Absorption of gamma radiation

1. Radioactive source

γ radiation can be emitted by transitions of atomic nuclei between their energy levels. Consequently, the radiation has character of spectral lines and energy of its photons is usually in the range 0.05 – 3 MeV. Further, it can be produced e.g. by electron-positron annihilation, nuclear fusion or fission or inverse Compton effect.

Two different sources of γ radiation are used during this measurement: ^{137}Cs which produces γ photons with energy 661.7 keV and ^{60}Co which produces protons with energies 1,1725 and 1,3325 MeV. The decay scheme of ^{60}Co nucleus is shown in the fig. 1. Since the time of life of γ emitters is usually short, the ^{60}Co is used instead of them. ^{60}Co is in the reality β^- source with half-life over 5 years. Product of the β^- decay is $^{60}_{28}$Ni with excited nucleus that relaxes by emission of γ radiation.

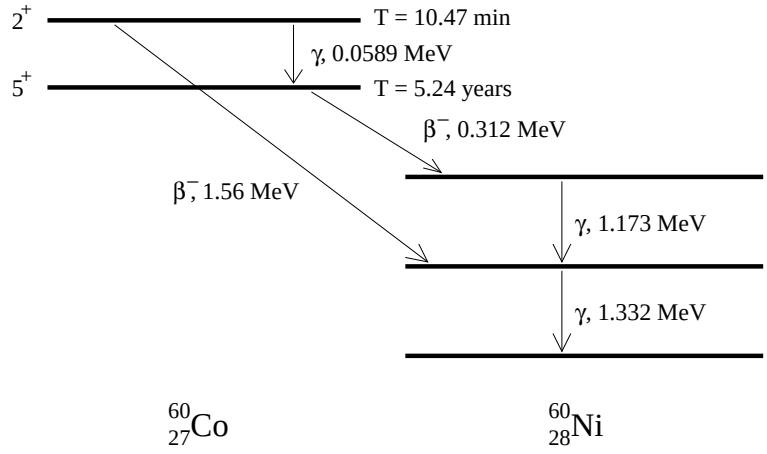

Figure 1: *Decay schema of* $^{60}_{27}$Co.

2. Absorption of gamma radiation

γ rays can penetrate relatively easily through materials. Therefore, shielding from γ radiation requires large amount of mass. γ photons are absorbed namely by three effects: creation of electron-positron pairs, Compton scattering and photoeffect. Consequently, the attenuation of γ radiation can be described by equation

$$\begin{aligned} I &= I_0 \exp(-\mu d) \\ \mu &= \mu_p + \mu_C + \mu_f \end{aligned}$$

where μ is the total absorption (attenuation) coefficient and μ_p, μ_C and μ_f are the absorption coefficients for creation of electron-positron pairs, Compton scattering and photoeffect, respectively. Energy dependences of cross sections for these three phenomena in lead are shown in the fig. 2.

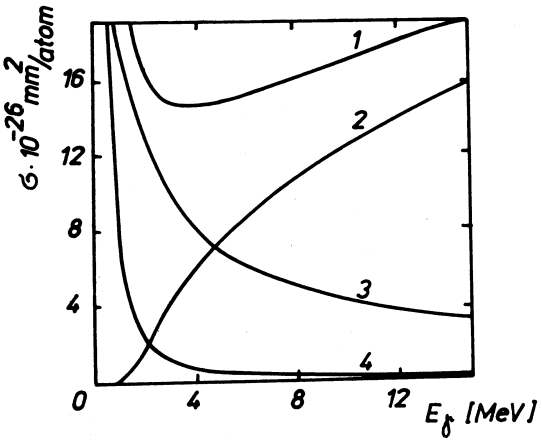

Figure 2: *Cross sections for phenomena occurring by transition of γ radiation through lead. Total cross section (1), cross section for creation of electron-positron pairs (2), Compton scattering (3) and photoeffect (4).*

Instead of the absorption coefficient μ the coefficient $\mu_m = \mu/\rho$ is frequently used, that is the absorption coefficient μ divided by density of the absorbing medium. Coefficients μ_m for selected materials are listed in the table 1. Detailed description of quantities that describe radioactive radiation and its absorption can be found in Tesař, Trunec, Ondráček: Fyzikální praktikum III.

Densities of materials that can be used for the measurements are listed below: Density of aluminum $\rho_{Al} = 2700$ kg m^{-3}, lead $\rho_{Pb} = 11340$ kg m^{-3}, air $\rho_{air} \approx 1.293$ kg m^{-3}, copper $\rho_{Cu} = 8960$ kg m^{-3}, plexiglass $\rho_{plx} = 1180$ kg m^{-3}.

Coefficient μ_m (m^2 kg^{-1})			
energy γ	$10^3 \cdot \mu_m$		
(MeV)	Al	Pb	air
0.1	16.9	546	15.5
0.2	12.2	94.2	12.3
0.4	9.27	22.0	9.53
0.6	7.79	11.9	8.04
0.8	6.83	8.66	7.06
1.0	6.14	7.03	6.35
1.5	5.00	5.50	5.15
2.0	4.31	4.63	4.45
3.0	3.60	4.10	3.60
4.0	3.10	4.21	3.07

Table 1: *Energy dependence of coefficient μ_m for absorption of γ radiation in aluminum, lead and air.*

3. Detector

A scintillation counter is used for the spectroscopy of γ radiation, which converts radioactive radiation into visible photons that are thereafter detected by a photomultiplier. If a γ photon looses all its energy in the scintillator, the number of produced (and measured) visible photons is directly proportional to the energy of the absorbed γ photon. This fact enables to measure the energy of γ photons detected by the scintillator.

4. Task

Student will measure absorption coefficients (μ and μ_m) of γ radiation in three different materials. Aluminum, lead, copper and plexiglass are available.

5. Measurement procedure

1. In the directory `cassy` execute the programme `mca` (english version) or `vka` (german version).

2. Choose the integration time of the measurement, set "resolution 9 bit" and "attenuator on".

3. Measure the energy spectrum of ^{137}Cs and calibrate the energy scale of the measured graph. The measured graph can be displayed again by means of the key "F6". The key "F9" will display the cursor that can be moved by arrows. After moving the cursor to the peak maximum and pressing "Enter" the energy of ^{137}Cs γ photons (662 keV) should be typed in order to calibrate the energy axis.

4. Measure the energy spectrum of γ radiation of $^{60}_{27}$Co and its absorption coefficients in three different materials. (Stepwise add plates of the selected material between the source and the detector and measure number of detected γ photons. The thickness of each plate measure by a calliper.) Compare the results with tabulated values.

   The intensity of the radioactive radiation should be measured by integration of the area under the measured peak. In the programme the borders of the integrated region should be selected at first by means of keys "Ctrl $\leftarrow$" and "Ctrl $\rightarrow$". Then, the key "F5" makes the integration and "Alt F5" displays the value of the integral.

   There is a quite high background signal due to the natural radioactivity and due to the scattered γ photons from the radioactive source. The intensity of the background can be measured by means of cursor and the key "+" that displays the actual coordinates of the cursor.