Performance study of wide dynamic range photon detection system using Ge detectors for muonic X-ray spectroscopy

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We are planning spectroscopy of the muonic atom of heavy nuclei and muon-induced fission reaction. The energy of muonic X rays of heavy elements, such as actinides, is above 6 MeV.[1)] Therefore, we develop a wide dynamic range X-ray and γ-ray detection system to detect such high energy X-rays. Evaluations of the detector's efficiency and energy resolution are required to understand the performance of the detector in a wide dynamic range. While standard γ-ray sources can be used to evaluate detector performance in low energy regions below 1.8 MeV, there are no sources available for above a few MeV. Therefore, we performed an experiment using the 992-keV resonance in the ^{27}Al$(p,\gamma)^{28}$Si reaction, primarily because the reaction emits several γ rays over a wide energy range from 1.5 to 10.8 MeV, and their energies and relative intensities are well known.[2,3)]

The experiment was performed at the RIKEN Pelletron facility. The proton beam at 1 MeV irradiated a 0.8-μm thick Al target. The energy loss of the beam in the target was estimated as 36 keV. The target thickness and beam energy were sufficient to induce a 992-keV resonance and not excite the nearest resonances at 937 and 1025 keV. The proton beam intensity was approximately 300 nA, and the measurement time was 6.5 h. The experimental setup is shown in Fig. 1. The photon detectors in the system consist of high-purity Ge detectors with high energy resolution. Two Ge detectors, GMX80 (Ortec) and GX5019 (Canberra), were used for γ-ray detection. GMX80 and GX5019 are an n-type 80% coaxial detector and a p-type 50% coaxial detector, respectively. The distances from the target to the detectors were 5 cm (GMX80) and 10 cm (GX5019), respectively. To suppress the Compton component, the main background of the Ge detector's spectrum, BGO detectors were used as a Compton suppressor. In this experiment, GX5019 was surrounded by the BGO Compton suppressors to test the performance of Compton suppression in such a high energy region. Signals from the detectors were acquired by a waveform digitizer (Caen V1730B).

The spectrum of the γ-ray energy acquired with GX5019 after Compton suppression is illustrated in Fig. 2. Figure 2 shows 13 γ-ray peaks in 1.5–10.8 MeV obtained more than 1000 counts for each peak for less than 3% statistical accuracy. Single escape peaks (SE) and double escape peaks (DE) were also observed in the spectrum. Detailed analyses of the γ-ray spectrum are carried out to estimate the Ge detectors' photopeak efficiencies and energy resolutions. Accordingly, we will discuss the performance of the photon detection system in a wide energy range below 10.8 MeV.

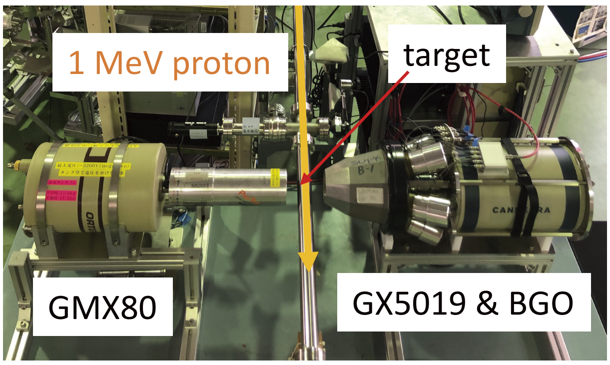

Fig. 1. Photograph of the experimental setup. Two Ge detectors were set next to the target and at an angle of 90-degrees to the beam.

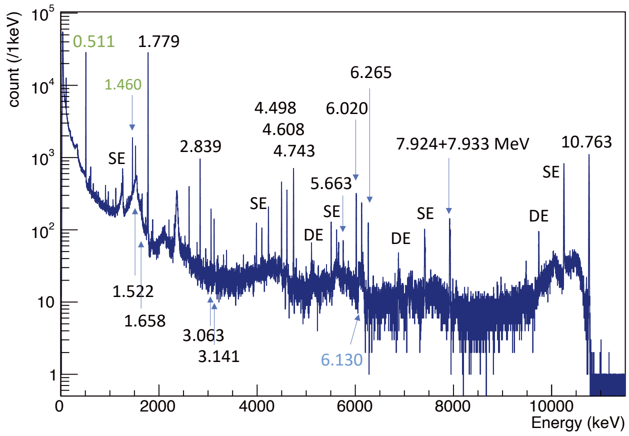

Fig. 2. γ-ray energy spectrum measured by GX5019 suppressed by a compton suppressor. The γ rays from 511 keV to 10.7 MeV can be observed. In the spectrum, SE (DE) means single (double) escape peaks corresponding γ-rays.

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