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Experiment 6

The gamma-ray Scintillation Spectrometer

The spectrometer is designed to record and display the spectrum of gamma-rays emitted by radioactive sources. The energies cover the range from about 10 KeV (X-rays) to nearly 10 MeV. The use of energy units, rather than the wavelength or frequency of the EM waves, for the classification of the emissions from radioactive materials emphasises the particle-like interaction of the gamma-rays with matter. There is no dispersive element, such as a grating or a prism, in the spectrometer. There are no slits, lenses or mirrors.

The detector is a crystal of thallium-doped sodium iodide. When radiation, in the form of an X or gamma-ray photon, or energetic electrons, interacts with the crystal a certain fraction of the energy deposited in the crystal is transferred to the thallium activation centres and subsequently emitted as visible light. Other fractions of the energy deposit are dissipated as heat or by radiation in the invisible portions of the spectrum. The energy deposit is itself proportional to the incident gamma or X-ray photon energy. The number of visible light photons emitted by the centres is directly proportional to the amount of energy deposited and, hence, to the energy of the radiation.

The group of photons emitted by the centres appears as a short flash of light, or scintillation. The photons are detected by a photomultiplier tube (PMT) which produces a voltage pulse with height proportional to the number of photons that entered the tube. Hence, the height of the voltage pulse is proportional to the energy deposited in the crystal. If the dimensions of the crystal are such that the incident radiation is completely absorbed (i.e., the probability of absorption approaches 1), the height is proportional to the energy of the radiation. By means of electronic circuits the number of voltage pulses per second with heights lying between V and $V + dV$ (a channel) is counted and recorded for channels having voltage V (proportional to energy) between pre-set limits. The channels are numbered in order of increasing energy. The device that performs the counting and recording function is called a multi-channel analyzer (MCA). The MCA, the detector crystal and the photomultiplier form the gamma-ray spectrometer.

If a source of monoenergetic gamma-rays, such as Cs^{137}, is examined with the spectrometer it is found that the recorded spectrum consists of a fairly well defined peak at some channel number, and a broad continuum with some smaller peaks that extends from the main peak towards lower channel numbers. The origin of these features of the spectrum is found in the nature of the interactions of the gamma-ray with the crystal.

The gamma-ray interacts with the crystal in one of three ways described below.

1. Photoelectric Absorption. The gamma-ray is annihilated and the energy of the photon is transferred to an electron bound to an atom or ion of the crystal. The kinetic energy of the electron (KeV or MeV), plus its binding energy to the atom or ion (eV), is equal to the energy of the gamma-ray photon. This photoelectron then transfers, on average, a certain fraction

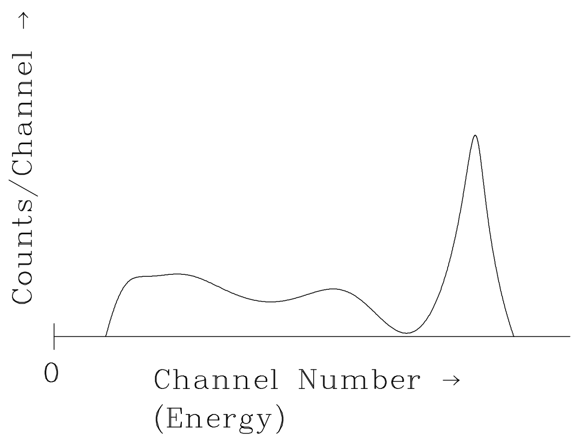

Figure 6.1: Spectrum recorded with $Cesium^{137}$ sources

of its energy to the thallium activation centres as it moves through the crystal. In crystals of the sizes used in practice the photoelectron loses all its kinetic energy within the crystal. The number of photons emitted by the thallium centres is proportional to the gamma-ray energy. The voltage pulse at the output of the PMT that collect the light from the NaI(Th) crystal is proportional to the gamma-ray energy.

2. Compton Scattering. The gamma-ray transfers momentum to an electron and is thereby "scattered" with lower energy and momentum. The scattered electron will excite some thallium centres and cause a voltage pulse to appear at the PMT output. The scattered gamma photon may interact by mechanism (1) and produce a PMT voltage pulse. The height of this pulse, as well as that produced by the interaction of the scattered electron with the crystal, will be less than that produced when the gamma photon energy is deposited as in (1). Since the loss of energy by the gamma photon depends on the scattering angle, there will be a range of pulse heights detected.

3. Pair Production. When a photon of energy greater than or equal to twice the rest energy of an electron interacts with matter it may be annihilated. The photon energy appears as a positron electron pair. When the positron meets another electron a gamma photon (annihilation radiation) appears. For our purposes this effect may be ignored because the gamma sources used do not have sufficient energy.

The spectrum recorded for a $Cesium^{137}$ source with the equipment to be used is shown in Figure 6.1. The large peak at the high end of the pulse height (gamma energy) axis arises from mechanism (1). It is called the Full Energy Peak. The energy corresponding to the channel of the maximum height is the energy of the gamma photon. The step to the lower energy side is the Compton Edge. It is produced by the most energetic electrons arising from the Compton scattering process. The secondary peak at still lower energy arises from the full energy peak of the back-scattered photons in the Compton process. Other lower energy peaks may arise from x-rays produced in the PMT shielding or from background effects. The recognition of the full energy peak and its channel number provides a means to calibrate the apparatus.

6.1 Calibration Procedure

The scintillation crystal and PMT are housed in a protective shield. The anode voltage of the PMT has been set to +1000 V. The gain of the amplifier that follows the PMT has been adjusted to give about 6 volt pulses for the full energy peak of the cesium. If the gain setting or the PMT voltage is altered your calibration will be invalidated and will have to be repeated.

The MCA electronics are mounted on a card in an Apple computer. The program that runs the analyzer and permits various display options for the data, as well as recording on disk, is loaded and set for 256 channels. This setting is sufficient for the energy resolution of the detector. (Read the instruction manuals or ask for help.)

Place the cesium source near the crystal end of the detector and record the spectrum until you have a clean looking spectrum. Note the channel for the full energy peak. Print out a spectrum and a channel count around the peak. Identify the backscatter peak and the Compton edge and verify that the energy value of the feature corresponds to theory in each case.

Repeat the measurements for the sodium^{22}, barium^{133} and cobalt^{57} sources.

The energies are:

Source	Energy
Cs^{137}	0.662 MeV
Na^{22}	0.511 MeV
Ba^{133}	0.356 MeV
Co^{57}	0.1222 MeV

(!) Plot a graph of Channel Number vs. Energy in MeV and determine the slope so that you may measure other gamma energy values.

[?] Why is the full energy peak not sharp?

References

A discussion of the scintillation detector is given in: *Radiotracer Methodology in Biological, Environmental and Physical Sciences*, C. H. Wang, D. L. Willis and W. D. Loveland (Prentice-Hall), Chapters 4, 6, 7, 12. Call Number QC 795.42 W36 1975.

The electronic equipment described is obsolete. The physics of the processes is the important part.

Computer and Printer Commands

Equipment activation procedure

1. Turn on "AC" toggle switch on Regulated High Voltage Power Supply
2. Turn dial from "HV Off" to "1000"
3. Turn on CI Power Supply (lower far right) toggle switch
4. Turn on Oscilliscope
5. Turn on printer and set to "Draft" mode (see section "**Printer Commands**" on page 28).

6. Turn on Apple monitor followed by the Apple computer which computer will display:

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Dos Version 3.3 Apple II Plus
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`alternate slot?  (Y/N)`	type `y`
`alternate slot #(3 or 5)`	type `5`
`printer slot #`	type `1`

(DO NOT TOUCH ANY OTHER DIALS !)

Multi-channel Analyser commands:

Key(s)	Function
`f`	full screen display (spectrum broken into 2048 channels)
`h1`, `h2`	half screen display
`q1`, `q2`, `q3`, `q4`	quarter screen display
←, →	continous scrolling of spectrum (left, right)
`a`	accumulate
`d`	halt accumulation
`c + [return]`	clear screen
`[esc]`	quit
`<` , `>`	change (decrease, increase) vertical scale
`p`	print

For use with paddle: (halt accumulation first)

`r`	paddles control two pointers, the total counts between pointers and the channel numbers are displayed

Printer Commands

Draft Mode

- with the printer on, press "ON LINE" to take the printer offline (the light next to "ON LINE" should now be off)
- press "PRINT MODE" twice (until only the "HS" (**H**igh **S**peed) light is on) to set the printer to draft mode
- press "ON LINE" to put the printer online

Line Feed/Form Feed

- press "ON LINE" to take the printer offline
  - to perform a "line feed", press and release "LF/FF" to move the paper forward one line
  - to perform a "form feed", press and hold "LF/FF" to eject the page
- to put the printer online, press "ON LINE"