International Conference on Nuclear Data for Science and Technology 2007
DOI: 10.1051/ndata:07407

Measurement of total gamma absorption for high energy gamma rays

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Abstract. Total gamma absorption cross sections are the most important data used in various fields related to the application of gamma rays. However, the measurements of the total gamma absorption cross section were difficult for high energy gamma rays since there were no suitable gamma ray sources. Recently, the nuclear photo-absorption measurement system using the laser-Compton backscattering (LCS) gamma rays and the high-resolution high-energy photon spectrometer (HHS) were developed. We have utilized the system to measure the total gamma absorption cross section, that is, the sum of the atomic and nuclear interactions. The total gamma absorption cross sections at 10 MeV for Al and Cu have been measured with the system. The preliminary results show that the obtained values agree fairly with the theoretical ones.

1 Introduction

Total gamma absorption cross sections are the most important data used in various fields related to the application of gamma rays. However, the measurements of the total gamma absorption cross section were difficult for high energy gamma rays since there were no suitable gamma ray sources. The gamma sources for such experiments in the past were

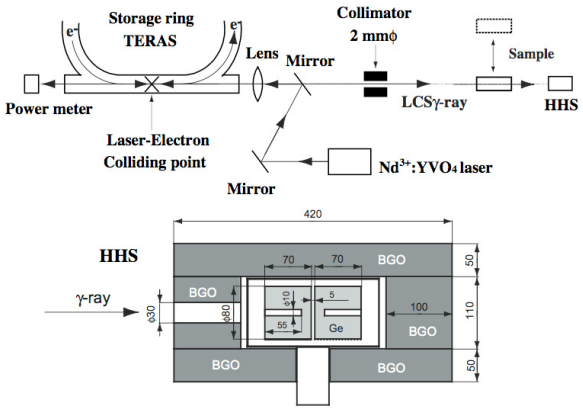

Fig. 1. Experimental setup and structure of the HHS.

neutron-capture gamma rays [1] and RI sources [2]; it was difficult to tune the energy and intensity of the gamma rays. Recently, the nuclear photo-absorption measurement system using the laser-Compton backscattering (LCS) gamma rays and the high-resolution high-energy photon spectrometer (HHS) were developed [3]. The energy and intensity of LCS gamma rays are able to be tuned, and the LCS beam be sharply collimated. Therefore, it is expected to be a powerful

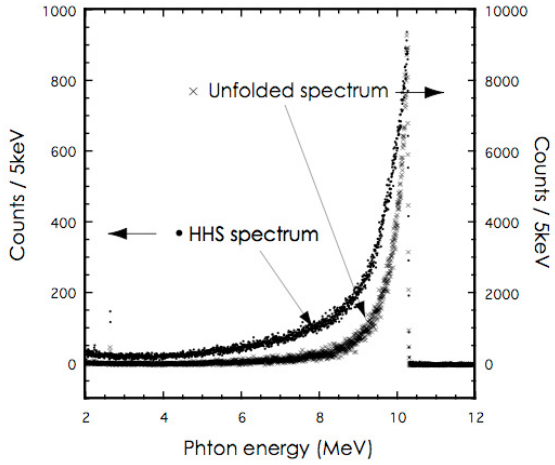

Fig. 2. LCS gamma ray spectrum (electron energy: 542.2 MeV, electron beam current: 26.0 mA, input laser power and frequency: 24 W and 20 kHz).

tool for the measurement of the total gamma absorption cross sections. The HHS, consisting a twin Ge detector and BGO ($Bi_3Ge_4O_{12}$) anti-coincidence shields, made a super high-resolution spectroscopy possible. In this study, the total gamma absorption cross sections of Al and Cu at 10 MeV were measured by using LCS gamma rays and the HHS.

2 Experiment

A LCS gamma ray is generated by the interaction between high energy electron and laser photon. In this study, LCS gamma rays are generated at the electron storage ring, TERAS in the National Institute of Advanced Industrial Science and Technology (AIST). The energy of electron was tuned at 542.2 MeV. The laser photon was 2nd harmonics of Nd^{3+}:YVO_4 laser. The LCS gamma ray was collimated by a lead block with 2 mm ϕ aperture. The energy distribution of

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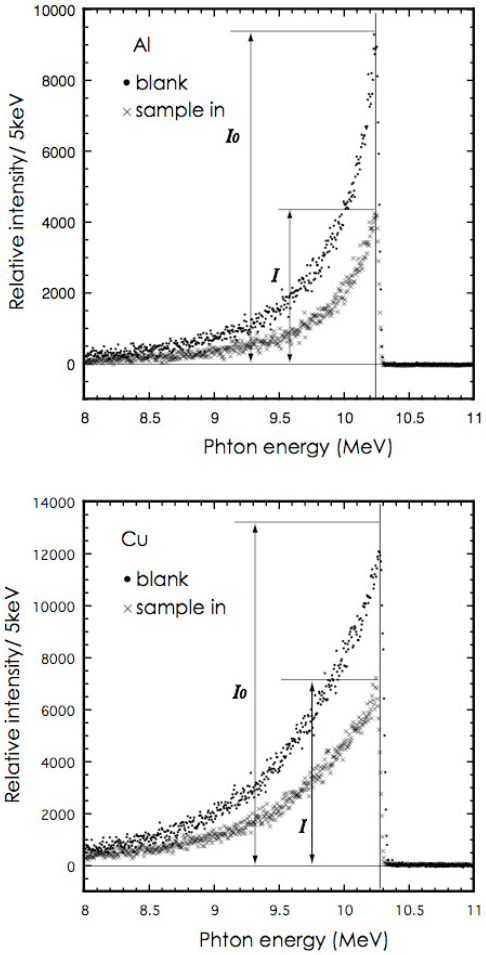

Fig. 3. Energy distributions of transmitted LCS gamma rays for the cases of an Al and a Cu, sample (×) and blank (•).

LCS gamma rays was measured by the HHS. The HHS is a super high-resolution spectrometer consisting of a twin Ge detector and BGO anti-coincidence shields [4]. The experimental setup and the structure of the HHS are shown in figure 1.

Total gamma absorption cross section is determined by the ratio of the intensity of the incident gamma ray to that of the attenuated gamma ray when the sample is put on the beam line. The measured samples are Al and Cu. The Al sample is made of aluminum material A1050P specified by JIS H4000. This purity is 99.53%. The size is 120 × 20 × 20 (mm) and the allowance is 0.1% or less. The Cu sample is made of copper material C1100 specified by JIS H3250. This purity is 99.96%. The size is 25 × 20 × 20 (mm) and the allowance is 0.1% or less. To deduce the energy distribution of the LCS photon beam, the observed pulse height spectra by the HHS were unfolded by using the response function of the HHS for monochromatic photons. The response functions were calculated by using EGS4 simulation code [5]. The LCS gamma ray spectrum measured with the HHS (×) and unfolded (•) spectrum are shown figure 2. The parameters of generated the LCS gamma ray were electron energy: 542.2 MeV, electron beam current: 26.0 mA, input laser power and frequency: 24 W and 20 kHz.

Table 1. Calculation results of the total gamma absorption cross sections.

Al: Counts / 200 keV					
I_0	err(%)	I	err(%)	μ_{mass} (g/cm^2)	err
256244	0.33				
254264	0.23	121199	0.48	0.0228	0.0003
252284	0.34	120766	0.35	0.0227	0.0002
249650	0.24	120333	0.50	0.0225	0.0003
247017	0.34	117394	0.35	0.0229	0.0002
245583	0.24	114455	0.51	0.0235	0.0001
244150	0.35				
Al: Counts / 100 keV					
I_0	err(%)	I	err(%)	μ_{mass} (g/cm^2)	err
169261	0.88				
168682	0.62	79236	1.29	0.0233	0.0007
168102	0.88	79379	0.91	0.0231	0.0006
166802	0.63	79523	1.29	0.0228	0.0007
165502	0.89	77429	0.93	0.0234	0.0006
164300	0.63	75336	1.33	0.0240	0.0008
163099	0.90				
Cu: Counts / 200 keV					
I_0	err(%)	I	err(%)	μ_{mass} (g/cm^2)	err
370828	0.58				
376704	0.41	194591	0.82	0.0296	0.0005
382579	0.58	196927	0.58	0.0298	0.0005
385042	0.41	199263	0.81	0.0295	0.0005
387505	0.57	198623	0.58	0.0300	0.0005
387393	0.41	197983	0.82	0.0301	0.0005
387280	0.57				
Cu: Counts / 100 keV					
I_0	err(%)	I	err(%)	μ_{mass} (g/cm^2)	err
246395	0.70				
250326	0.49	130041	0.99	0.0294	0.0006
254256	0.69	130880	0.70	0.0298	0.0006
256344	0.49	131720	0.98	0.0299	0.0006
258432	0.69	131754	0.69	0.0302	0.0006
258527	0.49	131788	0.98	0.0302	0.0006
258622	0.69				

3 Result

The total gamma absorption cross section, μ_{mass} is calculated by equation (1),

$$\mu_{mass} = \frac{\ln(I_0/I)}{\rho \cdot T}[\mathrm{g/cm^2}], \quad (1)$$

where I_0 is incident intensity, I attenuated intensity, ρ density (g/cm^3), and T thickness (cm). Figure 3 shows the energy distributions for the cases of an Al and a Cu, sample (×) and blank (•).

The incident photon intensity, I_0, is obtained from the HHS spectrum of a blank in beam line and the attenuated photon intensity, I, is obtained from the HHS spectrum of the sample in beam line. However, these are not able to be measured at the same time. Therefore, the measurements with a sample and without sample (blank) were repeated

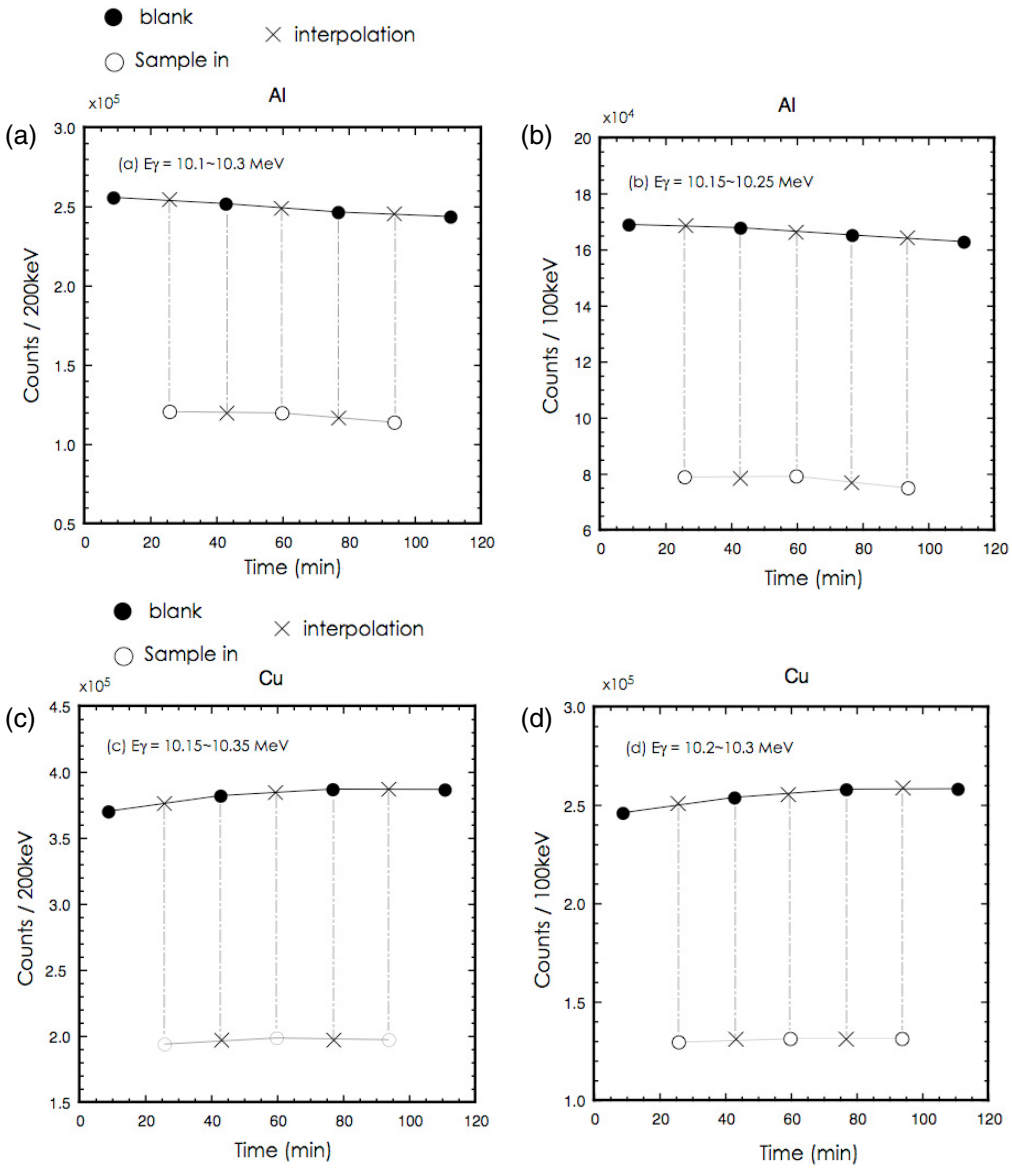

Fig. 4. Change of the measured gamma ray intensity as a function of time. (a) Al sample Eγ = 10.1 ~ 10.3 MeV, (b) Al sample Eγ = 10.15 ~ 10.2.5 MeV, (c) Cu sample Eγ = 10.15 ~ 10.35 MeV, (d) Cu sample Eγ = 10.2 ~ 10.3 MeV.

Table 2. Time average of the result at each measurements.

Al:	10.2 keV	MeV/200	μ_{mass} :	0.0229 ± 0.0004 (g/cm^2)
Al:	10.2 keV	MeV/100	μ_{mass} :	0.0233 ± 0.0004 (g/cm^2)
Cu:	10.25 keV	MeV/200	μ_{mass} :	0.0298 ± 0.0002 (g/cm^2)
Cu:	10.25 keV	MeV/100	μ_{mass} :	0.0299 ± 0.0004 (g/cm^2)

alternately during the same measurement period. I_0 and I at same time were determined by interpolation.

The change of the measured gamma ray intensity as a function of time is shown in figure 4 (a–d). The results are shown for each sample in both case of the width of energy 100 keV and 200 keV. In all the measurements, the measurement time is 15 min and the interval time is 2 min.

The calculated results of the total gamma absorption cross sections are shown in table 1.

The results on Al agree with the theoretical value (0.0232 g/cm^2) [6] within the limits of error. The results on Cu are about 3% smaller than the theoretical value (0.0310 g/cm^2) [6]. The detailed examination on systematic errors will be done in near future.

4 Conclusion

Total gamma absorption cross sections, the most important data used in various fields related to the application of gamma rays, nuclear data, radiation shield, etc., were measured by the method using LCS gamma rays and the HHS of Al and Cu at the vicinity of 10 MeV. Results for both samples agree well with the theoretical values. The effectiveness of the measurement method using the LCS gamma rays and the HHS were demonstrated for the total gamma absorption cross sections. It is scheduled that detailed examination of the systematic error analysis will be done, and a systematic

measurement will be executed on the total gamma absorption cross sections in the future.
Next, the total gamma absorption cross sections obtained by taking the average of the results at each measurements are shown in table 2. The errors include only statistical ones.

References

1. R.H. Barlett, D.J. Donahue, Phys. Rev. **137**, A532 (1965).
2. T.K. Umesh, C. Ranganathaiah, R. Gowda, K.S. Puttaswamy, B. Sanjeevaiah, Phys. Rev. A **23**, 2365 (1981).
3. H. Harada, Y.S higetome, J. Nucl. Sci. Technol. **32**, 1189 (1995).
4. H. Harada, K. Furutaka, S. Nakamura, K. Osaka, H. Akimune, H. Utsunomiya, T. Ohsaki, M. Igashira, Nucl. Instrum. Meth. A **554**, 306 (2005).
5. F. Kitatani, H. Harada, K.Y. Hara, M. Ohsima, H. Utsunomiya, K. Yamada, H. Toyokawa, in *Proceedings of 2006 Fall Meeting of the Atomic Energy Society of Japan*, p. 214.
6. M.J. Berger, J.H. Hubbell, S.M. Seltzer, J. Chang, S. Coursey, R. Sukumar, D.S. Zucker Smith, *XCOM: Photon Cross Sections Database*, NIST. (http://www.physics.nist.gov/PhysRefData/Xcom/Text/XCOM.html).