Physics Department
Royal Holloway
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PH2510 - Nuclear Physics Laboratory

Gamma spectroscopy (NP3)

1 Objectives

The aim of this experiment is to demonstrate how γ-ray energy spectra may be obtained using a NaI(Tl) scintillation detector. The spectrometer will be used to investigate the energy spectra of several gamma sources and to relate these to γ-ray interaction mechanisms.

In order to prepare adequately for this experiment you will have to consult the material indicated in the References section at the end of this script.

2 Apparatus

Gamma rays are photons with energy in the 0.1–10 MeV range. Nuclei have discrete energy levels with a typical spacing of the order of MeV. Therefore nuclear transitions can result in the emission of gamma rays of specific energies.

Figure 1 shows the block diagram of a simple $\gamma-$spectrometer. The demonstrator will identify the components and explain the function of each of the electronic modules.

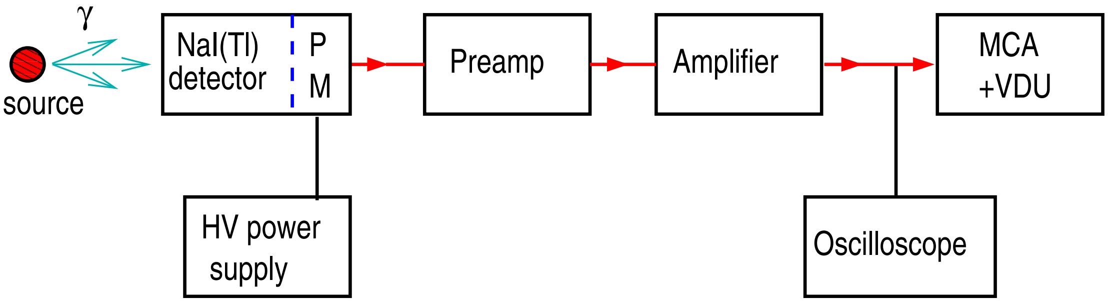

Figure 1: Schematic diagram of the $\gamma-$spectrometer used in this experiment. PM=Photomultiplier; MCA= Multi-Channel Analyzer; VDU= Visual Display Unit.

In your report:
Explain *succintly* (i.e., totalling less than $\frac{1}{2}$ a page!):

- the physical principles of operation of the NaI(Tl) detector;
- the function of the Photomultiplier;
- the function of the Multi-Channel analyzer.

3 Procedure

3.1 Energy calibration

The spectrometer's energy scale needs to be calibrated. You have access to several radioactive sources that emit gamma-rays of different energies: Na-22, Co-60, Cs-137, Bi-207. The energies of the gamma-rays emitted by these sources are given in a separate table ("Commonly Used Radioactive Sources") available in the Lab, as well as in Reference 3. Calibrate the spectrometer using two suitable peaks of known energy.

In your report:

- Explain concisely what is the calibration supposed to achieve;
- Include the printout of the calibration spectrum, clearly indicating the two peaks used for the calibration, and justifying your choice of calibration energies;
- Calculate the relative precision of your energy calibration by comparing the measured and the expected energy of some of the photopeaks which you did not use for calibration.

3.2 Gamma ray spectra and their features

Record the spectra of three out of the following four radioactive sources: Na-22, Co-60, Cs-137 and Bi-207.

In your report:

- Include the spectra and clearly label their features (photopeaks, Compton continua, Compton edges and sum peaks);
- Explain the physical origin of each of these features succintly;
- Calculate the predicted energy of the Compton edges and any sum peaks and compare these to the spectra you obtained.

3.3 Energy resolution

Determine the full width at half maximum (FWHM=ΔE) and energy ($\bar{E}$) of the photopeaks. Indicate both values clearly for each photopeak, on the printout of each spectrum.

In your report:

- Determine the energy resolution, $\Delta E/\bar{E}$, of the spectrometer, as a function of energy and plot the results.
- Does the energy resolution vary with the $\gamma-$ray energy? How do your results compare with the expected variation of the energy resolution?

3.4 Total linear attenuation coefficients

When a gamma-ray beam is made incident on a slab of some absorber material, some of the gamma-rays will interact (via photoelectric absorption, Compton scattering or production of an electron-positron pair) in the material. Such interactions effectively either absorb the gamma-ray or scatter it away from the incident beam direction. Figure 2 is a sketch of the typical experimental setup to measure the reduction in beam intensity due to an absorber of thickness t. The so-called linear attenuation coefficient μ is the probability, per unit length of the absorber, that a gamma-ray photon will be removed from the beam, for photons of a given energy. The intensity I of the beam after crossing a thickness t of absorber is expected to vary according to $I(t) = I_0\, e^{-\mu t}$.

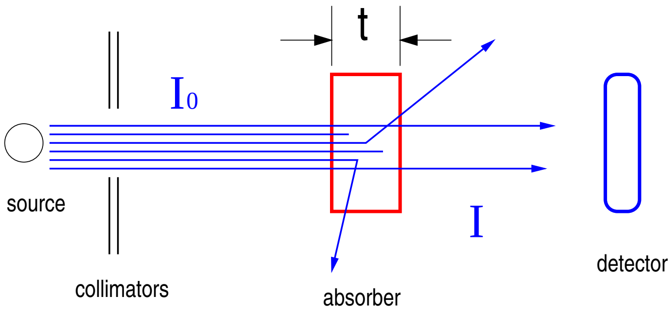

Figure 2: Experimental setup to determine the linear attenuation coefficient of an absorber material. I_0 and I are the intensities of the beam incident on and surviving the absorber, respectively. t is the thickness of the absorber.

In this experiment you will measure the linear attenuation coefficient μ for gamma radiation in lead and aluminium at gamma-ray energies of 0.66 MeV and 1.33 MeV.

In your report:

- Include the graphs showing the intensity of the detected radiation *vs.* t, the thickness of absorber used;
- Explain clearly how you determined the linear attenuation coefficients (μ);
- Include a table with the μ values that you obtained (a) from your measurements and (b) from the literature (K.S. Krane; Fig. 7.10, p. 203 or the data shown below). Compare your results with those in the literature and comment.

  (Note that the attenuation coefficients given in the literature are *mass* attenuation coefficients, which have units of cm^2/g. You will need to convert these to *linear* attenuation coefficients by using the corresponding absorber density. The densities of lead and aluminium are $\rho_{\mathrm{Pb}} = 11340\,\mathrm{kg/m^3}$ and $\rho_{\mathrm{Al}} = 2700\,\mathrm{kg/m^3}$, respectively.)

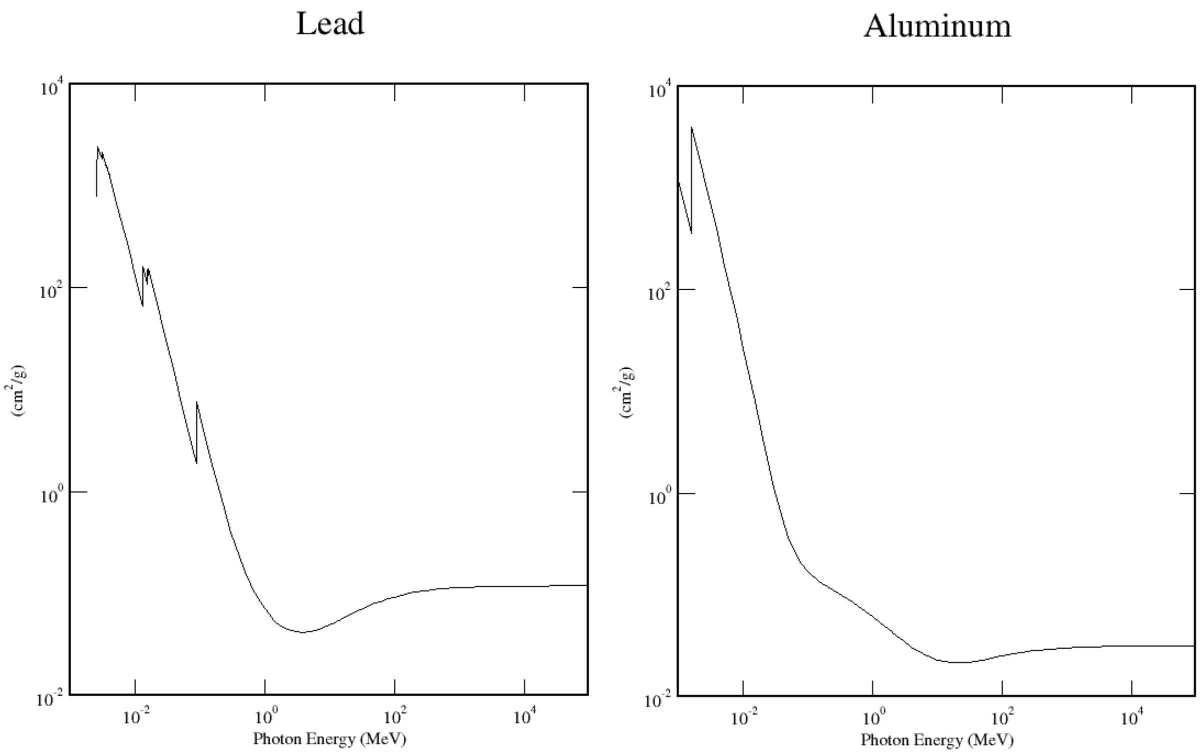

Figure 3: Photon mass attenuation coefficients in Pb and Al. (US National Institute of Standards and Technology, `http://www.physics.nist.gov/PhysRefData/Xcom/Text/XCOM.html`).

E (MeV)	0.511	0.569	0.662	1.063	1.173	1.333	1.770
Pb: μ (cm^2/g)	0.156	0.134	0.110	0.0672	0.0618	0.0561	0.0482
Al: μ (cm^2/g)	0.0837	0.0799	0.0747	0.0596	0.0568	0.0532	0.0460

Table 1: Photon mass attenuation coefficients in Pb and Al. (US National Institute of Standards and Technology, `http://www.physics.nist.gov/PhysRefData/Xcom/Text/XCOM.html`).

Radiation safety

In this experiment you will need to use radioactive sources. These are to be dealt with with care. You must follow these rules:

- Keep the source in its container when not in use;
- Do not point the open end at yourself or anyone else;
- Do not tamper with the source;
- Handle using tongs or wearing disposable gloves;
- No eating or drinking in the lab;
- Wash your hands thouroughly before touching food;
- Do not handle the source if you are pregnant;
- When you have finished using the source, advise the demonstrator so that it can be returned to the store.

References

The following references are from the book **Introductory Nuclear Physics** by KS Krane, Chapter 7: "Detecting Nuclear Radiations".

1 Electromagnetic radiation interaction with matter (Section 7.1, pp. 198-204);

2 Scintillation detectors (Section 7.3);

3 Commonly used energy calibration standards (Table 7.2, p. 226);

4 Energy measurements (Section 7.6);

5 Total linear attenuation coefficients (Section 7.1, pp. 201-3).

PTD, February 2007.

30. COMMONLY USED RADIOACTIVE SOURCES

Table 30.1. Revised November 1993 by E. Browne (LBNL).

			Particle		Photon	
Nuclide	Half-life	Type of decay	Energy (MeV)	Emission prob.	Energy (MeV)	Emission prob.
$^{22}_{11}$Na	2.603 y	β^+, EC	0.545	90%	0.511	Annih.
					1.275	100%
$^{54}_{25}$Mn	0.855 y	EC			0.835	100%
					Cr K x rays	26%
$^{55}_{26}$Fe	2.73 y	EC			Mn K x rays:	
					0.00590	24.4%
					0.00649	2.86%
$^{57}_{27}$Co	0.744 y	EC			0.014	9%
					0.122	86%
					0.136	11%
					Fe K x rays	58%
$^{60}_{27}$Co	5.271 y	β^-	0.316	100%	1.173	100%
					1.333	100%
$^{68}_{32}$Ge	0.742 y	EC			Ga K x rays	44%
→ $^{68}_{31}$Ga		β^+, EC	1.899	90%	0.511	Annih.
					1.077	3%
$^{90}_{38}$Sr	28.5 y	β^-	0.546	100%		
→ $^{90}_{39}$Y		β^-	2.283	100%		
$^{106}_{44}$Ru	1.020 y	β^-	0.039	100%		
→ $^{106}_{45}$Rh		β^-	3.541	79%	0.512	21%
					0.622	10%
$^{109}_{48}$Cd	1.267 y	EC	0.063 e^-	41%	0.088	3.6%
			0.084 e^-	45%	Ag K x rays	100%
			0.087 e^-	9%		
$^{113}_{50}$Sn	0.315 y	EC	0.364 e^-	29%	0.392	65%
			0.388 e^-	6%	In K x rays	97%
$^{137}_{55}$Cs	30.2 y	β^-	0.514 e^-	94%	0.662	85%
			1.176 e^-	6%		
$^{133}_{56}$Ba	10.54 y	EC	0.045 e^-	50%	0.081	34%
			0.075 e^-	6%	0.356	62%
					Cs K x rays	121%
$^{207}_{83}$Bi	31.8 y	EC	0.481 e^-	2%	0.569	98%
			0.975 e^-	7%	1.063	75%
			1.047 e^-	2%	1.770	7%
					Pb K x rays	78%
$^{228}_{90}$Th	1.912 y	6α:	5.341 to 8.785		0.239	44%
		3β^-:	0.334 to 2.246		0.583	31%
					2.614	36%
(→$^{224}_{88}$Ra → $^{220}_{86}$Rn → $^{216}_{84}$Po → $^{212}_{82}$Pb → $^{212}_{83}$Bi → $^{212}_{84}$Po)						
$^{241}_{95}$Am	432.7 y	α	5.443	13%	0.060	36%
			5.486	85%	Np L x rays	38%
$^{241}_{95}$Am/Be	432.2 y	6×10^{-5} neutrons (4–8 MeV) and				
		4×10^{-5} γ's (4.43 MeV) per Am decay				
$^{244}_{96}$Cm	18.11 y	α	5.763	24%	Pu L x rays	~ 9%
			5.805	76%		
$^{252}_{98}$Cf	2.645 y	α (97%)	6.076	15%		
			6.118	82%		
		Fission (3.1%)				
		≈ 20 γ's/fission; 80% < 1 MeV				
		≈ 4 neutrons/fission; $\langle E_n \rangle = 2.14$ MeV				

"Emission probability" is the probability per decay of a given emission; because of cascades these may total more than 100%. Only principal emissions are listed. EC means electron capture, and e^- means monoenergetic internal conversion (Auger) electron. The intensity of 0.511 MeV e^+e^- annihilation photons depends upon the number of stopped positrons. Endpoint $\beta^\pm$ energies are listed. In some cases when energies are closely spaced, the γ-ray values are approximate weighted averages. Radiation from short-lived daughter isotopes is included where relevant.

Half-lives, energies, and intensities are from E. Browne and R.B. Firestone, *Table of Radioactive Isotopes* (John Wiley & Sons, New York, 1986), recent *Nuclear Data Sheets*, and *X-ray and Gamma-ray Standards for Detector Calibration*, IAEA-TECDOC-619 (1991).

Neutron data are from *Neutron Sources for Basic Physics and Applications* (Pergamon Press, 1983).