SECOND YEAR LABORATORY

HIGH-RESOLUTION GAMMA-RAY SPECTROSCOPY

1 Aims

To introduce the basic properties of γ-rays measured using a germanium detector and multi-channel analyser, and their use in sample analysis.

2 Objectives

1. To understand the apparatus used in high-resolution γ-ray spectroscopy using a germanium detector.

2. To measure and understand the efficiency of a γ-ray detector with standard sources.

3. To investigate the radioactive isotopes present in a series of samples using the detection of γ-rays.

3 Introduction

The advent of Ge(Li) detectors in the 1960s and the availability of large high purity germanium crystals in the 1980s, both lead to revolutions in high-resolution γ-ray studies. Such detectors are comparatively expensive and must be kept at liquid nitrogen temperatures, but are widely used in industry and research where the best possible energy resolution is required. They are used in applications as diverse as studies of the properties of rapidly rotating nuclei and materials analysis.

Gamma-rays interact with matter by photo-electric effect, Compton scattering and pair production, which all lead to the production of fast electrons. As these electrons slow down in the depletion layer of a semiconductor (eg. germanium), they cause electron particle-hole excitations across the band gap, the number of which is proportional to the original γ-ray energy. These excitations act as charge carriers, and under a bias voltage can be collected. Electrical pulses associated with this charge collection are amplified and fed to a computerised multichannel analyser system. For discussions of γ-ray spectroscopy and the mode of operation of a Ge or Ge(Li) detector refer to the references below. A folder of useful information is also available. You will be expected to demonstrate an understanding of the detector system in the lab assessment.

4 Response of the Ge Detector

Familiarise yourself with the apparatus and multichannel analyser by examining the γ-ray spectra associated with the decay of sources of ^{137}Cs, ^{60}Co and ^{22}Na (Also look at ^{241}Am, time permitting). Interpret the spectra using the decay schemes displayed on the wall. Take particular note of the response of the detector to the monoenergetic ^{137}Cs γ - rays. There is considerable structure to this spectrum, despite the incident γ - rays being of only one energy. Explain the origin of the Photopeak, Compton Continuum, Compton Edge and backscatter peaks.

Use the known γ-ray energies of these sources to perform a rough energy calibration of the detector. Look at the spectra for ^{152}Eu, and identify as many peaks as possible in the spectrum

using your rough energy calibration. Plot channel number against energy for the peaks using LSQ or some other suitable program, and once you are happy with the fit, enter the calibration into the multichannel analyser. Save your ^{152}Eu spectrum, and print a copy, on which mark the peak identities. In subsequent weeks, use this information to directly calibrate the detector using just the ^{152}Eu source.

5   Efficiency Measurements

Sources which produce many different γ-rays with known relative intensities can be used to determine the variation of the detector efficiency with energy. Use the ^{152}Eu and ^{133}Ba sources, relative intensities from the folder of information and details about sources from above the source safe, to determine the relative detector efficiency as a function of energy. Explain qualitatively the measured efficiency curve.

6   Sample Analysis

Measurements of radiation coming from a sample can be used to identify components of the sample by detecting γ-rays associated with particular isotopes. Such radioactivity might be natural or induced in such techniques as neutron activation and fluorescence.

Make measurements of the γ-ray spectra associated with the two rocks, and the mud samples available from the demonstrator. In addition, take a long background spectrum, with no other sources around the detector, in order to identify any background peaks that may be present.

Many rocks contain naturally occurring heavy elements with long half lives, such as ^{232}Th and ^{238}U. Over time these elements decay through a chain of unstable isotopes until they reach stable isotopes of Pb or Bi. Using your spectra, and the Segre chart on the wall, identify the decay chains associated with ^{232}Th and ^{238}U. Why are only a some of the isotopes in the decay chains visible in the spectra?

Several of the mud samples are contaminated with a man-made isotope that does not occur in large quantities naturally. With reference to the spectra associated with the mud, identify the contaminant. By comparison with the standard sources, estimate the mass of the contaminant present in the mud. What process could result in the introduction of this isotope into the natural environment?

7   References

[1] J. S. Lilley, *Nuclear Physics: Principles and Applications* (Wiley, 2001).

[2] K. S. Krane, *Introductory Nuclear Physics* (Wiley, 1988).

[3] G. Gilmore and J. Hemingway, *Practical Gamma-Ray Spectroscopy* (Wiley, 1995).

[4] G. F. Knoll, *Radiation Detection and Measurement* (Wiley, 1989).

[5] R.J. Barlow, *Statistics* (Wiley, 1989).

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