Student’s name ____

Experiment O6

STUDY OF GAMMA ABSORPTION OF A MATTER USING THE GEIGER COUNTER

Objective: to learn radioactive decay law, to determine gamma absorption of lead

1 EQUIPMENT

1) Geiger counter of gama-particles;
2) Radioactive source of gamma-particles;
3) Lead plates;
4) Stop-watch;
5) Micrometer.

2 THEORY

Radioactivity is a spontaneous transformation of atomic nuclei. In these nuclear transformations chemical elements are transformed into other elements and high-energy particles can be emitted. The most widespread radioactive processes are

1. **alpha (*α*)** decay (nuclei of helium are emitted by matter),
2. **beta (*β*)** decay (electrons or positrons are emitted),
3. **gamma (*γ*)** decay (electromagnetic radiation of very short wavelength, 10^{-3} Å to 1 Å, are emitted).

These processes are also known as ionizing radiation. Ionizing radiation is either particle radiation or electromagnetic radiation in which an individual particle/photon carries enough energy to ionize an atom or molecule by completely removing an electron from its orbit. Ionizing radiation is produced by radioactive decay, nuclear fission and nuclear fusion, by extremely hot objects (the hot sun, e.g., produces ultraviolet), and by particle accelerators.

Radioactivity was discovered by Henry Becquerel who studied uranium salts. Becquerel found that certain uranium salts are phosphorescent, that is, emit rays which expose photofilms. Two years later Pierre Curie and Marie Sklodowska-Curie discovered two radioactive elements, unknown before, namely raidum and polonium. In 1908 Ernest Rutherford discovered new radioactive gas, radon. All these elements are notable for their intensive radioactivity. Both natural and artificial radioactivity are described by radioactive decay law

$$N = N_0 e^{-l \cdot t}, \qquad (2.1)$$

where N_0 is initial number of radioactive nuclei, N is number of nuclei after time t, λ is known as radioactive constant, characteristic to every chemical element. Time, in which half of initial number of nuclei transform, is known as half-life. Half-life $T_{1/2}$ is related to λ:

$$T_{1/2} = \frac{\ln 2}{l} = \frac{0{,}693}{l}. \qquad (2.2)$$

Half-lives of chemical elements known today are in time range from $3 \cdot 10^{-7}$ s to $5 \cdot 10^{15}$ years. The law (2.1) is very accurate and is used, for example, to date fossil records, as explained below. The

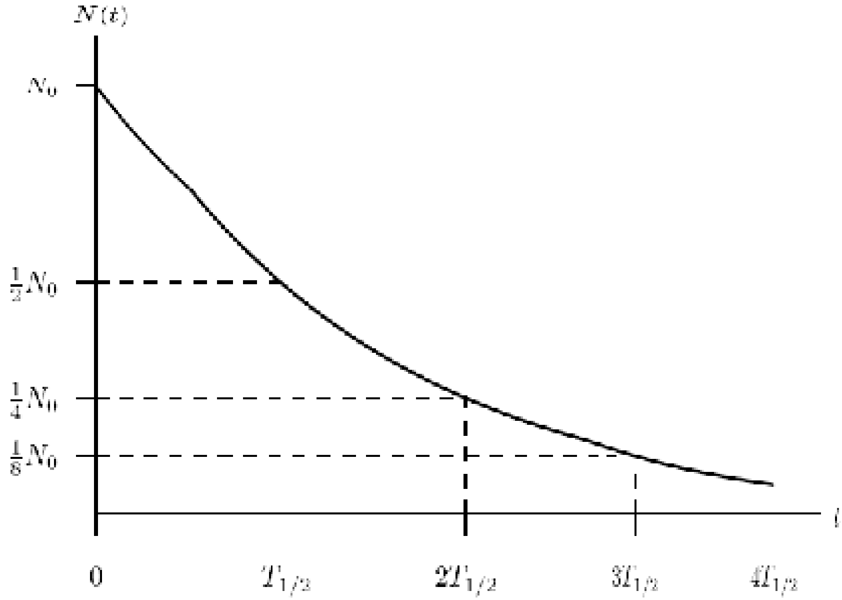

Figure 2.1

isotope ${}^{14}_{6}C$ decays inside living bodies but is replenished from the air and food. Therefore, while an organism is alive, the concentration of this isotope in the body remains constant. After death, the replenishment from the breath and food stops, but the isotopes that are in the dead body continue to decay. As a result the concentration of ${}^{14}_{6}C$ in it gradually. Therefore, by measuring the radioactive emissions from once-living matter and comparing its activity with the equilibrium level of emissions from things living today, an estimation of the time elapsed can be made.

Source activity is an important characteristic of a radioactive body. Activity is equal to number of decay acts per unit time. Source activity as proportional to radioactive constant and number of survived nuclei

$$\frac{dN_{розп}}{dt} = lN \,. \tag{2.8}$$

1 becquerel=1decay per second is a unit of activity. Other widely used unit is 1 curie =3,700·10^{10} decays/s.

Since they are able to penetrate matter, ionizing radiations are used for a variety of measuring methods. Here is the list of a few applications of radioactivity: radiography by means of gamma or X rays, gauges wich use the exponential absorption law of gamma rays to indicate level of a substance in container or thickness of materials, detection of smoke, radioactive tracers for industry when the behavior of a certain chemical substance can be followed by tracing the radioactivity. Radiation is also useful in sterilizing medical hardware or food. Electrons, x rays, gamma rays or atomic ions may be used in radiation therapy to treat malignant tumors (cancer). Electrons, x rays, gamma rays or atomic ions may be used in radiation therapy to treat malignant tumors (cancer).

Mean lifetime t of radioactive nucleus is a quantity inversed to radioactive constant

$$t = \frac{1}{l} \,. \tag{2.3}$$

Nuclei, created in radioactive transformation, can be radioactive as well. Products of their transformations can be radioactive in their turn. This way radioactive families are formed. There are three natural radioactive families and one artificial. The natural ones are starting from uranium U^{238}, thorium Th^{232}, protactinium U^{235}. All the three end with isotopes of lead, Pb^{206}, Pb^{208} and Pb^{206}, respectively.

Alpha decay, in which nuclei of helium ${}_{2}He^{4}$ are emitted, are expressed by the following equation

$${}_{Z}X^{A} \rightarrow {}_{Z-2}Y^{A-4} + {}_{2}He^{4}. \tag{2.4}$$

Here X denotes the initial nucleus, Y denotes created fission fragment. As a rule, in alpha decay a few gamma-rays (photons of short wavelength) are created. Speed values of created $\boldsymbol{\alpha}$-particles are very high (of order of 10^{7} m/s). Propagating through a matter, alpha particle looses most of its energy on ionization of molecules and atoms. The more dense the matter is, the less path will be covered by alpha particle. At normal conditions, $\boldsymbol{\alpha}$-particle's path in air is as long as a few centimeters, but only 10^{-6} m in solids.

In beta decay the initial nucleus emits or absorbs electron or its antiparticle, positron, in the following reaction

$${}_{Z}X^{A} \rightarrow {}_{Z+1}Y^{A} + {}_{-1}\boldsymbol{e}^{0} + \tilde{n} \,. \tag{2.5}$$

Mass of an electron is 2000 times less then mass of a nucleon (subatomic particle, proton or neutron), that is why mass of electron is taken to be zero in notation above. Neutral antineutrino $\tilde{n}$ is created together with electron and obtains a part of decay energy.

Reaction of positron decay can be written as

$${}_{Z}X^{A} \rightarrow {}_{Z-1}Y^{A} + {}_{+1}\boldsymbol{e}^{0} + n, \tag{2.6}$$

where ${}_{+1}\boldsymbol{e}^{0}$ denotes positron, which has mass and charge magnitudes equal to those of an electron but charge of opposite sign, n denotes neutrino.

In a process of electron capture a nucleus absorbs one of electron from atom's shell and one of protons $\boldsymbol{p}$ transforms into neutron $\boldsymbol{n}$, emitting neutrino n

$${}_{1}\boldsymbol{p}^{1} + {}_{-1}\boldsymbol{e}^{0} \rightarrow {}_{0}\boldsymbol{n}^{1} + {}_{0}n^{0}. \tag{2.7}$$

If the created nucleus has a surplus of energy (is in an excited state), the energy is emitted as gamma-quantum (a high-energy photon which has properties of both a particle and electromagnetic wave).

The negatively charged electrons and positively charged ions created by ionizing radiation may cause damage in living tissue. If the dose is sufficient, the effect may be seen almost immediately, in the form of radiation poisoning. Lower doses may cause cancer or other long-term problems. Alpha and beta rays cause most damage when they are emitted inside the human body. Gamma rays are less ionizing than either alpha or beta rays, but protection against them requires thicker shielding. They produce damage similar to that caused by X-rays such as burns, and cancer through mutations in the DNA. Natural radioactivity is inherent to atmospheric air, causes of which are cosmic rays and presence of radon in the air. Radon-222 is produced by the decay of r-226 which is present wherever uranium is. Since radon is a gas, it seeps out of uranium-containing soils found across most of the world and may concentrate in well-sealed homes. Humans and animals can also be exposed to ionizing radiation internally: if radioactive isotopes are present in the environment, they may be taken into the body. For example, radioactive iodine is treated as normal iodine by the body and used by the thyroid; its accumulation there often leads to thyroid cancer. Although exposure to ionizing radiation carries a risk, it is impossible to completely avoid exposure. Radiation has always been present in the environment and in our bodies. We can, however, avoid undue exposure. In addition, there are some factors able to reduce risk, namely exposition time, distance to the radiation source and proper shielding. For people who are exposed to radiation in addition to natural background radiation, limiting or minimizing the exposure time will reduce the dose from the radiation source. The intensity of the radiation decreases with distance from the source of the radiation. The dose decreases dramatically at increase of distance from the source. Alpha radiation consists of heavy helium-4 nuclei and is readily stopped by a sheet of paper. Beta radiation, consisting of electrons, is halted by an aluminium plate. Gamma radiation is eventually absorbed as it penetrates a dense material. Barriers of lead, concrete, or water give good protection from penetrating radiation such as gamma rays and neutrons. This is why certain radioactive materials are stored or handled underwater or by remote control in rooms constructed of thick concrete or lined with lead. Inserting the proper shield between human body and the radiation source greatly reduces or eliminate the extra radiation dose.

Although people cannot sense ionizing radiation, there is a range of simple, sensitive instruments capable of detecting minute amounts of radiation from natural and man-made sources. Ionizing radiation cause chemical reactions (chemical action), ionize atoms (ionizing action), stimulate luminescence of some substances (luminescent action). Accordingly, the detection methods may be classified as photochemical (photofilms and photoemulsions), ionizing (Geiger counter, cloud chamber, bubble chamber) and luminescent (scintillation counter). In the present experiment Geiger counter is used for detection of gamma radiation. The counter consists of a thin metal cylinder (see Fig.2.2) filled with inert gas (usually helium, neon or argon with halogens added) at low pressure. A wire electrode runs along the center of the tube and is kept at a high voltage (above 2000 V) relative to the cylinder. When a particle passes through the tube, it causes ionization of the gas atoms and thus an electric discharge between the cylinder and the wire. The electric pulse can be counted by a computer or made to produce a click in a loudspeaker. The number of counts per second is proportional to intensity of the radiation.

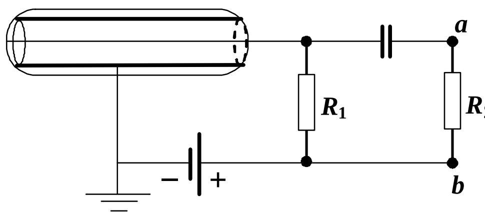

Figure 2.2

Absorption of ionizing gamma-radiation by a matter is described by the following equation (also known as absorption law)

$$I = I_0 e^{-m \cdot x}, \qquad (2.9)$$

here I_0 is intensity of incident radiation, proportional to ionizing particles flow, I is the intencity inside the matter, after a distance x is covered by particles in the matter, μ is the linear coefficient of gamma absorption, which characterizes an ability of specific matter to interact with gamma-quanta. If the matter is a homogeneous one (composed of atoms of the same sort), it is reasonable to introduce mass coefficient of absorption $\mu_m = \mu / r$, where r is density of the matter.

3. DERIVATION OF COMPUTATION FORMULA

By comparing intensities of the ionizing particles flows before and after a metal plate

$$\frac{I}{I_0} = e^{-m \cdot x}, \qquad (2.10)$$

one can determine absorption coefficient as

$$m = \frac{1}{x} \cdot ln \frac{I_0}{I}. \qquad (2.11)$$

Expression (2.11) is the calculation formula for this experiment.

RULES OF SAFE OPERATION WITH RADIOACTIVE MATERIALS

1. Ionizing radiation can be very dangerous for a human. The lead box with radioactive material should not be kept open for long lime.
2. Taking the container with radioactive matter out of the lead box is strictly prohibited.
3. Radioactive matter must not be touched with hands. If so happen, one should immediately wash hands in warm water using a soap.
4. All operations with radioactive material are performed under supervision of a lab assistant.

4 PROCEDURE AND ANALYSIS

4.1 Put into operation the Geiger counter. Set it in regime of exposure dose determination.
4.2 Measure exposure dose due to background radiation three times and calculate the mean value. This value is to be subtracted from subsequent results for exposure dose.
4.3 Safely place the box with radioactive material close to Geiger counter. Shield the counter with a metal plate to absorb beta particles.
4.4 Open the box with radioactive material. Measure exposure dose three times and calculate the mean value.
4.5 Place a metal plate between the source of radiation and the counter Measure exposure dose three times and calculate the mean value.
4.6 Close the box and return it back to lab assistant.
4.7 Measure thickness of the used plate three times by micrometer and calculate the mean value.
4.8 Substitute the mean values into computation formula (2.11) and calculate the linear coefficient m of gamma absorption.
4.9 Fill the table 4.1 with results of measurements and calculations

Table 4.1

	I_{bg}	ΔI_{bg}	I_0	ΔI_0	I	ΔI	x 10^{-3} m	Δx 10^{-3} m	m m^{-1}
1									
2									
3									
mean value									