used for the estimation of concentration of arsenic in air as a pollutant, concentration of potassium in fertilizers for the uptake rate in plants, concentration of copper in gold or any steel alloy and the data of sodium can be used in the reactor technology, which is used as a coolant material in reactor.

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