DETERMINING THE ISOMERIC RATIO OF NUCLEAR REACTION $^{46}T_i(\gamma, pn)^{44}Sc$ BY EXPERIMENT

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Abstract. The bremsstrahlung beam with energy end point of $65MeV$ created when the e^- beam with energy of $65MeV$ irradiated to thin wolfram target was used to irradiate to $\mathrm{TiO_2}$ sample in order to make the $^{46}T_i(\gamma, \mathrm{p}n)^{44m,\mathrm{g}}Sc$ reaction. The gamma spectrum of $\mathrm{Sc}^{44m,g}$ was analyzed by the gammavision spectrometry with HPGe detector at linear accelerator laboratory in POSTECH, Korea. As the result, the isomeric ratio Υ_m/Υ_g of the reaction is presented.

1. Introduction

The isomeric ratio data of nuclear take an important role in nuclear structure research and nuclear reaction mechanism, that why, there are many laboratories in the world studying these. In our experiment, the beam of bremsstrahlung radiations is created when e^- current with energy of $65MeV$ irradiating to thin wolfram - target, then the bremsstrahlung beam irradiating to $\mathrm{TiO_2}$ sample of 99.99% pure degree. After 2 hours of irradiation, the sample disintegrates in a period of time depending on the sample radioactivity. The sample is measured by the geometric arrangement fixed for minimizing the error.

The ^{44}Sc is created by reaction as follows

$$\gamma \quad + \quad {}^{46}\mathrm{T}i \rightarrow \quad {}^{44}\mathrm{S}c + n + p.$$

After being produced, $^{44}\mathrm{S}c$ nuclei is in excited states. However, the life-time of these states is very short($< 10^{-10}sec$). Then the nuclei jump into the lower energy states, and at the end, they jump to the isomeric state or ground state. On the other hand, $^{44}\mathrm{S}c$ is a radioactive nuclear. It disintegrates to $^{44}\mathrm{C}a$ from isomeric state and ground state. The gamma spectrum of $^{44}\mathrm{S}c$ created from two parts, one is due to $^{44}\mathrm{S}c$ transferred from isomeric state in to ground state, and the other is due to $^{44}\mathrm{C}a$ transferred from higher energy excited states to the lower one or to the ground state (Fig.1).

2. Calculating the essential parameters of reaction

In this paper the following symbols are used: $\mathrm{t_1}$ is time for irradiating to $\mathrm{TiO_2}$ target, $\mathrm{t_2}$ is the disintegrating time (the period of time from radiation stop to spectral measurement) and $\mathrm{t_3}$ is time spectral measurement.

The equation representing the irradiating at sample is as follows

$$\frac{\mathrm{dN}_m}{\mathrm{dt}} = \mathrm{N_0}\sigma_m\phi(\mathrm{t}) - \lambda_m\mathrm{N}_m \tag{2.1}$$

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$$\frac{dN_g}{dt} = N_0\sigma_g\phi(t) + P_{m,g}N_g - \lambda_g N_g, \tag{2.2}$$

where σ_m and σ_g are cross-sections of the metastable and the ground state, respectively, λ_m and λ_g are the decay constants of these states, $P_{m,g}$ is the branching ratio for the decay of metastable to ground state, N_0 is the number of target nuclei, $\phi(t)$ is the flux of beam per $1cm^2$of bremsstrahlung irradiated in to the sample, N_m and N_g are the number of nuclei in the metastable and the ground state.

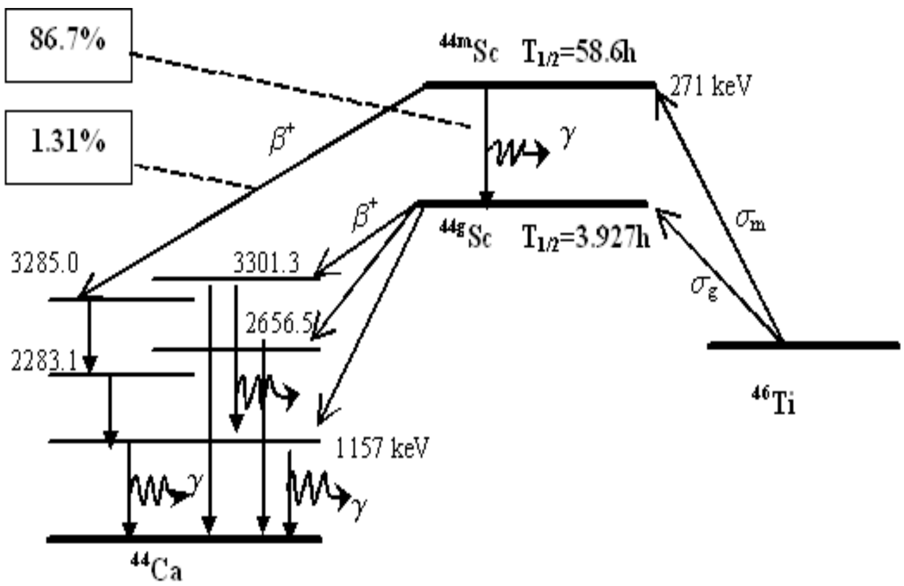

Figure 1. Production and decay of the metastable and the ground state

In gamma spectra, the area (number of count) of peak with energy E_γ is determined as follows:

$$S = f_\gamma \epsilon \int_0^{t_3} A(t)dtC$$

f_γ: intensity of photopeak

ϵ: detection efficiency of gamma spectrometry

For gamma spectrum of $^{44}Sc^m$, the spectral peak area with energy E_γ calculated as follows:

$$\begin{aligned} S_m = N_m = & f_\gamma^m \epsilon_m \int_{t_2}^{t_2+t_3} \lambda_m N_m dtC_m \\ = & f_\gamma^m \epsilon_m N_0 \phi_0 \frac{\sigma_m}{\lambda_m}(1 - e^{-\lambda_m t_1})e^{-\lambda_m t_2}(1 - e^{-\lambda_m t_3})C_m \end{aligned} \tag{2.3}$$

Similarly, the area of spectral peaks caused by the disintegration of nuclei ^{44,g}Sc is

$$S_g{=}N_g{=}f_\gamma^g\epsilon_g N_0\phi_0\left[P_{m,g}\frac{\sigma_m\lambda_g}{\lambda_m(\lambda_g-\lambda m)}(1-e^{-\lambda_m t_1})e^{-\lambda_m t_2}(1-e^{-\lambda_m t_3})\right]C_g$$
$$+f_\gamma^g\epsilon_g N_0\phi_0\left[\frac{1}{\lambda_g}\left(\sigma_g-P_{m,g}\sigma_m\frac{\lambda_g}{\lambda_g-\lambda m}\right)(1-e^{-\lambda_g t_1})e^{-\lambda_g t_2}(1-e^{-\lambda_g t_3})\right]C_g, \quad (2.4)$$

where f_γ^m and f_γ^g is intensity of gamma ray corresponding with the state of ^{44,m}Sc and ^{44,g}Sc, ϵ_γ is detection efficiency of gamma spectrometry at spectral peak with energy E_γ, C_m and C_g are the self-absorption correction coefficient of radiated sources, $C_m \leqslant 1$, $C_g \leqslant 1$.

With the result of equations (2.3), (2.4) the isomeric ratio can be determined

$$IR=\frac{\sigma_m}{\sigma_g}$$
$$=\left[\frac{\lambda_g(1-e^{-\lambda_m t_1})e^{-\lambda_m t_2}(1-e^{-\lambda_m t_c})}{\lambda_m(1-e^{-\lambda_g t_1})e^{-\lambda_g t_2}(1-e^{-\lambda_g t_c})}\left(\frac{C_m N_m f_\gamma^m\epsilon_m}{C_g N_g f_\gamma^g\epsilon_g}-\frac{P_{m,g}\lambda_g}{\lambda_g\text{-}\lambda_m}\right)+\frac{P_{m,g}\lambda_m}{\lambda_g-\lambda_m}\right]^{-1} \quad (2.5)$$

And the error

$$\frac{\Delta IR}{IR}=\sqrt{\left(\frac{\Delta N_m}{N_m}\right)^2+\left(\frac{\Delta N_g}{N_g}\right)^2+\left(\frac{\Delta\epsilon_m}{\epsilon_m}\right)^2+\left(\frac{\Delta\epsilon_g}{\epsilon_g}\right)^2}, \quad (2.6)$$

in which $\frac{C_m}{C_g}$ is the rate of correction coefficients and has value of around 1.

3. Experiment

3.1. Experimental arrangement

The experimental flowchart is arranged as *fig*.2.

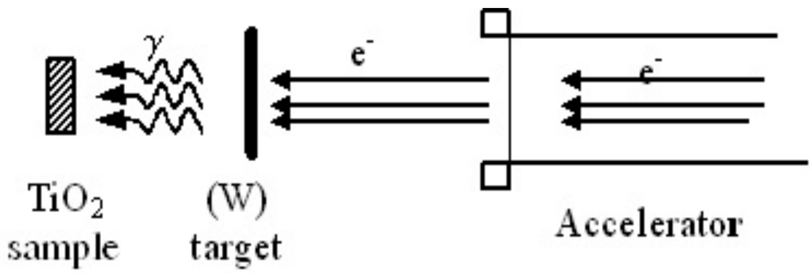

Figure 2. Experimental arrangement.

Gamma spectrum of^{44}Sc from Ti(γ, pn)Sc reaction is measured by HPGe gamma spectrometry. The measurement scheme is presented in fig.3, and the gamma spectrum of ^{44}Sc presented in Fig.4.

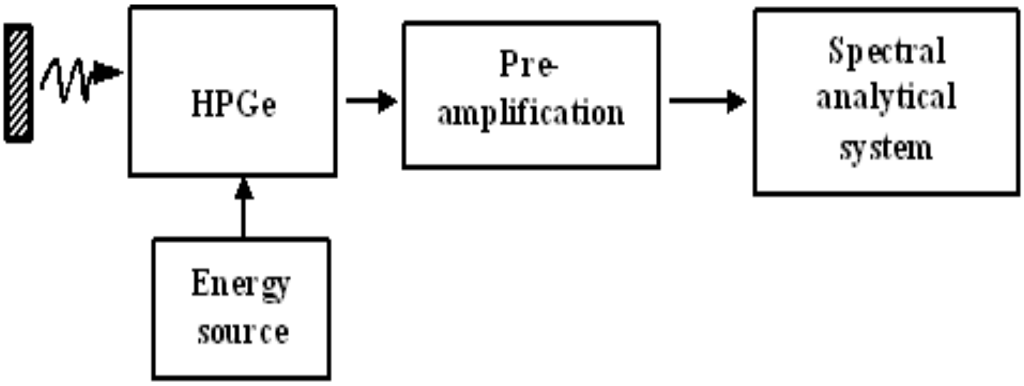

Figure 3. Scheme of analytical system for gamma spectrum of reaction preduction

Figure 3. Gamma spectrum of ^{44}Sc measured by Gammavision Spectrometry

3.2. Calculation of typical peak area

In the gamma spectrum of ^{44}Sc, there are two spectral peaks with energies of 271keV created due to ^{44}Sc transferring from metastable to ground state and of 1157keV created when the ^{44}Sc nuclei in both metastable and ground state disintegrate to ^{44}Ca. With ^{44m}Sc, relative intensity of gamma ray with energy $E_\gamma = 271$keV and with energy $E_\gamma = 1157$keV is 86.7 : 1.31. So that, the count of peak with 271keV energy of metastable state is equal the area of spectral peak of 271keV energy. But, the count number of 1157keV energy peak of ground state is not equal the area of 1157 keV energy peak. It is determined as follows

$$N_m = S_{271} \tag{3.1}$$

$$N_g = S_{1157} - \frac{1.31\epsilon_g}{86.7\epsilon_m} N_m, \tag{3.2}$$

where S_{271} is the area of 271 keV energy peak and S_{1157} is the area of 1157 keV one.

3.3. Isomeric ratio

The detection-efficiency of gamma spectrometry with energy of 271 keV and of 1157 keV has been determined in the paper " Surveying the HPGe gamma detector absolute efficiency", and their value is as follows: at 271 keV energy $\epsilon_m = 0.01068 \pm 0.00029$; at 1157 keV energy: $\epsilon_g = 0.00291 \pm 0.00007$

According to the part mentioned above, we can determine the values of N_m and N_g. Substituting the parameters into formula (2.5), we calculate the isomeric ratio of $^{46}\mathrm{Ti}(\gamma, \mathrm{n})^{44}\mathrm{Sc}$ reaction:

$$\mathrm{IR} = 0,112$$

The error of isomeric ratio calculated according to the formula(2.6) and it's value is:

$$\triangle\mathrm{IR} = 0.011$$

So, the isomeric ratio of reaction $^{46}\mathrm{Ti}(\gamma, \mathrm{pn})^{44m,g}\mathrm{Sc}$ is:

$$\mathrm{IR} = 0,112 \pm 0.011$$

4. Conclusion

Using the beam of bremsstrahlung with energy end point of 65MeV from the accelerator in POSTECH - South Korea, we have determined the isomeric ratio (IR) of the reaction $^{46}\mathrm{Ti}(\gamma, \mathrm{pn})^{44m,g}\mathrm{Sc}$ as follows:

$$\mathrm{IR} = 0.112 \pm 0.011$$

In order to compare this data with the others, we have consulted a lot of published data and those from in the Internet. But, we could not get any data that is similar to this reaction. Consequently, the result of our experiment can be considered as the new result that may contribute to database of isomeric ratio of nuclear reaction.

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