PHYWE

Photonuclear cross-section / Compton scattering cross-section

LEP 5.2.46

Related topics

γ-radiation, interaction with material, photoelectric effect, Compton effect, pair formation, detection probability, scintillation detectors.

Principle and task

The radiation of ^{137}Cs and ^{22}Na is measured with a scintillation detector and the energy spectrum determined with a pulse height analyzer. The fractions of the spectra caused by Compton scattering and those caused by the photoelectric effect are determined on the basis of their areas. The results are used for determining the ratio of the effective cross-sections and examining its energy dependence.

Equipment

Radioactive source, Na-22, 74 kBq	09047.52	1
Source Cs-137, 37 kBq	09096.01	1
Pulse height analyser	13725.93	1
Gamma detector	09101.00	1
Operating unit f. gamma detector	09101.93	1
High-voltage connecting cable	09101.10	1
Oscilloscope, 20 MHz, 2 channels	11454.93	1
xyt recorder	11416.97	1
Support rod -PASS-, square, l 400 mm	02026.55	1
Right angle clamp -PASS-	02040.55	1
Tripod base -PASS-	02002.55	1
Adapter, BNC-socket/4 mm plug pair	07542.26	1
Screened cable, BNC, l 750 mm	07542.11	3
Connecting cord, 750 mm, red	07362.01	2
Connecting cord, 750 mm, blue	07362.04	2

Problems

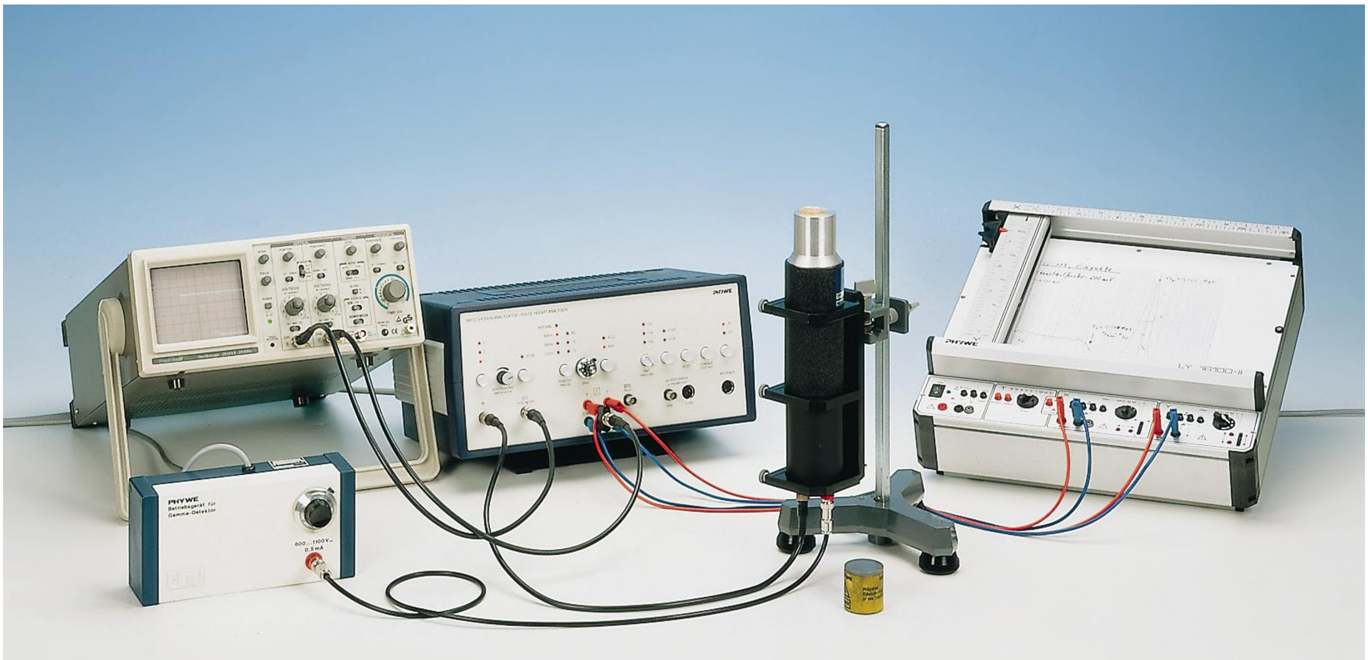
1. Measurement of the γ-spectra of ^{22}Na and ^{137}Cs, using a scintillation detector.
2. Determination of the ratio of the specific effective cross-sections due to the Compton effect and the photoelectric effect in photons having energy values of 511, 662 and 1275 keV.

Set-up and procedure

The layout of the detection apparatus is shown in Fig. 1. The detailed directions in the operation instructions for the γ-detector, the pulse height analyzer, the oscilloscope and the recorder must be complied with. The detection apparatus must be calibrated before each measurement. The following settings are selected:

Detector voltage:	10.00 scale divisions in the case of ^{137}Cs 8.50 scale divisions in the case of ^{22}Na
Pulse height analyzer:	
Mode of operation:	automatic
Window:	200 mV
Zoom:	Off
Base:	10.00 scale divisions
Dwell time:	1.6 s
Amplification:	Coarse and fine adjustment to be made with the oscilloscope in such a way that the highest pulses at the analogue output reach a height of 9 V
Recorder:	Input amplification to conform with the paper format; zero point and coordinates to be marked exactly.

Fig. 1: Experimental set-up for γ-spectroscopy.



After these settings have been completed, no furhter changes may be made to the detection apparatus or to the counter geometry.

Photon detectionis based on interactions between the electromagnetic radiation and the electrons of the scintillator material. A distinction has to be made between the photelectric effect, the Compton effect and pair formation. The specific cross-sections for each of these effects are critical in determining the shape of a spectrum and the integral detection probability. They are to a large extent energy-dependent.

Pair formation requires an energy of at least 1022 keV, which is double the resting energy of the electron. This effect can therefore be disregarded in the energy range in question.

In the case of the photoelectric effect, the electromagnetic field of a γ-quantum interacts with an electron in accordance with the laws of quantum mechanics, transmitting its complete energy to this electron which continues to move preferentially in the direction of the γ-quantum. Photoelectrons are represented by a sharply defined line in the γ-spectrum. The interaction integral assumes imperceptibly small values at high energy levels.

The Compton effect is a corpuscular property of the γ-quantum. It results from the laws of conservation of energy and of momentum, using a conventional calculation, that on impact a γ-quantum imparts a proportion of its energy to the impact electron; this proportion is a function of the direction of scattering and amounts to:

$$\Delta E = \frac{E\, 2\, \Lambda \sin^2\frac{\Phi}{2}}{2\, \Lambda \sin^2\frac{\Phi}{2} + \frac{h \cdot c}{E}}$$

in which $\Lambda = h/m_o c^2$ denotes the Compton wavelength.

The effective cross-section for the Compton effect is obtained only from a quantum-electro-dynamic calculation, which yields the Klein-Nishina equation.

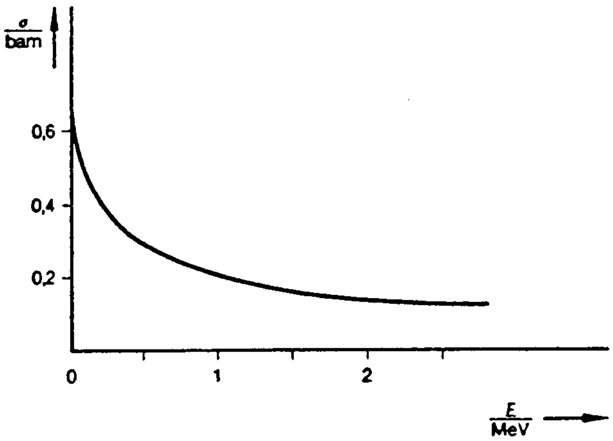
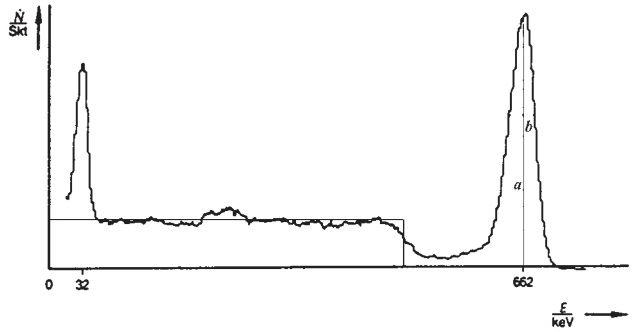


Fig. 2: Cross-section for the Compton effect σ_C in acordance with the Klein-Nishina equation.

Fig. 3: γ-spectrum of ^{137}Cs.



The Compton-scattered fraction in a γ-spectrum is represented by a continuous plateau which extends from the energy 0 to a steep fall at the Compton border; the electrons detected here are generated by a central impact and entrain the maximum possible energy. The area portions in the spectrum provide a direct measurement of the occurrence of the particular effect.

Photoelectric lines have an approximately gaussian shape, so that their area A_F is obtained from the peak height α and the half width b in accordance with the following formula

$$A_F = \alpha \cdot b\, \sqrt{\pi}/2 \cdot \sqrt{ln2}\ .$$

The Compton background can be approximated by a rectangular area A_C.

The ^{137}Cs spectrum includes in addition to the photoelectric line a further X-ray line which can be disregarded in the evaluation.

In the ^{22}Na spectrum the Compton background of the 1275 keV line is used as the startline for evaluation of the 511 keV line. A rise is observed in the Compton background of the 511 keV line, which sould not be taken into account in the evalua-

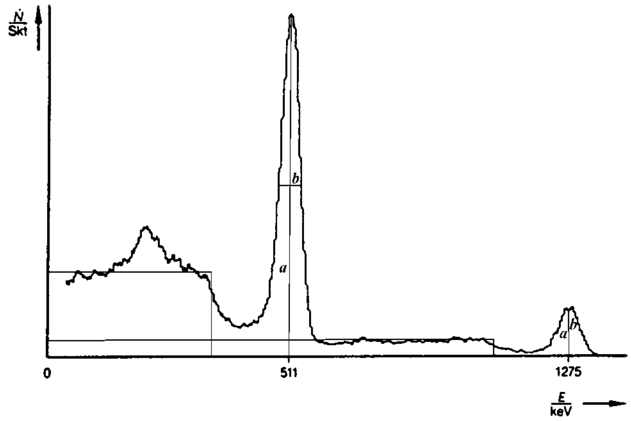
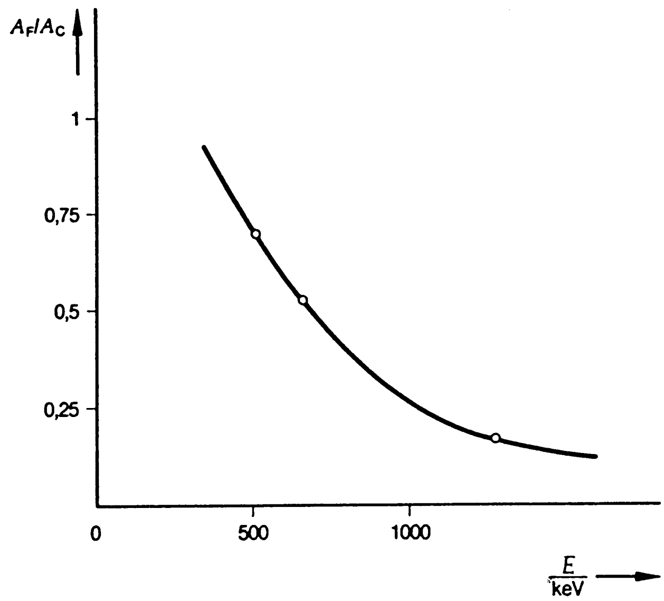


Fig. 4: γ-spectrum of ^{22}Na.

Fig. 5: Compton fraction and photoelectric fraction in the spectra in Fig. 3 and 4.



tion, since it originates from γ-quanta which have undergone back-scattering in the source holder and in consequence have a lower energy.

The following areas are obtained from the spectra in Figs. 3 and 4:

A_F = 18 cm^2 and A_C = 25.6 cm^2 where E = 511 keV.

The ratio of the areas is therefore A_F/A_C = 0.70.

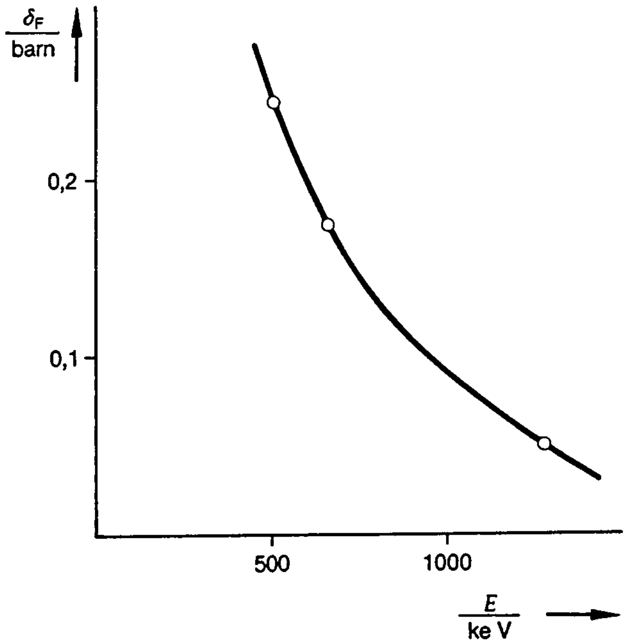
A_F = 19.5 cm^2 and A_C = 36.7 cm^2 where E = 622 keV.

The ratio of the areas is therefore A_F/A_C = 0.53.

A_F = 2,8 cm^2 and A_C = 16.3 cm^2 in the case of E = 1275 keV.

The ratio of the areas is therefore A_F/A_C = 0.17.

Fig. 6: Specific effective cross-section for the photoelectric effect σ_F .



On the assumption that the area ratio corresponds to the effective cross-section ratio, the specific cross sections for the photoelectric effect σ_F are obtained by inserting the numerical values for the cross-section in the case of the Compton effect σ_C from Fig. 2.