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Total Nuclear Photon Absorption Cross Section for $^{27}$Al

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We have developed a new technique to measure the total photon absorption cross section. We found that this method shows the possibility of quick data acquisition of the total photoabsorption cross section. We demonstrate the measurement of the total photon absorption cross section of $^{27}$Al.

The total nuclear photon absorption cross section is a sum of all nuclear photo-reaction channels. It is one of the most sensitive quantity to the nuclear structure information. Ahrens et. al. [1] reported the measurements of the total photon absorption cross sections $\sigma(E_\gamma)$ for Li, Be, C, O, Al, Si and Ca nuclei from $E_\gamma = 10$ MeV to the meson threshold. They used bremsstrahlung photons produced by pulsed electrons from the Mainz linear accelerator with a duty factor of $0.45 \times 10^{-3}$. A pair of Compton spectrometers was used to count the photons before and after the absorption target. A lot of beam time was required to achieve sufficient statistics owing to not only the low duty electron beam but also the inefficient spectrometer system. Several small fluctuations are seen above the giant dipole resonance. Recently, they have noticed as possibilities of the double giant resonance [2].

In this report, we show the development of a new method to measure the total photon absorption cross section $\sigma(E_\gamma)$. The preliminary data for $^{27}$Al in an energy range of $E_\gamma = 40\sim110$ MeV are presented.

The experimental setup is shown in Fig. 1. The 140 MeV electrons from the pulsed beam stretcher were transported to the photon tagger. Bremsstrahlung photons were produced in a gold radiator of 1/1000 radiation length. We employed a 3 cm $\phi \times 15$ cm lead glass Cherenkov counter to detect photons. The recoil electrons were momentum-analyzed by a magnetic field and detected by a 64-channel tagging counter (TC). The momentum width of each counter was 1.4 MeV. We used a 5.0 cm $\phi \times 12.0$ cm aluminum rod as the absorber. The rod included 5% magnesium and the specific gravity was 2.65 g/cm$^3$. The absorber was mechanically putting in and out of the photon beam every 10 seconds. The timing signals for the measurement are shown in Fig. 2. Single and coincidence counts of the tagging counters were registered in scalers. The background was measured without the radiator and found to be negligibly small.
Experimental Hall-1

Fig. 1. Layout of the photon tagging system and the setting for this experiment.

Target State
Count Start
Inhibit
Clear
Scaler

Fig. 2. Timing chart of absorber movement.

The energy of photon \( (E_{\gamma}) \) is defined by the energy of electron \( (E_e) \) which is determined by tagging counters as,

\[
E_{\gamma} = E_e - E_a,
\]

where \( E_a \) is the energy of the incident electron. The tagging counters are consisted of 64-channel thin plastic scintillators lining up on the focal plane of the tagging magnet from 0.2 \( E_0 \) to 0.8 \( E_0 \) at an interval of 0.094 \( E_0 \). The energy of the tagged photon at the \( i \)th channel becomes,

\[
E_{\gamma} = E_0 - (0.2 E_0 + 0.094 E_0^{(i-1)})
\]

The low energy side of \( E_{\gamma} \) deviates from this equation because of non-uniform fringing field of the magnet. This deviation was investigated by T. Suda using the measurement of \(^2\text{H (} \gamma, n, \nu)\) reaction. They were tabulated by P. Harty [3].
The total photon absorption cross section \( \sigma_{\text{tot}}(E_\gamma) \) as a function of the photon energy \( E_\gamma \) can be deduced from the absorption law,

\[
N(E_\gamma) = N_0(E_\gamma) \exp(-n \sigma_{\text{tot}}(E_\gamma)),
\]

where \( N \) and \( N_0 \) are the number of photons in a certain energy bin with and without the absorption, respectively. Here, \( n \) is the number of nuclei per cm\(^2\) in the absorber. The coincidence counts between tagging counters and the Cherenkov counter were normalized by a sum of counts in each cycle with or without the absorber. Obtained \( \sigma_{\text{tot}}(E_\gamma) \) is shown in Fig. 3. The curve in the figure shows the calculated photon absorption cross section of the atomic process. The calculation overestimates the data at high energies.

During the measurement, the beam intensity was kept at low enough to avoid the pile-up of the coincidence counts. However, a slight influence of the pile-up, which depends on the beam intensity, was observed. The beam intensities measured as the sum of tagging electrons distributed from 30 kHz to 100 kHz. Because the coincidence count without absorber is about twice of that with absorber, the pile-up of the coincidence count without and with absorber is not same. Since the \( \sigma_{\text{tot}}(E_\gamma) \) does not depend much on \( E_\gamma \) at \( E_\gamma = 30 \sim 110 \) MeV, we summed \( N_0 \) and \( N \) for all tagging channels. The experimental results of \( N_0/N \) divided into 7 intensities are shown in Fig. 4. The best fitted curve showed that \( N_0/N \) at zero intensity was \( 2.118 \pm (0.425 \times 10^{-3}) \). The obtained value was 2.110. The correction factor for \( \sigma_{\text{tot}}(E_\gamma) \) was \( \ln(2.118) / \ln(2.110) = 1.005 \), irrespective of the photon energy.

![Graph](image)

**Fig.3.** Total photon absorption cross section for Al. The curve is the theoretical prediction of the atomic process.
Absorption of photons produces electrons, positrons and secondary bremsstrahlung photons in the absorber. These particles are detected in the Cherenkov counter. We calculated these electrons, positrons, and photons using GEANT3. We calculated the correction factor ($\nu$) due to those processes at 11 photon energies (Fig. 5). The photon energy dependence of $\nu$ was obtained with the best fitted curve as shown in the figure.

We corrected the data in Fig. 3 for the pile-up and the mixing of the secondary bremsstrahlung. The result is shown in Fig. 6. By subtracting the calculated atomic cross section [4], we obtained the total nuclear photon absorption cross section as shown in Fig. 7. The magnitude of the cross section roughly agrees with the previous measurement [1]. In the present measurement a peak is observed at $E_\gamma = 62$ MeV. This peak was also observed by Ahrens et al. [1] together with two peaks at $E_\gamma = 56$ MeV and $E_\gamma = 76$ MeV. We did not observe the latter two peaks. We checked present $^{27}$Al data by dividing runs into 4 sections, and the peak at $E_\gamma = 62$ MeV was observed in all sections. Just after the $^{27}$Al measurement, we measured the cross section for $^{12}$C. The peak at $E_\gamma = 62$ MeV was not seen in the $^{12}$C data. Additional measurements are needed to confirm the peaks.
Fig. 5. Photon energy dependence a correction factor due to secondary bremsstrahlung.

Fig. 6. Total photon absorption cross section corrected for the pile-up and secondary bremsstrahlung. The curve is the calculated atomic cross section [4].

We wish to thank Mr. K. Matsuda for the guidance to make the target mover. We also thank the accelerator crew of the Laboratory of Nuclear Science for providing stable beam.
Fig. 7. Total nuclear photon absorption cross section for $^{27}$Al.

References