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Neutron activation cross section for $^{56}Fe(n,p)$ and $^{87}Rb(n,2n)$ reactions

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and Igor Ribansky

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Neutron activation cross section for $^{56}Fe(n,p)$ and $^{87}Rb(n,2n)$ reactions

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1. Introduction

The Department of Physics of the Institute of Physics in Hanoi is entering the Coordinated Research Programme "Measurement and analysis of 14 MeV neutron nuclear data needed for fission and fusion reactor technology" sponsored by IAEA, Vienna. During the preparation phase for measurements of 14 MeV neutron activation cross sections for Cr isotopes within this Programme we decided to measure $^{56}Fe(n,p)$ and $^{87}Rb(n,2n)$ cross sections both relative to $Al(n,\alpha)$ reaction. The first reaction was chosen in order to check the method used and to determine its overall accuracy (reproducibility). The second reaction for which several mutually inconsistent data were reported [1] was measured with the hope that our result could improve the existing situation.

2. Experimental procedure

The targets for $^{56}Fe(n,p)$ experiment were prepared by mixing pure Fe and Al oxyde powders. The mixture was pressed to form ø 20 mm samples (the adopted standard sample size for future experiments). Four irradiations (duration ~1 h) were carried out with fresh targets. The rubidium target was prepared by pressing Rb powder (enriched to 98 %) between two Al foils. Due to insufficient amount of the enriched material and the long half-life of the reaction product ground state (18.7 d)

only one (~6 h) irradiation was performed. Four γ-ray spectra were measured during next 6 days.

A 120 kV DT-neutron generator was used for target irradiation at the closest possible distance from the neutron source. The neutron energy was (14.8 ± 0.2) MeV [2]. The neutron flux was monitored using plastic scintilator. The flux turned out to be fairly constant even for the longest irradiation.

The activated samples were counted with Ge(Li) detector at close geometry (i.e. at the detector cover). The relative photopeak efficiency of the detector for this geometry was determined using ^{226}Ra source. Due to its complex decay scheme and the fact that Ge(Li) detector was not absolutely calibrated the coincidence summing corrections [3] could not be applied. Hence the slope of the measured relative efficiency curve in the region 800 - 1100 keV (relevant for our experiment) was not accurately determined. The error involved was estimated to be ~5 %. The coincidence summing for reaction products were negligible small due to their simple decay schemes.

3. Results and discussion

The cross sections were calculated according to expression which assumes the existence of an isomeric state of the reaction product [4]

$$\sigma_g = \sigma_m \frac{\lambda_m I_T}{\lambda_g - \lambda_m} + \frac{e^{\lambda_g (T_i + T_c)}}{[1 - e^{-\lambda_g T_M}] \int_0^{T_i} e^{\lambda_g t} \phi(t) dt} \left\{ k \frac{P_\gamma A}{\varepsilon_\gamma I_\gamma \eta G} - \right.$$

$$\left. - \frac{\sigma_m \lambda_g I_T}{\lambda_g - \lambda_m} e^{-\lambda_m (T_i + T_c)} [1 - e^{-\lambda_m T_M}] \int_0^{T_i} e^{\lambda_m t} \phi(t) dt \right\} \qquad (1)$$

where k is the normalization factor determined by the reference reaction. In our case

$$k = \sigma_r \frac{\varepsilon_{\gamma,r} I_{\gamma,r} \eta_r G_r}{P_{\gamma,r} A_r} \times \frac{[1 - e^{-\lambda_r T_{M,r}}] \int_0^{T_{i,r}} e^{\lambda_r t} \phi(t) dt}{e^{\lambda_r (T_{i,r} + T_{c,r})}} \quad . \qquad (2)$$

In the above equations the indeces g,m,r refer to the ground and the isomeric states of the reaction product and the reference reaction; σ is the cross section, λ is the decay constant, I_T is the fraction of isomeric transitions; T_i, T_c, T_M are irradiation, cooling and measuring times; P_γ, ε_γ, I_γ are the photopeak area, photo-efficiency and absolute intensity of the measured transition; A, η, G are the atomic weight, isotopic abundance and weight of the sample and finally ϕ is the relative neutron flux measured by the neutron monitor. We note that eq. (1) reduces to the simple case (no isomeric state) by putting $\sigma_m = 0$.

The decay data of the reaction products were taken from [5]. The value of the reference reaction cross section was assumed to be 115.5 mb [6] and its uncertainty $\lesssim 1$ % [7].

3.1 ^{56}Fe(n,p) reaction

From the four measurements of ^{56}Fe(n,p) reaction we have calculated the weighted average value of the cross section and its standard deviation - the weights were given by the statistical errors of photopeak areas. We have obtained σ_{np} = = (118.7 ± 10.3) mb. The error quoted represents the reproducibility which characterizes the precission one can achieve with the method used. To this error one has to add other errors (quadratically) comming from the photo-efficiency (~5 %) and reference reaction cross section. Remaining errors we believe, were negligible. Thus the final result for our ^{56}Fe(n,p) activation cross section is (118.7 ± 12) mb which is in very good agreement with the recommended value (114 ± 10) mb [1].

3.2 ^{87}Rb(n,2n) reaction

Due to a relatively short half life of ^{86m}Rb (1.02 m) we were not able to measure the isomeric cross section under present experimental conditions (we could not utilize our own γ-spectroscopy system due to wrong multichannel analyzer). What we have measured in fact was the total cross section $\sigma_{tot} = \sigma_g + \sigma_m$. This possibility follows from eq. (1) noting that $\lambda_g \ll \lambda_m$, $I_T=1$ and the second term in curly brackets is close to zero under our experimental conditions. The total cross section was determined as a weighted mean from the four γ-ray spectra measurements. The statistical uncertainty of this number was 3 %. Because only one irradiation was performed we have to add to this error the reproducibility which we assume to be the same as in the ^{56}Fe(n,p) experiment and errors due to the detection efficiency and reference reaction. Then the final result for the total activation cross section of ^{87}Rb(n,2n) reaction is $\sigma_{tot} = (1226 \pm 128)$ mb which is again in good agreement with the recommended value 1300 mb [1].

We would like to express our deep gratitude to Prof. Nguyen Van Hieu for his strong support and permanent interest in this work. The kind offer of the National Institute of Nuclear Research for Vietnam, to use their γ-spectroscopy system for counting our samples is highly appreciated.

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