Measurement of the D-D Neutron Generation Rate by Counting Protons

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1. Introduction

Neutron generation rate of the D-D neutron generator [1] developed at Seoul National University is measured by counting protons produced from the D(d,p)T reaction. It is rather preferable than by counting neutrons because (i) the proton has a high energy of about 3 MeV, which make it easy to distinguish the proton peak from background spectrum, (ii) the efficiency of a detector for a proton is well defined at a given source-detector arrangement, (iii) the cross sections of the D(d,p)T, D(d,n)^{3}He reactions are well known. The measurement system and the experimental results are described.

2. D(d,p)T Reaction

The cross section of the D(d,p)T reaction is nearly equal to that of the D(d,n)^{3}He reaction. The difference between the cross sections is less than 10% when the incident energy of a deuteron is below 120 keV.

The emission of protons from the D-D reaction is not spherically symmetry [2]. Figure 1 shows the angular distribution of the emission probability of a proton at certain incident energies. The anisotropy increases as the incident energy rises, which may cause a serious error in the measurement of neutron generation rate. However, the emission probability at 55° or 130° is nearly constant independently of the incident energy and it is nearly 1. Therefore, the effect of the anisotropic emission of proton on the measurement can be minimized by placing a detector at an angle near to 55° or 130°.

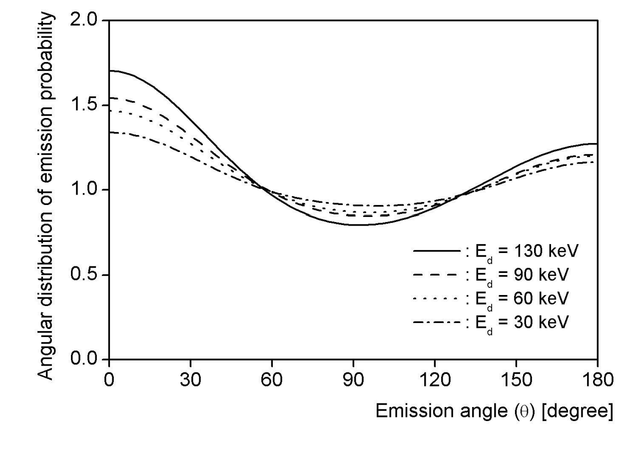

Figure 1. Anisotropic emission of protons from the D(d,p)T reaction. (θ: emission angle in lab. System, E_d: deuteron energy)

3. Measurement System

A Si detector (sensitive depth: 100 μm) is used to detect protons. The arrangement of the detector is as shown in figure 2, where only the components near to a target and the detector are drawn together, while the others (e.g. ion source, Faraday cup) are omitted for simplicity.

In the figure, deuteron beam comes from left side and irradiated on the target, and the detector views the target at a backward direction through a narrow gap between a suppression electrode and the target. It was purposed to place the detector at an angle as near as possible to 130°. However, it is restricted by other components near by the target and the detector is placed at 118°.

The detector is covered with a stopping foil and an aperture. The stopper foil is made of an aluminum foil with a thickness of 40 μm, which keeps the detector from the scattered beam, energetic electrons and light photons. The aperture defines an efficiency of the detector. It has a hole with a diameter of 1.3 mm and it is placed at 112 mm from the center of target surface.

A simple spectroscopy system is set up to detect the protons. Measurement is controlled by Gamma Vision [3] and GVU code on a PC platform. Gamma Vision is a commercial program which controls a MCB&ADC (Multi-Channel-Buffer & Analog-to-Digital-Converter) module and analyzes the measured spectrum. GVU code is a home made utility which helps Gamma Vision user retrieve spectra automatically and sequentially with a certain time interval, and it also displays the results of spectrum analysis which is performed by Gamma Vision.

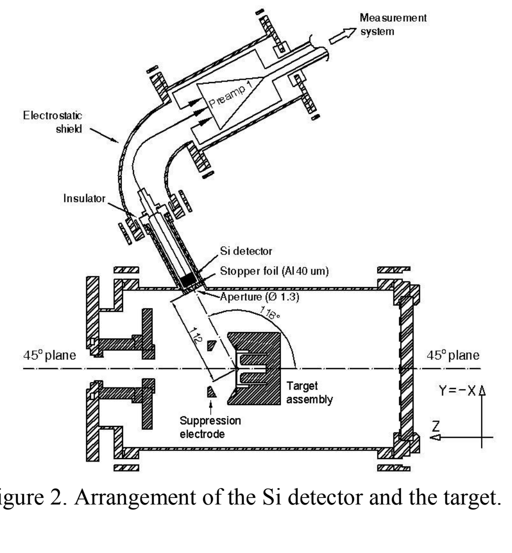

Figure 2. Arrangement of the Si detector and the target.

4. Experimental Results

Detector efficiency has been measured by counting 5.486 MeV alphas from a ^{241}Am source. The source is a standard alpha source with an activity of 1 μCi (error: ±2% at 68% confidence level) and it has an active area of 20 mm^2. The measured efficiency is 8.6×10^{-6}, and an error of 5% (at 68% confidence level) is given to the detector efficiency, where the effect of source size is considered.

A measured proton spectrum is shown in figure 3. It was accumulated for 10 minutes when 7.8 mA deuteron beam was being irradiated on the target biased at -72 kV. The peaks of proton and pulser are broadened because the target bias voltage has increased the noise level. However, the proton peak is not interfered by anything and is well distinguishable from the background.

The effect of anisotropic emission of proton is corrected. Let $p(\theta,\Delta\Omega)$ be the probability that a proton emitted from the D(d,p)T reaction enters a detector placed at an angle θ with a solid angle $\Delta\Omega$, then it is given by

$$p(\theta,\Delta\Omega)=\frac{\int_0^R dx\int_{\Delta\Omega}d\Omega\left(\left.\frac{d\sigma(\theta')}{d\Omega}\right|_{E(x)}N(x)\right)}{\int_0^R dx[\sigma(E(x))N(x)]} \qquad (4-1)$$

where, R is the range of deuteron beam, x is depth in the target, $d\sigma(\theta')/d\Omega|_{E(x)}$ is the differential cross section at $E(x)$ which is the energy of deuteron beam at x, $\sigma(E(x))$ is the cross section at $E(x)$ and $N(x)$ is the number density of deuterium in the target at x. Here, a narrow pencil beam and a thick target are assumed. Then the total number of protons generated per unit time, Y_p, is given by

$$Y_p=\frac{S}{\varepsilon}\times\frac{\Delta\Omega/4\pi}{p(\theta,\Delta\Omega)} \qquad (4-2)$$

where, S is the proton peak count rate and ε is the detector efficiency.

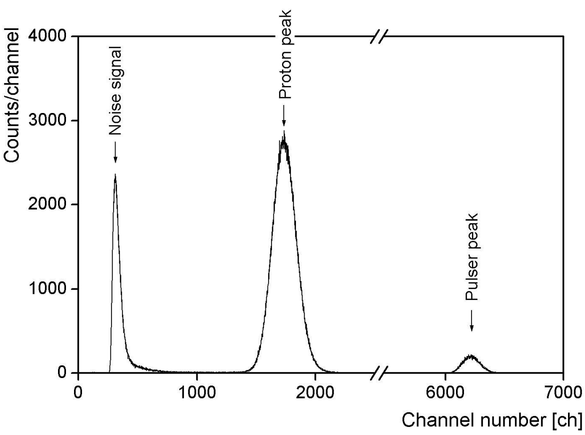

Figure 3. Measured proton energy spectrum by the Si detector. (Peak center: 1.74 MeV, FWHM: 243 keV)

In this study, the neutron generation rate is regarded to be equal to Y_p in the eq. (4-2). Because the range of deuteron beam energy does not exceed 100 keV, the difference of cross section between the reactions is much less than 10%. Figure 4 shows a result of a neutron generation run. The measurement was performed at every minute. Areas of proton peaks were over 10,000 counts when the deuteron beam energy got over 55.0 keV, while the dead time was less than 4%. In the figure, the error of the neutron generation rate is about ±5% and the neutron generation rate at 96.0 keV is 1.5×10^8 n/s.

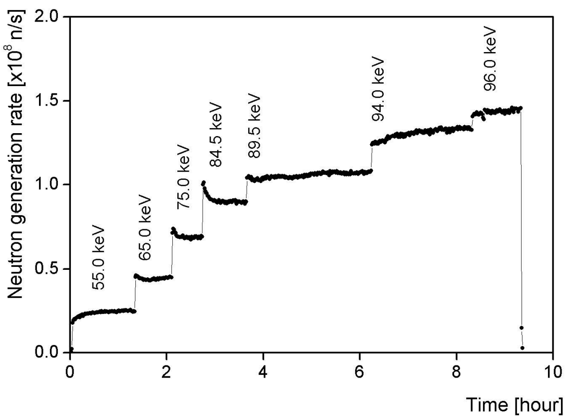

Figure 4. The measured neutron generation rate during a neutron generation run. (Deuteron beam current: 7.8 mA)

5. Conclusion

Neutron generation rate in the D-D reaction was measured by counting protons. In the measurement, the effect of anisotropic emission of protons was corrected. The error of the measured neutron generation rated was about 5%.

ACKNOWLEDGEMENTS

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