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High resolution spectroscopy of the giant resonance in the ^{16}O(γ,abs) reaction

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Abstract. The characteristics of the nuclear photo-absorption spectroscopy using the laser Compton scattering (LCS) photons and the high-resolution high-energy photon spectrometer (HHS) are presented in this paper. The maximum energy of a LCS photon was increased up to 30 MeV, and the response functions of the HHS were improved. By taking advantage of these achievements, the ^{16}O(γ,abs) cross section was measured in the giant resonance region, that is, 20 to 25 MeV. The preliminary result with the energy resolution of about 0.1% is presented and compared with the preceding data.

1 Introduction

The laser Compton scattering (LCS) photon source developed [1] at the National Institute of Advanced Industrial Science and Technology (AIST) has been extensively used for studies of various photonuclear reactions, for examples, (γ,γ') [2], (γ,abs) [3], and (γ,n) [4] reactions. By utilizing a high-resolution high-energy photon spectrometer (HHS) for measurements of LCS photon energy distributions, a super high-resolution data on a (γ,abs) reaction has been obtained with the energy resolution of about 0.1% [5]. However, the maximum energy of the LCS photon available for the photonuclear spectroscopy was limited under about 20 MeV.

Recently, a high-power Nd:YVO_4 laser has been installed at the LCS photon facility in AIST. This enables the maximum energy of a LCS photon to be increased up to about 30 MeV with a sufficient flux of LCS photons for photonuclear spectroscopy. On the other hand, the accuracy of the response functions of the HHS for high-energy γ rays was also improved based on the experimental information [6].

By taking advantage of these achievements, the ^{16}O(γ,abs) cross section, which is regarded as one of the most important reaction in nuclear physics, is able to be measured in the giant resonance region, that is, 20 to 25 MeV. In past, the ^{16}O(γ,abs) cross section were measured at several institutes using bremsstrahlung photons [7–10]. They used a pair or Compton spectrometer for the measurements of energy distributions of bremsstrahlung photons. However, their energy resolutions were limited to about 1%.

The same cross section has also been investigated theoretically using calculations including large numbers of particle-hole excitations [11–13]. The calculations reproduced well the experimental observations, although a smearing parameter of about 500 keV [12] had to be used in the calculations.

The present method using LCS photons and the HHS is unique tool for the study of fine structure in the giant resonance with exceptional resolving power up to 30 MeV. The preliminary result on the ^{16}O(γ,abs) reaction with the energy resolution of about 0.1% is presented and compared with the preceding data.

2 Experiments

2.1 Generation of LCS photons

The scheme of LCS photon generation is shown in figure 1. When a laser photon of energy $\hbar\omega$ is scattered by an energetic electron of kinetic energy E_e, a very energetic LCS photon with energy of $\hbar\omega'$ is produced and its energy depends on the scattering angle θ.

The energy of the LCS photon is expressed by the well-known formula of the Compton backscattering [14],

$$\hbar\omega' = \frac{4\gamma^2\hbar\omega}{1 + (\gamma\theta)^2 + 4\gamma\hbar\omega/(mc^2)}, \tag{1}$$

where mc^2 is the rest mass of an electron and $\gamma = E_e/mc^2$. The maximum energy of a LCS photon is approximately proportional to the energy of an incident laser photon.

The maximum average power of the installed Nd:YVO_4 laser is about 8 W in case of third harmonics mode supplying photons with a wavelength of 355 nm. According to equation (1), the maximum energy of a LCS photon reaches 30 MeV when the electron energy is 764 MeV. The electron energy is variable in the range of 200–800 MeV in the storage ring TERAS [15], which stores electrons up to typically about 300 mA.

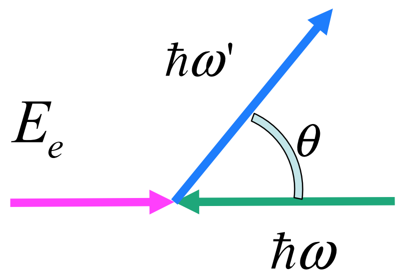

Fig. 1. The scheme of LCS photon generation.

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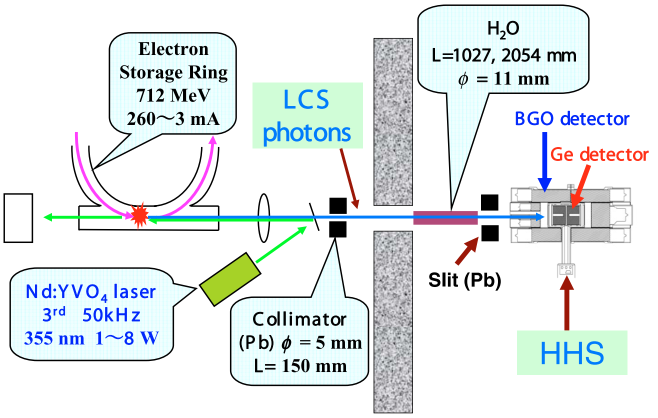

Fig. 2. Experimental setup.

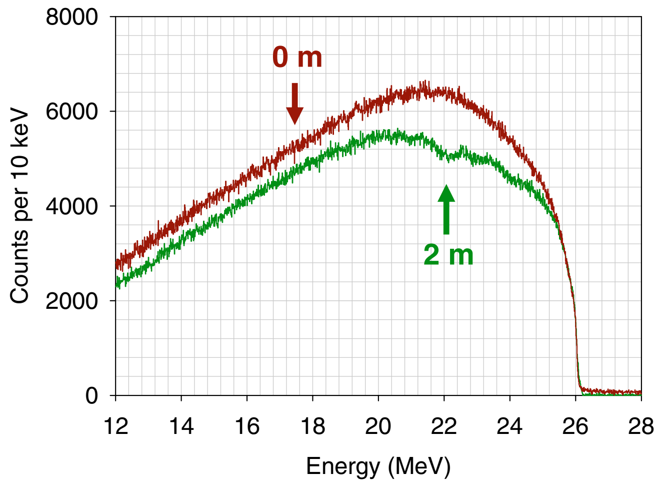

Fig. 3. Pulse height spectra of transmitted LCS photons measured by the HHS for the cases of an absorber of 2 m (lower) and a blank absorber (upper).

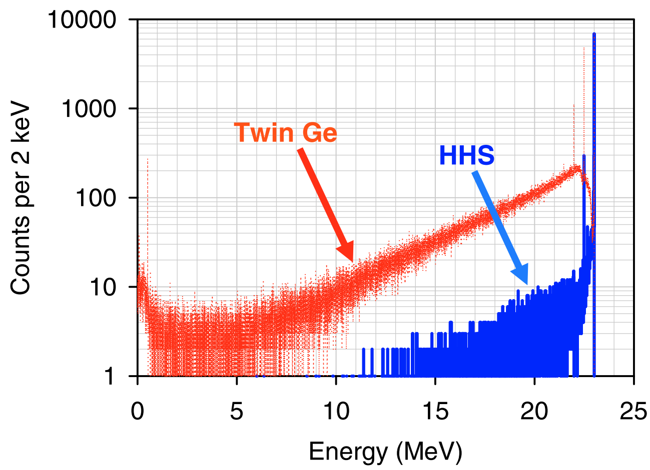

Fig. 4. Calculated response functions of the twin Ge (thin dotted line) and the HHS (bold solid line) for monochromatic 23 MeV γ rays.

2.2 Experimental setup

The experimental setup for the nuclear photo-absorption spectroscopy using LCS photons and the HHS is shown in figure 2.

The Nd:YVO_4 laser was operated in the third harmonics mode with a repetition rate of 50 kHz. The electron energy in the storage ring was set at 712 MeV, corresponding to the maximum LCS photon energy of 26 MeV. The stored electron current was 3–260 mA. The laser power was adjusted in the range of 1–8 W according to the stored electron current.

The lead collimator of 150 mm in length with a hole of 5 mm ϕ was placed along the LCS photon beam line to cut off the low energy portion of the LCS photon beam. Water absorbers contained in two acrylic cylinders were used of each thickness of 1027 mm with an inner diameter of 11 mm; the length of the water absorber was 2054, 1027, or 0 mm. Transmitted LCS photons were measured by the HHS. A lead slit of thickness of 20 cm with a hole of about 10 mm ϕ was set between the absorber and the HHS to prevent the scattered LCS photons by the absorber from entering the HHS. Measurements with the absorber and without it were repeated.

The HHS consists of two large N-type Ge crystals (sensitive volume 668 cm^3) called as a twin Ge detector and thick bismuth germanate (BGO) anti-coincidence shields. The performance of the HHS was described in ref. [6]. The energy resolution of the HHS for high-energy photons is about 0.1% [5].

3 Results and analyses

Figure 3 shows pulse height spectra of transmitted LCS photons measured by the HHS for the cases of an absorber of 2 m (lower) and a blank absorber (upper). Backgrounds due to bremsstrahlung were subtracted in the spectra. It is seen that there are prominent dip peaks in the spectrum of a 2 m absorber, where no structure in the spectrum of a blank absorber. This means the absorption dips originate in the nuclear photo-absorption by the ^{16}O absorber.

The (γ,abs) cross section is given by

$$\sigma_{abs}(E_\gamma) = \frac{1}{\rho\ell}\log_e\left(\frac{cU_0(E_\gamma)}{U(E_\gamma)}\right) - \sigma_{atom}(E_\gamma), \quad (2)$$

where ρ and ℓ mean the atomic density and the length of the ^{16}O absorber. The U and U_0 are obtained by unfolding the observed pulse height spectra $Y(^{16}O)$ and Y(blank) shown in figure 3 with the response functions [6] of the HHS calculated using the EGS4 simulation code [16], respectively. The c in equation (2) is the normalization constant on the observed spectrum for the blank target. The $\sigma_{atom}(E_\gamma)$ is the photo-atomic cross section that is well known to have smooth energy dependence and tabulated [17].

In the calculations of the response functions of the HHS from 3 MeV to 30 MeV in step of 10 keV, a pulse-height degradation effect [18] associated with a surface channel of the twin Ge detector has been included as was described in ref. [6]. Examples of the calculated response functions of the HHS and the twin Ge detector are shown in figure 4 for monochromatic γ rays of 23 MeV. The performance of the BGO suppression shields is significant for high energy γ rays as was shown in figure 4. The peak efficiencies and the total efficiencies for both of the twin Ge detector and the HHS are summarized for

Table 1. Calculated peak efficiencies and total efficiencies of the twin Ge detector and the HHS for monochromatic 23 MeV γ rays.

Detector	ε_p (%)	ε_t (%)
Twin Ge	1.37	93.4
HHS	1.37	5.06

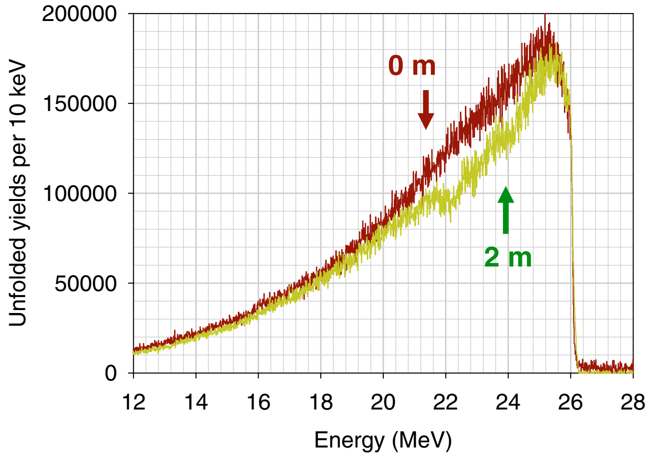

Fig. 5. Unfolded spectra of transmitted LCS photon pulse height spectra for the case of an absorber of 2 m (lower) and a blank absorber (upper).

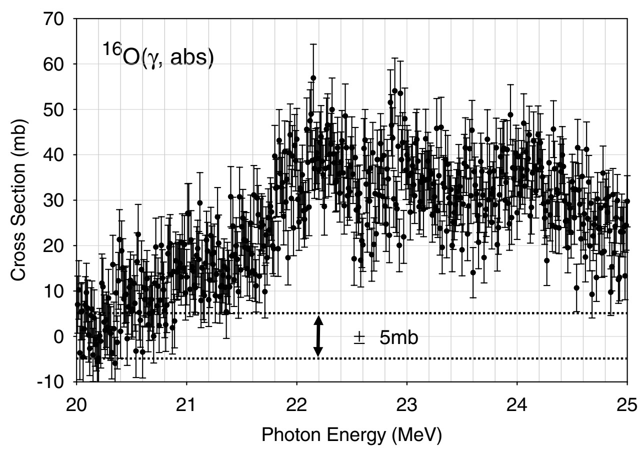

Fig. 6. Nuclear photo-absorption cross section of ^{16}O (tentative). The energy mesh of the present result is 10 keV.

the case of 23 MeV in table 1. The average suppression factor is about 25.

The unfolded spectra using the calculated response functions are shown in figure 5 of transmitted LCS photon pulse height spectra for the case of an absorber of 2 m and a blank absorber.

The preliminary result on the (γ,abs) cross section for ^{16}O obtained in the present experiments is shown by the closed circle in figure 6. The error bars show only the statistical errors. The systematic error is estimated to be about 5 mb due to the ambiguity on determining the normalization constant c and the photo-atomic cross section. The attempt to measure the photo-atomic cross section for high-energy photons using

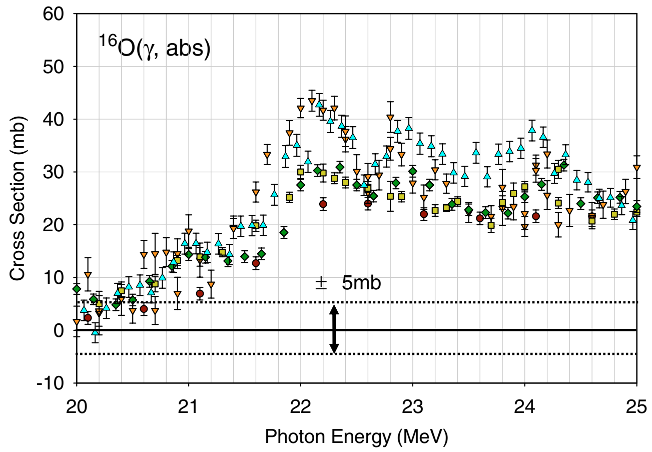

Fig. 7. A comparison between the present tentative nuclear photo-absorption cross section of ^{16}O (indicated by triangles up) and those of references (triangles down [7], closed circles [8], squares [9], and diamonds [10]). The energy mesh of the present result is 100 keV.

LCS photons and the HHS is underway [19]. The energy mesh in figure 6 is 10 keV. The uncertainty on the photon energy is about 0.1%, and the energy resolution is about 0.1% [4].

It is remarkable that there is no distinguished sharp peak as was observed in ^{13}C at 15.11 MeV [4], although the energy resolution was improved about 10 times compared to previous measurements [7–10].

4 Discussions

To compare the present tentative result with the previous measurements, the data were packed as the energy bin being 100 keV, and shown in figure 7. The present (γ,abs) cross sections are shown by the triangle up and the error bars show only statistical errors. The data by Burgov [7], Wyckoff [8], Bezic [9], and Ahrens [10] are shown by triangles down, closed circles, squares, and diamonds, respectively.

The fine structure peaks are shown in figure 7 at 21, 22, 23, and 24 MeV as were observed previously [7–10]. There are indications of substructure peaks at 21.55 and 21.95 MeV.

The absolute values of the present cross section seem to be larger than previous reported values. However, more detailed analyses are necessary on the systematic errors for the quantitative comparison on the absolute values.

5 Conclusions

The maximum energy investigated by the nuclear photo-absorption spectroscopic method using the laser Compton scattering (LCS) photons and the high-resolution high-energy photon spectrometer (HHS) are extended up to 30 MeV. The developed method was applied for the study of the fine structure of ^{16}O in the giant resonance.

The fine structure of ^{16}O in the energy range of 20–25 MeV was observed as was observed in preceding measurements, although the energy resolution was improved about 10 times compared to previous measurements.

The absolute values of the present cross section seem to be larger than previous reported values. The systematic errors on the absolute values of the cross section need to be studied in detail.

References

1. H. Ohgaki et al., Nucl. Instrum. Meth. A **455**, 54 (2000).
2. H. Ohgaki et al., Nucl. Instrum. Meth. A **353**, 384 (1994).
3. H. Harada et al., Phys. Rev. Lett. **80**, 33 (1998).
4. H. Utsunomiya et al., Phys. Rev. C **63**, 018801 (2000).
5. H. Harada et al., J. Nucl. Sci. Technol. **35**, 733 (1998).
6. H. Harada et al., Nucl. Instrum. Meth. A **554**, 306 (2005).
7. N.A. Burgov et al., Soviet Phys. JETP **16**, 50 (1963).
8. J.M. Wyckoff et al., Phys. Rev. B **137**, 576 (1965).
9. N. Bezic et al., Nucl. Phys. A **128**, 426 (1969).
10. J. Ahrens et al., Nucl. Phys. A **251**, 479 (1975).
11. V. Gillet et al., Nucl. Phys. A **97**, 631 (1967).
12. H. Sagawa et al., Phys. Rev. C **59**, 3116 (1999).
13. N.D. Dang et al., Phys. Rev. C **61**, 064304 (2000).
14. C.K. Sinclair et al., IEEE Trans. Nucl. Sci. **NS-16**, 1065 (1969).
15. T. Tomimasu et al., IEEE Trans. Nucl. Sci. **NS-30**, 3133 (1983).
16. W.R. Nelson et al., SLAC Report No. 265, 1985.
17. J.H. Hubbell et al., NISTIR 5632, 1995.
18. H. Utsunomiya et al., Nucl. Instrum. Meth. A **548**, 455 (2005).
19. F. Kitatani et al. (these proceedings).