HIGH RESOLUTION MEASUREMENT OF TOTAL PHOTONUCLEAR CROSS SECTIONS

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A high-resolution photo-absorption spectroscopic method has been developed in order to investigate the fine structures in photonuclear reactions. To achieve an energy resolution of about 0.1% for high-energy photons (10-30 MeV), a new type of a photon spectrometer has been developed. To enhance a quality of data, the beam of laser Compton photon has been utilized. Recent progress of this new spectroscopic method is reviewed.

1. Introduction

Fine structures in photonuclear reactions are important quantities for the investigation of the innovative applications of photonuclear reactions because the photonuclear cross sections of some special states are expected to have huge values that are comparable to the photo-atomic cross sections. However, very little is known about the fine structures neither experimentally nor theoretically.

Nuclear photoabsorption (NPA) spectroscopic method is an ideal tool to investigate photonuclear reactions. The measurement gives the cross section of the total photonuclear reaction that is the sum of all the γ-induced reaction channels. The NaI scintillation spectrometer, LD_2/TOF spectrometer or the magnetic spectrometer has been applied for the photon absorption measurements.[1,2,3] However, the energy resolving power of these spectrometers were about a few percent, and were not enough to investigate fine structures in photonuclear reactions.

Recent progress on Ge detector fabrication technologies makes it possible to develop a high-resolution high-energy photon spectrometer (HHS)[4] with an excellent energy resolution of about 0.1% for high-energy photons, typically 10-30 MeV, with which NPA method can achieve a high resolution. As a result the fine structure in photonuclear reaction can be studied up to about 30 MeV.

The beam of laser Compton photon (LCP)[5] is now strong enough to be used in NPA experiments. The use of LCP overcomes the inherent disadvantage of the use of bremsstrahlung, that is, its high background, especially at the low energy side. The low energy tail of the LCP beam is cut off with a collimator since the energy of LCP is

determined by LCP's scattering angle.

The experimental technique of NPA using HHS and LCP has been developed for several years,[6] and recently the energy resolving power of 0.1% has been successfully demonstrated.[7] The progress of the new spectroscopic method is briefly reviewed.

2. Experiments

2.1 Principle of a new NPA spectroscopic method

In principle, the developed measurement method is similar to earlier NPA experiments[1,2,3], but in the present measurements two powerful devices, HHS and LCP, have been incorporated.

The total photo nuclear cross section is given by

$$\sigma_{tot}(E) = \frac{1}{\rho \ell} \log\left(\frac{cU_0(E)}{U(E)}\right) - \sigma_{atom}(E), \qquad (1)$$

where ρ and ℓ mean the atomic density and the length of the target. The E is the photon energy. The U and U_0 are transmitted LCP spectra obtained by unfolding the observed LCP spectra Y(target) and Y(reference), respectively, with the response functions of the HHS. The c in eq. (1) is a normalization constant. The $\sigma_{atom}(E)$ is the photo-atomic cross section that is tabulated in ref. (8).

2.2 Development of the super high-resolution photon spectrometer, HHS

The HHS was designed to detect high-energy photons in the energy range of 10-30 MeV with the energy resolution of about 0.1%. The HHS (Fig. 1) consists of two large N-type Ge detectors and thick BGO detectors. The energy resolution of the HHS is more than 10 times superior to the previously developed high-energy photon spectrometers[1,2,3]. This is the key device that enables it to obtain super high-resolution data of photo-absorption cross sections. The HHS is a new type of a super high-resolution photon spectrometer that enables the high-energy photon spectroscopy with the energy resolution of 0.1 %.

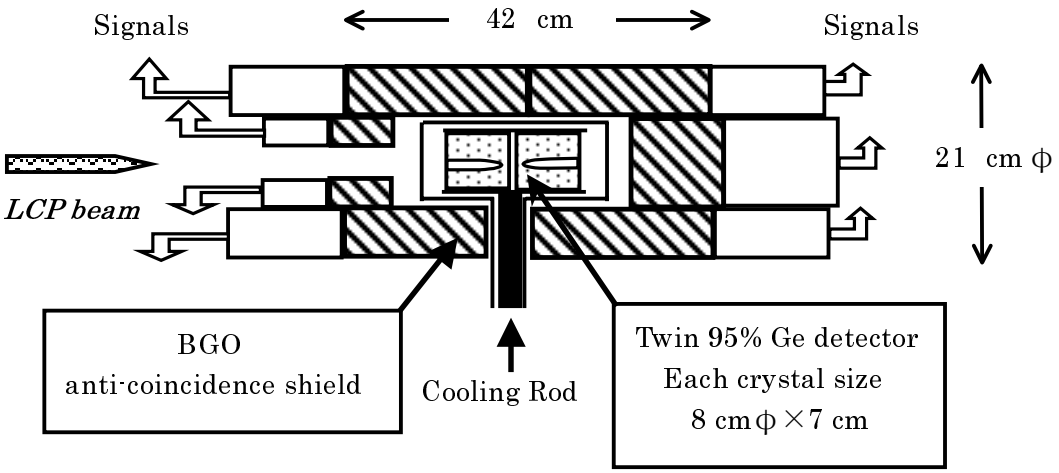

Fig. 1 A schematic representation of the HHS

2.3 Impact of LCP on NPA spectroscopy

The kinematics of the LCP is expressed by the next equation

$$E_{LCP}(\theta) \cong \frac{E_{\max}}{1+a(\gamma\theta)^2}, \quad \theta \ll 1, \qquad (2)$$

where $E_{max} = 4\gamma^2\omega a$, $a = 1/(1+4\gamma\omega/m)$, and $\gamma = E_e/m$. The E_e, m, and ω mean electron energy, electron mass, and laser (one photon) energy, respectively. For example, E_{max} is 13.23 MeV in the case of E_e = 613 MeV and ω = 2.35 eV (= 527 nm). The LCP energy at scattering angle of 0.01 ° is decreased to 12.67 MeV in this case. Therefore, the low energy tail of the LCP photon flux is eliminated with a collimator. The elimination of needless photons helps to reduce the counting rate of the photon spectrometer. The energy width of the LCP beam is also variable by changing the diameter of the hole in the collimator. These characteristics of the LCP make the NPA spectroscopy very powerful spectroscopic method compared to that using bremsstrahlung beam that has been traditionally used.

2.4 Setup

The experimental setup is shown in Fig. 2. A laser beam enters the window of a vacuum chamber of the electron storage ring TERAS[9] after being reflected by a mirror and passing through a lens (f = 2 m), and then interacted with the stored electron beam at the straight section. The lead collimator is placed along the LCP beam axis to cut off the low energy tail of the LCP beam. The distance between the centers of the interacting region and the collimator is 5.2 m.

Fig.2 Schematic overview of the NPA experimental area at the LCP facility

3. Results

Solid line and dashed line in Figure 3(a) show the transmitted LCP spectra observed by HHS for a water target enriched to 98 % in ^{18}O and a natural water target, respectively. Figure 3(b) shows the difference of the transmitted spectra, $Y(^{16}O)$ –

Y(^{18}O). The previous data reported the only four resonances at 9.1, 10.3, 11.4, and 13.1 MeV for ^{18}O(γ, abs) reaction in the observed energy region. The present data resolves the four resonances into nine resonances. The details of the analysis and the deduced cross sections are described in ref. 6.

Figure 4 shows the transmitted LCP spectra observed by HHS, Y(●) and Y(○), for a ^{13}C target and a blank target, respectively. A significant sharp dip is shown at 15.11 MeV in the spectrum for ^{13}C. The intrinsic width of the resonance at 15.11 MeV in ^{13}C was known to be 5.5 keV from the ^{9}Be+α reaction.[11] Assuming the intrinsic width to be 5.5 keV, the energy resolution of HHS is 12 keV for 15.11 MeV photon energy, that is, 0.08 %. This resolution is 20 times superior to that of July's state of art of present day photo-neutron measurement.[12]

4. Conclusions

New measurement method using HHS and LCP has been developed to investigate fine structures in photo-nuclear reactions. The energy resolution has been demonstrated to reach 0.1% by measuring the first T=3/2 resonance peak at 15.11 MeV in ^{13}C. Fine structure peaks in the ^{18}O(γ, abs) reaction have been observed for the first time by utilizing this method. It is required to obtain systematic data of high-resolution photoabsorption cross sections to shed light on the fine structures in photonuclear reactions.

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