Absorption of ionizinig radiation

Radiation hazard symbol:

OBJECT

- For two selected materials measure linear absorption (attenuation) coefficient and mass absorption (attenuation) coefficient for β radiation. Plot the dependences of the number of impulses measured by the Geiger-Muller counter for each of selected materials as a function of the thickness of the absorbing material.
- For two selected materials calculate linear absorption (attenuation) coefficient, mass absorption (attenuation) coefficient and half thickness for γ radiation. Plot the dependences of the number of impulses measured by the Geiger-Muller counter for each of selected materials as a function of the thickness of the absorbing material.
- Examine absorption of α radiation for different materials.

THEORY

Nuclei are made up from protons and neutrons. We represent the number of protons in the nucleus - called the atomic number (or the proton number) of the nucleus by the symbol Z and the number of neutrons - the neutron number by the symbol N.

The total number of neutrons and protons in a nucleus is called its mass number A, so that

$$A = Z + N$$

Neutrons and protons, when considered collectively are called nucleons. We represent nuclides by symbols as

$$^{A}_{Z}\mathrm{X} \qquad \text{or} \qquad \mathrm{X}^{A}_{Z} \qquad \text{or} \qquad A\mathrm{X},$$

where X stays for the chemical symbol, superscript A stays for mass number and subscript Z stays for atomic number.

Radioactivity, also called radioactive decay, occurs when an unstable nucleus emits radiation. Isotopes with unstable nuclei are called radioisotopes. The majority of all isotopes are radioactive. It was soon determined that there were actually three different types of nuclear radiation, named alpha (α), beta (β) and gamma (γ) radiation.

Alpha radiation

During the process of alpha radiation are produced α particles. These are energetic, positively charged particles (helium nuclei) that rapidly lose energy when passing through matter. They are commonly emitted in the radioactive decay of the heaviest radioactive elements such as uranium and radium as well as by some manmade elements. Alpha particles lose energy rapidly in matter and do not penetrate very far; however, they can cause damage over their short path through tissue. These particles are usually completely absorbed by the outer dead layer of the human skin and, so, alpha emitting radioisotopes are not a hazard outside the body. However, they can be very harmful if they are ingested or inhaled. Alpha particles can be stopped completely by a sheet of paper.

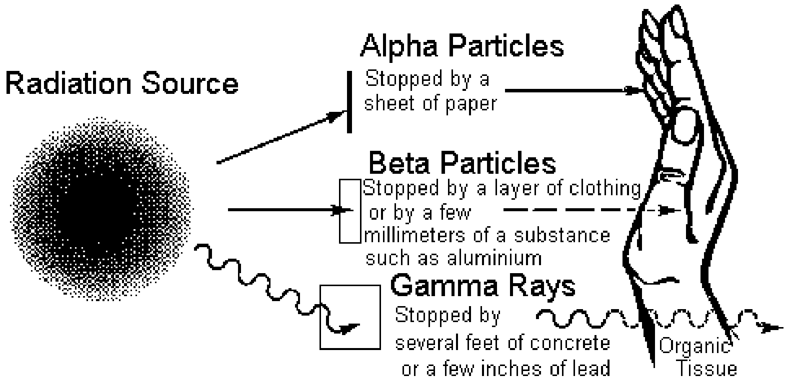
Beta radiation

During the process of beta radiation are produced β particles. These are fast moving, positively or negatively charged electrons emitted from the nucleus during radioactive decay. Humans are exposed to beta particles from manmade and natural sources such as tritium, carbon-14, and strontium-90. Beta particles are more penetrating than alpha particles, but are less damaging over equally traveled distances. Some beta particles are capable of penetrating the skin and causing radiation damage; however, as with alpha emitters, beta emitters are generally more hazardous when they are inhaled or ingested. Beta particles travel appreciable distances in air, but can be reduced or stopped by a layer of clothing or by a few millimeters of a substance such as aluminum.

Gamma radiation

Like visible light and x rays, gamma rays can be considered as a stream of photons. Gamma rays often accompany the emission of alpha or beta particles from a nucleus. They have neither a charge nor a mass and are very penetrating. One source of gamma rays in the environment is naturally occurring potassium-40. Manmade sources include plutonium-239 and cesium-137. Gamma rays can easily pass completely through the human body or be absorbed by tissue, thus constituting a radiation hazard for the entire body. Several feet of concrete or a few inches of lead may be required to stop the more energetic gamma rays.

The Penetrating Powers of Alpha and Beta Particles and Gamma Rays



Quantities describing radioactivity

The activity

The activity (decay rate) – of a radioactive source is defined as a number of disintegrations per second. The unit of activity is 1 **becquerel** (abbr. Bq).

1 Bq = 1 disintegration per second.

We still can meet with older unit of activity called the **curie** (abbr. Ci). It is defined as
1 Ci = 3.7×10^{10} disintegrations per second.
The dependence between activity of the source and time is expressed by equation

$$R = R_0\, e^{\lambda t},$$

where R_0 is the activity at time $t = 0$ and R is the activity of the source at any subsequent time t. The constant λ is called disintegration constant, which has a characteristic value for every radionuclide.

The radiation absorbed dose

A measure of the dose actually absorbed by a specific object in terms of the energy transferred to it was measured with units called the **rad** – Radiation Absorbed Dose. An object is said to have received an absorbed dose of 1 rad if each kilogram of the object absorbed 0.01 J of energy from the radiation, or

1 rad = 0.01 J/kg.

The present unit of radiation absorbed dose is called the **gray** (abbr. Gy). This unit is defined as

$$1\ \text{Gy} = 1\ \text{J/kg}.$$

The dose equivalent

The different types of ionizing radiation do not have the same ability to cause harmful effects. Therefore we introduce the dose equivalent, the unit of which is the **sievert** (abbr. Sv). The dose equivalent is fond by multiplying the radiation absorbed dose (in grays) by a Relative Biological Effectiveness (RBE) factor, or

$$[\text{Sv}] = [\text{RBE}] \times [\text{Gy}].$$

The RBE factor may be found in tabulated in various reference sources. Thus for example:

Gamma rays, β-particles	RBE ≈1
Slow neutrons	RBE ≈5
α-particles	RBE≈20.

It is therefore seen that 1 Gy of alpha radiation tends to do more harm than 1 Gy of gamma radiation.

Absorption of ionizing radiation by matter – defining equations

When an ionizing radiation passes through a slab of matter, the intensity of radiation decreases exponentially according to following equation:

$$I(d) = I_0 \cdot e^{-\mu d},$$

where I_0 is the original intensity of radiation, $I(d)$ is the intensity at distance d, μ is the linear absorption (attenuation) coefficient, measured in cm^{-1} and d is the thickness of material in cm.

The mass absorption (attenuation) coefficient μ_m is equal to the linear absorption (attenuation) coefficient μ, divided by the density of material.

EXPERIMENTAL ARRANGEMENT

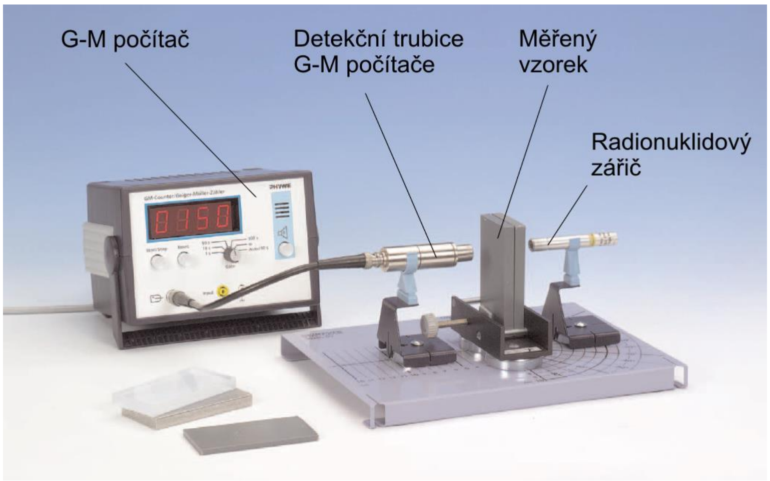


Fig. 1. Experimental arrangement. Geiger-Muller counter, GM counter detection tube, radionuclide, plates from measured materials.

PROCEDURE

- Measurement of radiation background.

Before you ask the instructor for the radionuclide source it is necessary to measure natural radiation background. This radiation background is caused by the fact that GM counter detects apart of the radiation from radionuclide sources also radiation background caused by natural sources. You have therefore to measure this radiation background as a number of impulses for some time interval (e.g. 4 minutes). You have to use the natural radiation background value for the purposes of correction of measured values.

- Measurement of β radiation absorption.

1. Remove very carefully protective cover from the GM counter detection tube. Place the radionuclide source 90Sr (activity 74 kBq) into the holder in such a way that the axis of source coincides with the axis of the GM counter detection tube Place the source at the distance about 25 mm from the entrance windows of the GM counter detection tube. When manipulating with GM counter detection tube be extremely careful.

2. Choose some thinner sample of absorbing material (aluminium, plexiglass, hard paper, paper) and place it into the table clamp. Determine how fast the GM counter registers impulses for different thicknesses of this material. For thick slabs or for slabs from unconviently chosen material the GM counter will not register radiation from the radionuclide source but only the background radiation. In this case it is necessary to use either thinner slab or other material.

Position of the GM detection tube and radionuclide source should be adjusted in such a way, that it will not be changed during this experiment.

3. For particular thicknesses of absorbing material (even for zero thickness) measure with GM counter number of impulses. As far as the radioactive decay is governed by statistical laws, it is necessary to perform the measurement for sufficient time interval, depending on the type and thickness of material from 10 s to 2 minutes. For the case of materials with higher mass density registered number of impulses will be approaching to the number of impulses of natural background. In this case finish the experiment.

If you perform the measurements for different time intervals it is necessary to recalculate obtained data to one time interval t_0. The best solution is to choose the time interval for which you performed majority of experiments. Thus if you during the ith measurement for the time interval t_i measured N_i impulses you can obtain

$$N_i^{'} = N \times \frac{\Delta t_0}{\Delta t_i}$$

- Measurement of γ radiation absorption.

Place the source of γ radiation 60Co (activity 74 kBq) into the holder in such a way that the axis of source coincides with the axis of the GM counter detection tube. The source should be at the distance about 45 mm from the entrance windows of the GM counter detection tube.

For measurement use thicker samples of absorbing material (lead, iron, aluminium, plexiglass, concrete). Choose the time for registration of impulses at least 1 minute.

Measurement of γ radiation absorption is performed in the same way as the measurement of β radiation absorption.

- Absorption of α radiation

Place the source of α radiation 241Am into the holder in such a way that the axis of source coincides with the axis of the GM counter detection tube. Persuade yourself that α radiation can be stopped completely even by thin layer of absorbing material such as a sheet of paper. As far as α radiation has low penetrating power it is necessary to remove a protective cover of the input windows of the GM detection tube. When manipulating with protective cover be very careful.

- After measurements.

After the end of measurements place carefully protective cover on the GM detection tube and return the source of radiation to the instructor.

Graphing and calculations:

For calculations and graphing you can use software „Univerzální nástroj pro kreslení grafů“, which you can find at: http://herodes.feld.cvut.cz/mereni/.

Geiger Muller counter.

In 1908 Hans Geiger, with Ernest Rutherford, developed a device that would later be called the "*Geiger counter* "This counter was only capable of detecting alpha particles. In 1928, Geiger and Walther Muller (a PhD student of Geiger) improved the counter so that it could detect alpha particles, beta particles or gamma rays.

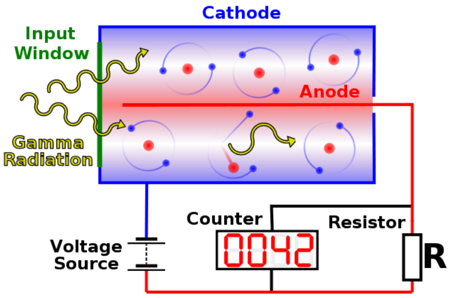


Fig.2. Principle of the Geiger Muller counter

A Geiger–Muller tube consists of a tube filled with a low-pressure (~0.1 atm) mixture of neon and argon. The tube contains electrodes, between which there is a potential difference of 400-2000 volts, but no current flowing. The walls of the tube are either entirely metal or have their inside surface coated with a conductor to form the cathode while the anode is a wire passing up the center of the tube.

When ionizing radiation passes through the tube, some of the gas molecules are ionized, creating positively charged ions, and electrons. The strong electric field created by the tube's electrodes accelerates the ions towards the cathode and the electrons towards the anode. The ion pairs gain sufficient energy to ionize further gas molecules through collisions on the way, creating an avalanche of charged particles.

This results in a short, intense pulse of current which passes (or *cascades*) from the negative electrode to the positive electrode and is measured or counted.

Most detectors include an audio amplifier, that produces an audible click on discharge. The number of pulses per second measures the intensity of the radiation field.

The cover of the Geiger–Muller tube allows transmission of the γ and β particles with sufficient energy. Probability of the detection is 20 % for energy 0,73 MeV, 60 % for energy 1,01 MeV, 85 % for 1,37 MeV and 95 % for energy 1,7 MeV. Low energy electrons and α paarticles which can not pass through the cover of the tube are detected through the thin mica windows from which must be before the start of measurements carefully removed the cover.

Manual for the use of G-M counter.

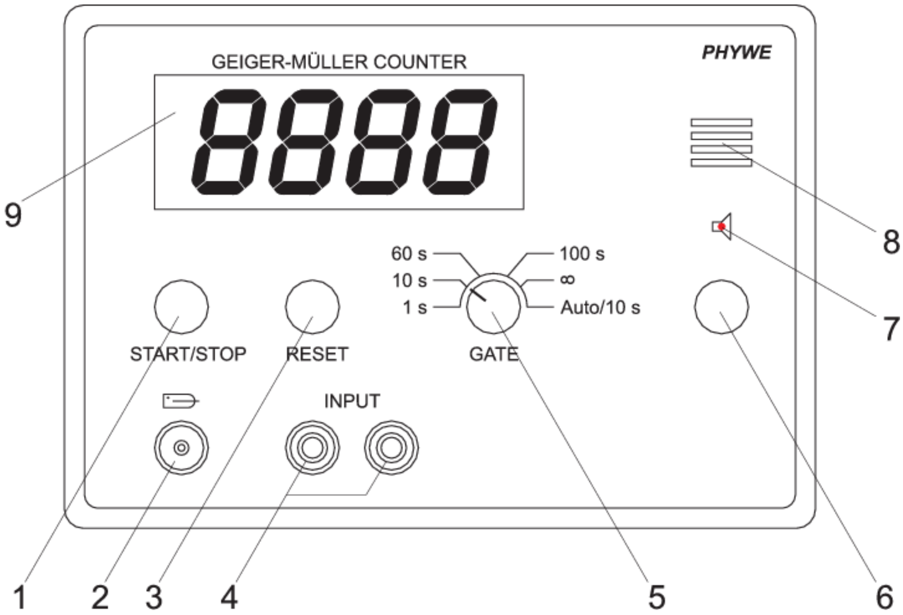


Fig.3. Geiger Muller counter.

1. The push button START/STOP is used to trigger counting of impulses. If it is pushed during the measurements before the end of pre-selected time interval, the counting of impulses is interrupted. You can start new measurement only after pushing the push button RESET.
2. BNC connector for cable of the detection tube.
3. Push button RESET. When you push this button the display will read zero.
4. Input terminals INPUT are used for counting of TTL signal.
5. The switch GATE is used to select the time during which the counter will register impulses and for selection of the operational regime. The individual measurements for selected time intervals 1 s, 10 s, 60 s and 100 s are triggered by pushing the START/STOP push button. When the selected time interval is over, the number of impulses will remain on the display. If you push again the START/STOP push button, counting will continue from preceding value. If you wish to start counting from zero it is necessary to push button RESET.

If the switch is in the position ∞ the counter registers the impulses between two consecutive pushing of the push button START/STOP. By another pushing of this button the new impulses will be added to initial number of impulses. After reaching 9999 impulses the counter will be stopped automatically.

If you select the regime Auto/10s, after pushing the button START/STOP the counting of impulses will start from zero impulses during the time interval 10 s. After this time the obtained number of impulses will be displayed for some time.

6. Push button of the load speaker. The state „ON“ is indicated by the lead diode 7.
8. Load speaker.
9. Display for reading of the number of impulses.

Appendix No.1. Safety rules for work with radionuclides

When manipulating with the radionuclides be very careful.

- Radionuclide sources used in the laboratory 413b are weak sources of ionizing radiation. The dose equivalent at any place at the distance of 0.1 m from the source surface is smaller than 1μSv/hour, which allows the work at their vicinity without any time limitation.
- Higher values of the dose equivalent can be however obtained in case of mechanical damage of the source. It is therefore forbidden to open the source or to make any constructional changes.
- After the experiment or when the source is not used it must be placed in the protective container.
- When you notice any damage of the source you have to inform immediately the instructor.
- For measurement ask the instructor for the source and return source after each measurement to the instructor.

Appendix No.2: Mass density of selected materials

Material	Mass density kg/m^3
Paper	852
Glass	2370
Lead	11340
Aluminium	2690
Iron	7860
Concrete	2350
Plexiglass	1119
Hard paper	1390

Detailed description of α, β and γ decay – see PHYSICS II, Pekárek, Murla, CTU in Prague, 2003.