A4: Compton effect

1. Abstract

The Compton effect and its evaluation belongs to the fundamental experiments in physics. In the experiment, the validity of the Compton formula will be demonstrated. Thereto, basic measurement methods of nuclear physics (γ-detection, coincidence methods) are applied. The aim is also to familiarize yourself with typical nuclear electronics circuits since their further developments are for example used in modern time-resolved spectroscopy.

2. Preparation

2.1 Theoretical foundations [1, 2]

Inelastic interaction of γ-radiation with matter can occur by **photoelectric effect***, **Compton effect*** and **pair production***, whose cross sections have different **dependence on energy and atomic number*** (see instructions for experiment A2 - gamma spectroscopy).
The energy loss due to the Compton effect can be described by scattering of a photon at a free electron, where conservation of energy and momentum in an elementary way lead directly to the **Compton formula in energy and wavelength notation***. The introduction of the **Compton wavelength*** allows a rapid estimation of the maximum energy loss. The intensity of Compton scattering is described by the **Klein- Nishina formula**, which yields the **energy and angular distribution** for the scattered γ-rays.

2.2 Operation of the used equipment

The energy of the γ-ray quanta and Compton electrons will be measured with a calibrated **scintillation counter***. Indications of photoelectric effect and Compton effect will be visible in the spectra. Particularly the **Compton edges*** can be observed. The Compton scattering in a given solid angle can be filtered out by **coincidence measurements*** of the scattered γ-photon and the Compton electron. Familiarize yourself with the circuit of a coincidence stage [3], the operation of a **multi-channel analyzer** in the **ADC mode** and the other mentioned instruments in the equipment list (see FB-library). At first, only the fundamental understanding of the experimental setup is important, the details arise when experimenting.

2.3 Measurement and evaluation methods

The scattered γ-ray photons and Compton electrons are measured in a coincidence circuit with two scintillation counters, where the electron detector is used at the same time as the scattering material.

* The topics marked with * must be learned before the start of the experiment and the **bold** printed should be known for the discussion in the debriefing.

The assignment of the channels of the multi-channel analyzer to energy values takes place by measurements with known photon energy of the calibration substances. The corresponding β^+ respective β^- **decays of ^{22}Na, ^{60}Co, ^{137}Cs and ^{241}Am** are shown for example in [4]. It is recommended to study the γ-spectrum of ^{22}Na (where do the individual lines come from? why can the 511 keV quanta be used for the coincidence adjustment?).

2.4 Radiation protection

Familiarize yourself with the **values*, units*** **and measures** of radiation protection. As a reminder: this experiment is not permitted for pregnant women.

3. Tasks

a) Verification of both scintillation detectors with the calibration substances ^{241}Am and ^{137}Cs (one calibration point each), ^{22}Na and ^{60}Co (two calibration points each). Draw a regression line.
b) Measurement of the Compton edges for both ^{22}Na lines at one of the scintillation detectors (which counter is more favorable?); comparison with the theoretical values. Discuss the relative intensity of photopeak and Compton continuum, and why this is different for the two detectors.
c) Adjustment of the coincidence with the ^{22}Na calibration substance. Verify the spatial correlation of the γ-photons (which one of the two γ-lines?). How can one distinguish between true and accidental coincidences? Take a measurement without radiative substance in order to record the background activity. Subtract this background spectrum from the other data.
d) Measurement in Compton geometry with a $\approx$0.2 mCi ^{22}Na source (inserted by the supervisor!), initially without coincidence. Where do you expect the Compton events for the two detectors at 60°, 90° and 120°?
e) Determination of the energy of the scattered γ-quanta and Compton electrons for the scattering angles of 60°, 90° and 120° for the 511 keV and 1274 keV radiation of the $\approx$0.2 mCi ^{22}Na source and proof of the Compton formula (energy and momentum conservation). Sketch the derivation of the Compton formula.
f) How does the of the ratio of random and true coincidences depend on the activity *A* of the source (decays per second) and the coincidence resolution time τ?

4. Experimental setup

4.1 Sketch

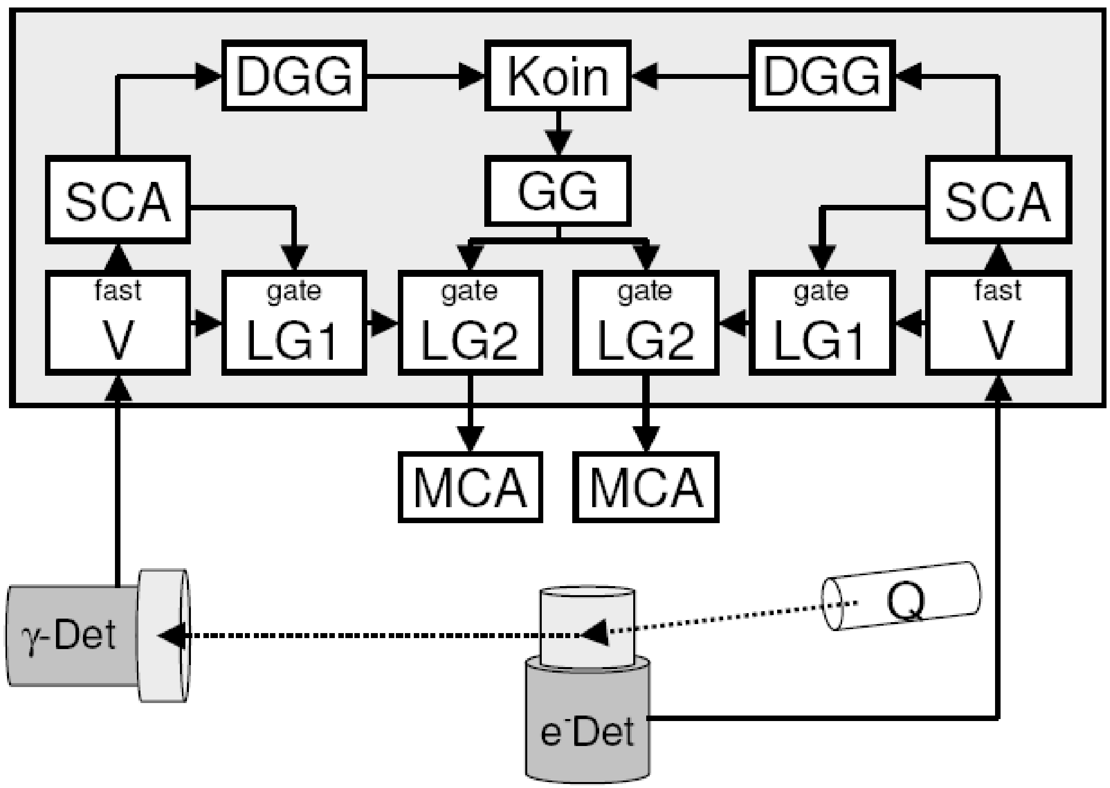

Figure 1: The block diagram is shown in the upper part of the picture (for explanation of abbreviations see equipment list). Note that the actual detector signal from the amplifier V via the linear gates (LGs) to the MCA pass depending on whether the control inputs (gates) of the LGs are enabled or not. The detection of the coincidence and blocking of random coincidences is done by the other components.
In the lower part of the picture, the scattering geometry for the tasks d-e is shown. The calibrating substances are placed between the two detectors for the tasks a-c. Can you guess the influence of the different geometries of the two otherwise identical scintillation detectors on the signals?

4.2 Equipment list

	device	note to the function
Q	^{22}Na source	
Det	NaI scintillation counter	including photomultiplier
V	amplifier	with direct and delayed output
SCA	single channel analyzer	amplitude window
DGG	delay gate generator	pulse shaping and delay
Koin	coincidence stage	
GG	gate generator	pulse lengthening
LG	linear gate	1:1 amplifier with control input ("gate")
MCA	multi channel analyzer	

4.3 Note on certain procedures

(a) The amplifiers of both scintillation detectors need to be adjusted so that the most energetic calibration line can yet easily be measured, the line positions (e. g. the 511 keV ^{22}Na line) should be approximately equal. Both counters have to be calibrated because of deviations in the calibration characteristics (where are they due to?).
(b) The adjustment of the coincidence with the coincident 511 keV γ-ray quanta of ^{22}Na is carried out at the delays of the DGGs regarding simultaneity of the DGG pulses (compare with the oscilloscope).
(c) The coincidence stage at the LG2s can be switched off and on ("normal/gated" or "anti-/coincidence"), so that the calibration measurements as well as the coincidence measurements can be performed without changing the wiring. The two LG1s serve for blocking random coincidences. Due to the high source activity attention must be paid to a good shielding of the detectors, but also of entire assembly. Please use the Geiger-Müller counter for this.
(d) For certain angular positions (which ones according to the Compton formula?) the energies of the scattered γ-quanta of the 511 keV and 1274 keV radiation move relatively close together. Hence, measure the lines again separately at that angle. You can do this by suppressing the other line through suitable adjustment of the SCA of the Compton electron signal.

5. Notes on analysis and discussion

Errors may occur at the calibration as well as during the coincidence measurements, which result in systematic deviations of the experimental values from the theoretically expected ones. Discuss the possible causes.
An essential role for the error discussion plays the **size of the two detectors** (measure out!). How is the Compton angle ϑ defined in this experiment? Calculate the error of the energy ΔE as a function of $\Delta\vartheta$ using the Compton formula. How big is $\Delta\vartheta$ in this experimental setup? Is $\Delta\vartheta$ dependent on ϑ?

6. Literature

[1] Marmier, Nuclear Physics I, 11 Ed 1985
[2] E.W. Schpolski, Atomic Physics I, 13 Edition 1975
[3] P. Stoll, Experimental Methods of Nuclear Physics, Springer 1966
[4] F. Kohlrausch, Praktische Physik, Vol 3, 23 Edition, 1986, No. 148 and 165

Current literature on the Fortgeschrittenpraktikum can be found in the Department Library.