Z33 - Measurement and Analysis of the γ Quanta Energy Distribution with a Scintillating Spectrometer. Determination of the γ Rays Attenuation Coefficients in Metals.

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The purpose of the experiment is to perform measurements of absorption spectra of γ rays originating from different radioactive isotopes using a NaI(Tl) scintillation detector and a multichannel analyzer. The spectra of ^{60}Co, ^{22}Na, ^{137}Cs, ^{1}33Ba isotopes are measured and analyzed based on appropriate decay schemes. Particular attention is paid to identification of parts of the spectra corresponding to different forms of interaction of γ quanta with a scintillator and shielding materials. In the second part of the experiment, γ quanta energies distributions of ^{60}Co and ^{137}Cs are measured after passing through a growing layer of metal absorbers of Al, Fe, Cu, Pb. A qualitative analysis of the change in the shape of the spectrum is carried out together wit the determination of the absorption coefficients for these materials.

Preparatory questions

- Natural radioactive decays, decay schema and basic quantities preserved during decays [1].
- Radiation activation and doses units, their definitions. Range of different types of radiation and methods for radioprotection [2].
- γ radiation sources and their characteristics: wavelength of the γ rays, their energy range. Diagrams of ^{60}Co, ^{22}Na, ^{137}Cs and ^{1}33Ba decays. Phenomenon of internal conversion and expected values of X-ray energies for the above isotopes[1].
- Interaction of the γ rays with materials. Description of different components of spectra coming from e.g. ^{60}Co or ^{22}Na [1].
- Absorption of the γ rays, qualitative description of the absorption coefficients energy dependence.
- Principle of NaI(Tl) scintillation counter and photomultiplier operation. Characteristics of such a counter. The definition of energy resolution $R = \Delta E/E$ [1].
- The definition of the of normal distribution (Gauss), standard deviation,confidence level, Full With at Half Maximum (FWHM). The concept of statistical and systematic uncertainty. Propagation of elementary uncertainties in indirect measurements [3].

Computational assignments

- Define the decay constant λ, decay half-life and mean lifetime and activity A of a given sample. Write the differential equation and its solution for the number N of nuclei as a function of time and for the activity.
- Derive from the conservation of energy and momentum equations describing energy of scattered photon/electron in the Compton effect. Calculate the Compton edge and explain why on the measured ^{60}Co spectrum one cannot see separated edges for the two γ quanta emitted.

Apparatus and materials

The experimental setup consists of a computer connected to a multi-channel analyzer, crate with electronic modules (including signal amplifier), high voltage power supply and scintillation detector (in Figure 1 it is hidden behind a lead shield). The scheme of the experimental system can be found in the exercise manual (IV. Scheme of the apparatus). When switching the power supply on, it is necessary to observe whether the voltage pointer shows the correct value.

Experiment

- Switch on the measurement apparatus according to the Instruction, put the ^{60}Co source and check detector signals with oscilloscope and after data collection using a multi-channel analyzer. If necessary, adjust the gain of the used amplifier. Set up the multi-channel analyzer to record of 1024 channels is sufficient. Before further measurements, please make sure that the acquired spectra (in the ASCII format) can be then exported and read by e.g. Origin program.
- Register spectra of ^{60}Co, ^{22}Na, ^{137}Cs and ^{1}33Ba isotopes. Save also parameters of the used sources (activity, label). One can also determine the energy resolution of the used scintillation detector and do its calibration curve. Determine the systematic uncertainty in determining the location of

Figure 1: Experimental setup

photoelectric peaks in the spectra (e.g. by performing few Gaussian fits changing the range of used data including asymmetric intervals. Discuss spread of the determined mean values).

- Prepare absorbent plates and measure their thickness using caliper (the measurement should be done in several places which minimizes the uncertainty due to deformations). Collect spectra for a given type of absorbent paying attention if the source throughout the measurement was at the same distance with respect to the detector (one can e.g. use a adhesive tape to fix the position of the source). One should also perform a measurements without any source to determine the spectrum for background. Please remember to normalize the collected spectra to the time of measurement (in seconds).

Data analysis

- Present spectra collected in the first part of the experiment in a raw form (number of counts normalized to the time of measurement as a function of a channel number) and determine the channel number corresponding to the lines of a total absorption of γ rays. To calibrate the detector use ^{60}Co, ^{22}Na, ^{137}Cs. Rescale the spectra changing the channel number to the energy deposited in the detector. Interpret all the structures on the spectra (mark the energies corresponding to the characteristic peaks including the Compton edges). Interpret the ^{133}Ba.

- Determine the energetic resolution $R = \Delta E/E$ of the detector as a function of energy. Calculate the mean resolution (with its uncertainty).

- Plot spectra (number counts per second in a function of the channel number) for all types of studied absorbents and their several selected thicknesses. Subsequently, determine the number of counts in the maximum of full absorption for all the spectra paying special attention to background originating from the Compton edge (or in the case of ^{60}Co also from the second peak). The background should be estimated either by modeling a function describing the Compton edge shape and Gauss function (for maximum of full absorption) or, in the case of the ^{137}Cs spectrum, by integration of the right and left half of the spectrum (relative to the maximum) and comparison of inputs and estimation of the contribution from the background.

- For each absorber make distributions of the number of events estimated in the peak of full absorption in a function of the thickness (in linear or logarithmic scale). For each absorber determine the linear and mass absorption coefficients by fitting the distribution with a linear or exponential function. Compare the obtained values to the coefficients in the literature paying attention to the energy of the γ quantum for which the given coefficient was determined.

Safety rules

Do not disassemble (e.g. by removing the housing) electronic circuits, high voltage power supplies and detectors since You can be electrocuted.

References

[1] W. R. Leo, *Techniques for Nuclear and Particle Physics Experiments*, Spriger-Verlag 1994 (chapters 2.7, 7.1, 7.2)

[2] W. R. Leo, *Techniques for Nuclear and Particle Physics Experiments*, Spriger-Verlag 1994 (chapter 3)

[3] W. R. Leo, *Techniques for Nuclear and Particle Physics Experiments*, Spriger-Verlag 1994 (chapters 4.5, 4.6, 4.7)