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ɣ-e^- Coincidences with Silicon and Scintillator detectors

Large experiments carried out in facilities such as CERN, GSI and RIKEN, and those carried out with smaller accelerators such as CMAM or CNA have something in common, their objective is the detection of radiation either as particles or photons. The objective of this practice is to study the detection of these two types of radiation using the most appropriate detectors for them. In addition, the different types of electronics necessary for each detector will be compared and the coincident detection of electrons and ɣ radiation emitted by ^{207}Bi source will be studied to obtain their decay scheme.

Introduction

Decay Scheme

A **decay scheme** is a graphical representation of all the transitions occurring in a radioactive decay and how these transitions relate to each other, the obtention of these schemes is crucial to test nuclear structure models. A decay scheme usually is the result of many physical processes and requires analyzing multiple types of radiation. In this practice, we will study two decays and through them four processes: Electron Capture, Internal conversion, Beta decay and Gamma Emission.

Transmutation: Beta decay vs Electron Capture

Both **Beta decay** and **Electron Capture (EC)** involve a transformation within the nucleus, where a proton is converted into a neutron or vice versa, resulting in a change in the atomic number and the transmutation of the element. If a charged particle and a corresponding neutrino are emitted to maintain charge and momentum conservation, the process is called β^+ ($p^+ \rightarrow n + e^+ + \upsilon$) or β^- ($n \rightarrow p^+ + e^- + \bar{\upsilon}$). If an electron from the inner atomic shell is absorbed, transforming the proton into a neutron, and emitting just a neutrino the process is called EC electron capture ($p^+ + e^- \rightarrow n + \upsilon$).

These decays are all exothermic processes with an associated quantity of energy available to be released, the Q-value. In beta decay, the released energy is shared between three decay products, while in EC, only between two thus the momentum of the daughter nucleus and the neutrino will be fixed. In both cases, the daughter nucleus can either populate its ground or excited states, if the latter is true a deexcitation process will follow.

Deexcitation: Gamma Radiation vs Internal Conversion

A **gamma ray** is a high-energy photon emitted by an excited atomic nucleus as a mode of de-excitation to a lower energy state; **internal conversion (IC)** is an atomic decay mode that normally competes with gamma decay. The main difference is that the latter case happens on an atomic (not nuclear) scale: **the atom ejects an electron** from an inner shell and the hole left is filled by an electron from an upper shell releasing an X-ray photon. In nuclear physics, the **internal conversion coefficient (*α*)** describes the rate of internal conversion, which can be empirically determined by:

$$\alpha = \frac{\text{number of de-excitations via electron emission}}{\text{number of de-excitations via gamma-ray emission}}$$

In this laboratory session, we will study the decay of ^{207}Bi (EC → γ / IC). Below we can see the decay scheme.

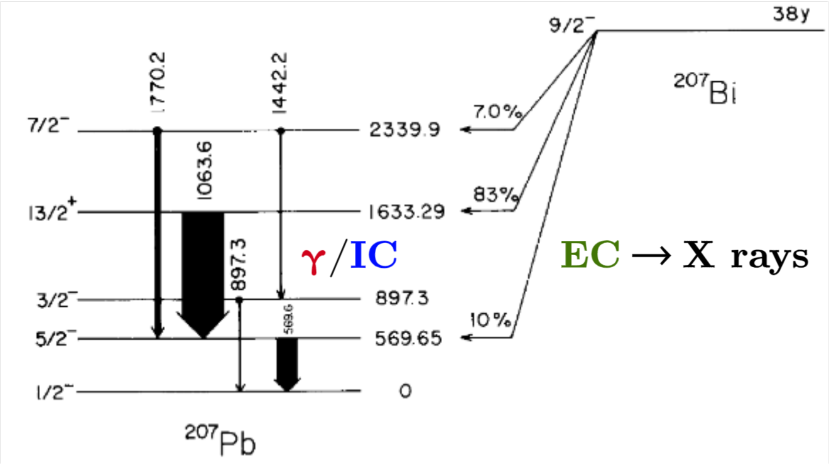

Figure 1: Partial decay scheme of ^{207}Bi [Modified from *Y. Fujita et al. Nuclear Physics A484 (1988) 77-89*]

Table 1: Intensities of gamma and conversion electron emissions of ^{207}Bi decay [*F.G. Kondev, S. Lalkovski. Nuclear Data Sheets 112, 707 (2011)*]

Gammas	
Transition (keV)	**Intensity (%)**
569.6	97.75 %
1063.6	74.5 %

Conversion electrons	
Transition (keV)	**Intensity (%)**
569.6	K ⟶ 1.537 %
	L ⟶ 0.442 %
1063.6	K ⟶ 7.08 %
	L ⟶ 1.84 %

Table 2: Atomic-electron binding energies of Pb atom [*Richard B. Firestone et al. Table of Isotopes (1996)*]

Atomic-Electron Binding Energies of Pb	
Shell	**Energy (keV)**
K	88.0045
L	15.8608

Table 3: GEANT4-simulated detection efficiencies for gamma transitions and electron emissions for Pyramid and DSSSD detectors, respectively. Efficiencies are expressed as percentages.

Pyramid	
Transition (keV)	**Efficiency**
569.6	1.528%
1063.6	0.661%

DSSSD	
Transition	**Efficiency**
K1	0.111%
L1	0.080%
K2	0.007%
L2	0.004%

Detectors

Photon detection

To detect a photon, it must transfer part or all its energy to an absorbent material, this can be done through three main mechanisms: photoelectric effect, Compton scattering and electron pair production (if the photon energy is high enough). To detect ɣ radiation, we will use **scintillation detectors** (see the Scintillator lab).

Electron detection

To detect charged particles, we will use **multi-segmented silicon semiconductor detectors (specifically, a Double-Sided Silicon Strip Detector DSSSD)**, that is, the metallic contacts that collect the charge are segmented in the form of independent horizontal and vertical strips of 3x50 mm^2, forming a pixelated surface that allows us to know the point at which the particle hits the detector. The detector has an active area of 50x50 mm^2, it is divided into 16 horizontal and 16 vertical bands in the front and rear electrodes, with the surface of each pixel being 3x3 mm^2.

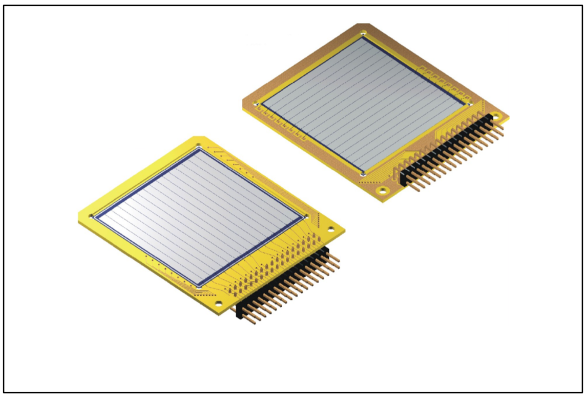

Figure 2: Double Sided Silicon Strip Detector (DSSSD)

Objectives

The main objective of the laboratory practice is to study the decay scheme of ^{207}Bi from the measurement of the radiation emitted by the source.

For this purpose, the detectors used to measure the different types of radiation as well as the electronic components and software used for data collection will be explained in detail. Several sets of measurements will be carried out with different configurations. These data will be analyzed by the students and both, the conclusions obtained and the detailed analysis process, will be included in the global report.

The objective of the electronic chain is to shape the electronic signal coming from the detectors to be processed by the Data Acquisition system (DAQ). In this practical exercise, we can observe the **energy signal** coming from both detectors. With the use of digital electronic, a **trigger** signal will be processed to detect properly the energy signal coming from the DSSSD and the pyramid detector. A scheme of the experiment can be found in Figure 3.

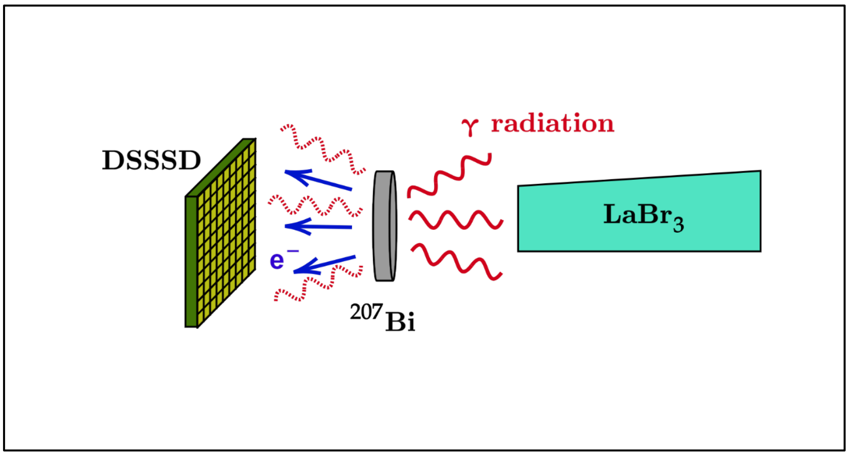

Figure 3: Diagram of the experimental setup.

The electronic modules that will be used in this exercise (see the **Materials** section) are:

1. **Preamplifier**: Amplifies the weak signals coming from the detector, they are normally mounted as close as possible to the detector to minimize energy losses of this weak signals in the cable.
2. **Digitizer (MDPP32-SCP):** Digitizes the slow preamp analogic signal
3. **Digitizer (MDPP16-QDC):** Digitizes the fast PM-tube signal
    i. **Amplifier:** Amplification is done by the digitizer
    ii. **Constant fraction discriminator:** CFD is done in the Digitizer
4. **MLVC:** Control the modules, performs the logic and transport the data to the computer
    i. **Gate Generator:** logic signal of a determined duration and frequency with which to generate the acquisition trigger.
    ii. **Logic units:** logic operations (AND, OR, ...), employed to define the conditions for the gate
5. **MVME software in the computer**
    i. **Perform the readout via USB3**
    ii. **Online/offline analysis**

Materials

1. DSSSD detector
2. Pyramid detector
3. Osciloscope
4. MHV-4 High Voltage Supply
5. Pre-amplifier: MPR-32
6. MDPP-16 QDC
7. MDPP-32 SFP
8. MVLC Controller
9. MVME Mesytec Acquisition Software
10. ^{207}Bi and ^{22}Na radiation sources

Laboratory Procedure

1. Setup Silicon and scintillator detectors. Align the setup.

2. Setup and test the electronics associated to both types of detectors.

3. Measure the radiation that we will use to calibrate our detectors.

4. ^{207}Bi radiation source measurements.

Laboratory Report

The report of this practice must include the following:

- Detailed comparison between analogic and digital electronics.

- Identification and explanation of each signal observed step by step from detector output to acquisition software input.

- All the spectra calibrated.

- Analysis of each spectrum obtained for each detector and particle (also ɣ).

- Coincidences study between the different detectors.

- Identification and physical explanation about the radiation emitted by ^{207}Bi source. What we see in our spectra? What should we see that it's not present in our data? Explain in detail the decay of ^{207}Bi.

Reports

For questions you can write to: amanda.nerio@csic.es, jf.gonzalez@csic.es

References

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