ɣ-e^{-} Coincidences with Silicon and Scintillator detectors

From the large experiments carried out in facilities such as CERN, GSI and RIKEN, to 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 and ^{22}Na sources 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

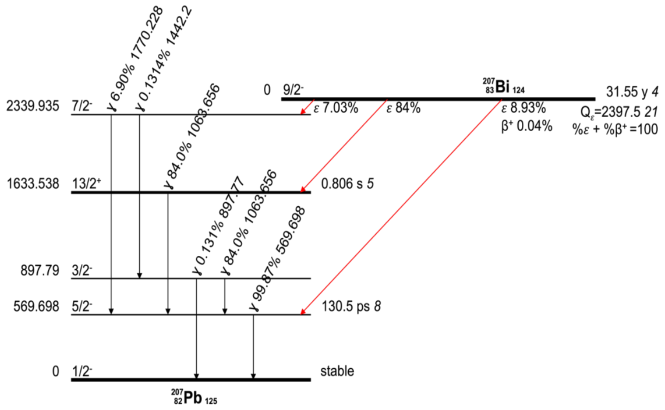
Both **Beta decay** and **Electron Capture (E.C)** involve a nucleon experiencing a transformation to the other type. If a charged particle and a corresponding neutrino are emitted to maintain charge and momentum conservation, the process is called β^{+} ($p^{+} \rightarrow n + e^{+} + \upsilon$) or 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 ($p^{+} + e^{-} \rightarrow n + \upsilon$).

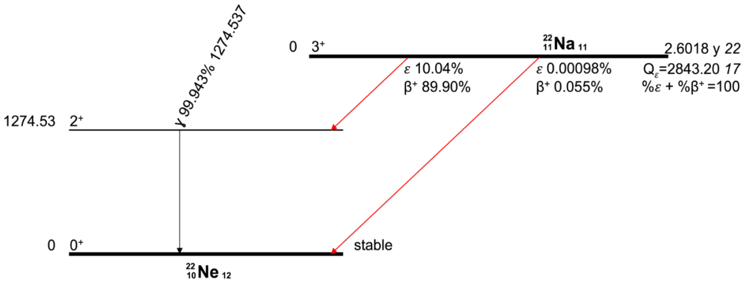
These decays are all exothermic processes with an associated quantity of energy available to be released, the Q-value. In beta decay, the released energy is shared between three decay products, while in EC, only between two thus the momentum of the daughter nucleus and the neutrino will be fixed. In 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 this laboratory session, we will study the decays of Na^{22} (β^{+} + ɣ) and Bi^{207} (EC +IC). Below we can see the decay schemes followed by each radiation source.





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**. A scintillator is a material that exhibits luminescence, this means that it will emit a light pulse of a characteristic wavelength in the visible spectrum when ionizing radiation passes through it, the amount of emitted light will be proportional to the energy of the impinging gamma ray. We speak of a scintillation detector when we attach a scintillating material to a light sensor, such as a photomultiplier tube (PMT) or a photodiode. The photomultiplier absorbs the light emitted by the scintillator and re-emits it as electrons by the photoelectric effect, and then causes the electrons to multiply in a cascade of dynodes at higher electrical potential, thus producing an electrical current.

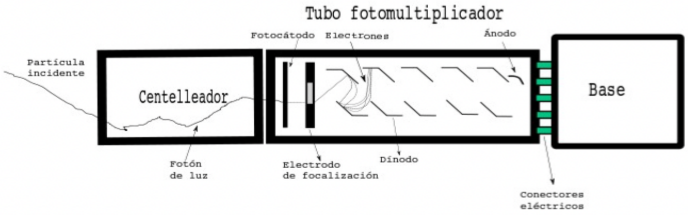


Figure 1. Scintillator crystal with photomultiplier attached.

Electron detection

To detect charged particles we will use **multi-segmented silicon semiconductor detectors (DSSSD)**, that is, the metallic contacts that collect the charge produce a segmentation 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.

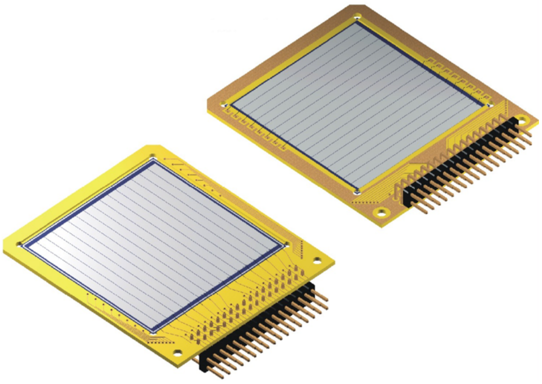


Figure 2: Double Sided Silicon Strip Detector (DSSSD) scheme.

Objectives

The main objective of the laboratory practice is to obtain the decay scheme of ^{207}Bi and ^{22}Na 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.

Electronic chain

The objective of the electronic chain is to shape the electronic signal coming from the detectors in order to be processed by the Data Acquisition system (DAQ). In this practical exercise, we can distinguish between **energy signal** which includes all the information about the radiation detected, and **trigger** signal that will be processed faster in order to detect properly the energy signal. A scheme of the path that the electric signals will go through can be found in Figure 3.

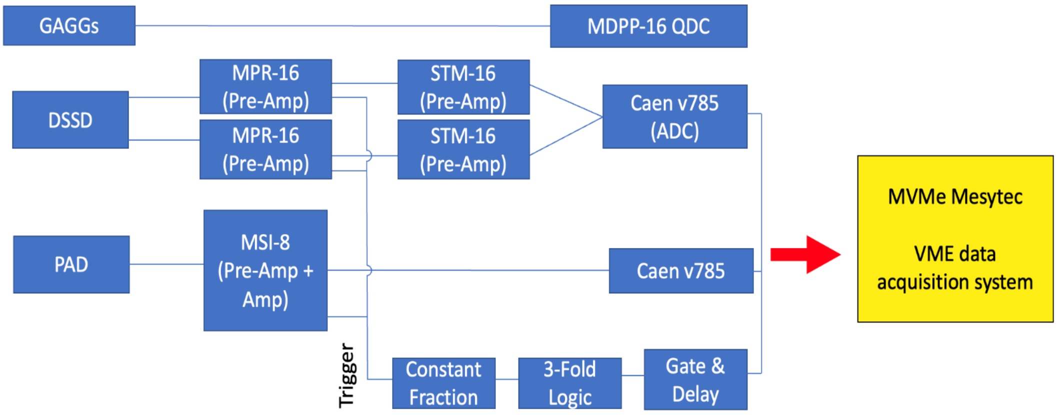


Figure 3: Scheme of the electronic chain of the experiment.

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. **Amplifier:** Amplifies the signal provided by the preamplifier and shapes it in a way convenient for further processing, this is crucial to avoid pile-up shaping at the end of the signal.
3. **Constant fraction discriminator:** Receives the time (fast) signal and transforms it into a logic (step) signal, that will be further utilized.
4. **Logic units:** Can perform multiple logic operations (AND, OR, ...), employed to define the conditions for the gate
5. **Gate Generator:** Provides a logic signal of a determined duration and frequency with which to generate the acquisition trigger.
6. **Multichannel analyzer:** Multichannel Analyzers (MCAs) are workhorse instruments in many scientific measurements. An MCA analyzes a stream of voltage pulses and sorts them into a histogram, or “spectrum” of number of events, versus pulse-height, which may often relate to energy or time of arrival.
7. **Analog to Digital Converter (CAEN-V785):** Converts the information of an analogic signal into an equivalent digital number.
8. **Charge integrator Digitizer (MDPP16-QDC):** Converts the signal from the detector to digital.
9. **MLVC:** Sends the digitalized information to the computer.

Materials

1. GAGG Scintillator detectors.
2. DSSSD and PAD Silicon detectors in Telescope configuration.
3. Osciloscope.
4. MHV-4 High Voltage Supply
5. Vacuum chamber.
6. Pre-amplifiers: MSI-8, MPR-16.
7. Amplifiers: STM-16.

8. MDPP-16 QDC and CAENv785 Digitizers and ADCs.
9. MVLC Controller.
10. MVME Mesytec Acquisition Software.
11. Fan In/Fan Out Unit, 3-Fold Logic unit and Gate & Delay.
12. 16 CH Constant Fraction Discriminator.
13. ^{207}Bi and ^{22}Na radiation source

Laboratory Procedure

1. Setup Silicon and scintillator detectors.

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 processed (energy and trigger) step by step from detector output to acquisition software input.

- All the spectra calibrated.

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

- Coincidences study between the different detectors and 2d-histograms plots.

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

Reports

All reports must be sent to: master.nuclear@iem.cfmac.csic.es
For questions you can write me to: vicente.garcia@csic.es

References

1. K.S. Krane "Introductory nuclear physics".
2. F. Knoll: "Radiation detection and measurement".