Surname ....

Name ....

Date ....

Degree program name…………

Exercise B_59_BIOPHYSICS

Study of types of radiation

Table 1: Counts through different materials

Background count = ___________ counts/30s

Natural radiation source (selected)	**Through Air (counts/30s)**	**Through Paper (counts/30s)**	**Through n…. Al shields (counts/30s)**	**Through plastic dish (counts/30s)**	**Through water in a plastic dish (counts/30s)**	**Through wood (counts/30s)**	**Identified/ predicted type of radiation**	**Type of LET: low or high**

Exercise B_59_BIOPHYSICS

Study of types of radiation

Materials and equipment

- data collection system
- wireless Geiger counter
- Geiger Counter Sample Holder
- ruler
- aluminum shields
- piece of paper
- piece of wood
- plastic dishes
- natural radiation sources: different rocks, food, KCl, water etc.

Figure 1.
Wireless Geiger Counter detects alpha, beta, and gamma ionizing radiation. The arrow indicates press ON button.

Safety

Follow these important safety precautions in addition to your regular classroom procedures:

- **The natural radiation source should be kept in its case.**
- **The natural radiation samples are safe.**
- **Due to the low activity and natural origin, and with regard to radiation protection regulations, do not require notification to the relevant institutions, in accordance with the Decree of the Council of Ministers of March 10, 2021, on cases in which activities involving exposure to ionizing radiation do not require authorization, notification or notification, and cases in which they may be performed on the basis of notification or notification.**

Objectives

- Use a Geiger counter to measure radiation counts.
- Measure how radiation passes through different materials.

- Draw conclusions about the penetrating power of radiation.
- Compare counts at different materials.

THEORY

Sources of ionizing radiation

Radiations are broadly categorized into natural and man-made sources**.** More than 90 % of radiation exposure to man occurs from natural sources e.g. cosmic rays, and terrestrial sources that comes from radionuclides in the earth’s crust, air, food and water and the human body itself. Man-made radiation exposure to populations occurs mainly from medical uses of radiation and radioisotopes in health care, occupational sources in the generation of electricity from nuclear power reactors, industrial uses of nuclear techniques, and in the past from nuclear weapons testing. Use of ionizing radiation in medical diagnosis and therapy is widespread and constantly increasing due to useful newer health care applications. It is widely accepted that diagnostic radiation exposures can be significantly reduced by adequate safety measures and optimization of nuclear-based procedures and practices.

Types of ionizing radiation

We distinguish between three types of radiation, denoted by the letters of the Greek alphabet: α, β and γ. Ionizing radiation may be divided into directly and indirectly ionizing for the understanding of biological effects. Most of the particulate types of radiation are directly ionizing i.e. individual particles with adequate kinetic energy can directly disrupt the atomic structure of the absorbing medium through which they pass producing chemical and biological damage to molecules. In contrast, electromagnetic radiations, namely, X and γ rays, are indirectly ionizing because they do not produce chemical and biological damage themselves but produce secondary electrons (charged particles) after energy absorption in the material. Different types of radiation have differing abilities to pass through material (Figure 2). A very thin barrier, such as a sheet or two of paper, or the top layer of skin cells, usually stops alpha particles. Because of this, alpha particle sources are usually not dangerous if outside the body, but are quite hazardous if ingested or inhaled. Beta particles will pass through a hand, or a thin layer of material like paper or wood, but are stopped by a thin layer of metal. Gamma radiation is very penetrating and can pass through a thick layer of most materials. Some high-energy gamma radiation is able to pass through a few feet of concrete. Certain dense, high atomic number elements (such as lead) can effectively attenuate gamma radiation with thinner material and are used for shielding. The ability of various kinds of emissions to cause ionization varies greatly, and some particles have almost no tendency to produce ionization.

Radiation α are nuclei of helium atoms. These are particles made up of two protons and two neutrons. Particles α are formed by the transformation of the parent nucleus into a daughter nucleus with a reduced atomic number relative to the parent nucleus by two units and a mass number of four. Particles α passing through matter strongly ionize it and lose kinetic energy in the process - thus they are not very penetrable. ***Radiation β+*** , or positron emission (e+), accompanies nuclear decays, in which, at an unchanging mass number, the charge number of the nucleus decreases by one. More frequently emitted are electrons (e-) - then we are dealing with decay β-. With ***emission β-*** the mass number also does not change, but the charge number of the final nucleus increases by unity. In transformation β the energy distribution of emitted particles (their energy spectrum) is continuous. This means that we are dealing with particles from zero energy to maximum energy, determined by the difference in masses of the nuclei participating in the decay. Beta particles on their way weaker ionize matter and thus are more penetrating. Only ***gamma quanta (γ)***, as electromagnetic radiation, fully justify their name. The spectrum of radiation γ is monoenergetic, since the energy of its quanta closely corresponds to the difference in energy states of the nucleus before and after emission. The γ quanta react weakly with matter, as a result of which they are very permeable - the gas hardly ionizes at all.

Type of radiation	**source**	**half-life ($t_{1/2}$)**
α	Po-210	138 days
β	Sr-90/Co-60	28.6 /5.27 years
γ	Co-60/Cs-137	5.27 /30 years

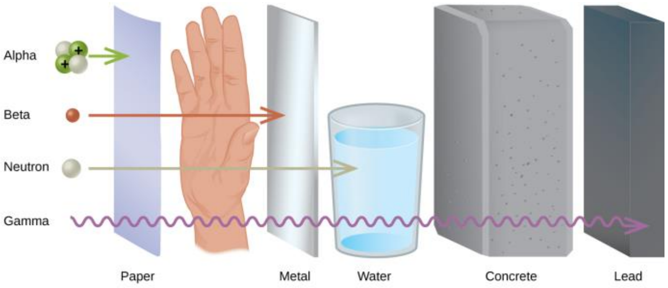


Figure 2. Different types of radiation, sources and half-time (left panel). The ability of different types of radiation to pass through material is shown (right panel). From least to most penetrating, they are alpha < beta < neutron < gamma. A diagram shows four particles in a vertical column on the left, followed by an upright sheet of paper, a person's hand, an upright sheet of metal, a glass of water, a thick block of concrete and an upright, thick piece of lead (source: *Openstax:chem.libretexts.org/Bookshelves*).

Linear energy transfer

When ionizing radiations traverse through matter, they lose energy gradually through various interaction processes along the length of their path. For a particular absorber, the rate of loss of energy depends on the energy and type of radiation as well as the density of the material. The density of energy deposition in a material such as tissue is called the ***Linear Energy Transfer (LET)*** of the radiation. It is defined as the average energy deposited per unit length of track of radiation and the unit is keV/μm. Note that the LET varies along the length of the track of charged particles because as the charged particle deposits energy in tissue it slows down. Charged particles generally have higher LET than X and γ rays because of their greater energy deposition along the track. Radiations are categorized into low and high LET radiations with particulate radiations usually being high LET radiations whereas X and γ rays are low LET radiations due to their sparse ionizations. Energy loss events are essentially randomly distributed along the track of the photon or charged particle. For low LET radiations the energy deposition events along the track of the photon are sparse relative to the dimensions of biomolecules such as DNA with the result that photons may pass through such a molecule without depositing any energy.

The transmission of nuclear radiation through matter.

The nature of absorption of γ radiation is different from that of charged particles such as β or α. Particles α or β lose energy in inelastic collisions (collisions with atoms of the medium and electromagnetic interactions), slowing down until they eventually stop. Radiation γ does not undergoes "deceleration" - only its intensity weakens due to the photoelectric phenomenon, **Compton scattering** (scattering on free or weakly bound electrons), formation of electron-positron pairs. During the passage through matter of radiation β or γ, the initial intensity of the radiation I_0 decreases exponentially with increasing thickness of the absorbing substance:

$$I = I_0 e^{-\mu x},$$

where I is the irradiance after the passage of a layer of thickness x, and $\boldsymbol{\mu}$ is the absorption coefficient of absorption that characterizes the absorbent. The dimension of $\boldsymbol{\mu}$ is m^{-1}. We calculate the natural logarithm of both sides of the above equation:

$$\ln N = \ln N_0 - \mu x.$$

We get the equation of the straight absorption coefficient, μ is determined by the slope of this straight line.

The construction and operation of a Geiger-Müller counter

The Geiger-Müller counter is a gaseous radiation detector - it belongs to the group of detectors ionization detectors. The G-M counter usually has the shape of a cylindrical metal tube, inside which along its axis of symmetry, is placed a thin tungsten wire, axially fixed inside the cylinder. The cylindrical tube is called a cathode because it always operates at a potential lower than that of the tungsten wire, which bears the name of anode. Fig. 3 shows a diagram of the of the electronic apparatus operating the G-M counter. In simple terms, the operation of the counter can be described as follows: Radiation passing through the window ionizes the gas between the electrodes. The electrons released as a result of as a result of ionization, the electrons are accelerated by an electric field. At sufficiently strong intensity of the field, the electrons reach such high energy that they induce another ionization. The process proceeds in an avalanche. It is sustained by ultraviolet radiation from excited gas molecules and ions positive ions, which can knock more electrons out of the cathode. In order to stop the discharge continuous, small amounts of gas with multi-atomic molecules are added to the working gas (methane, alcohol vapors), which absorb ultraviolet radiation and block the knockout of electrons from the cathode. After the avalanche expires, the counter is ready to register the next particle. The pulse of discharge current in the counter corresponds to a change in voltage across the resistance R incorporated in the counter circuit.

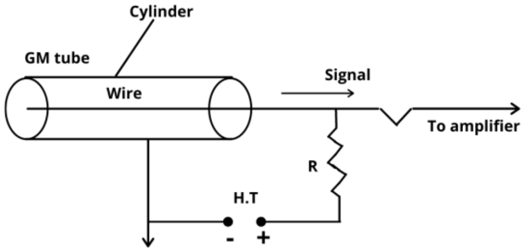


Figure 3. Schematic of the Geiger-Müller counter circuit (source: *physicswave.com*)

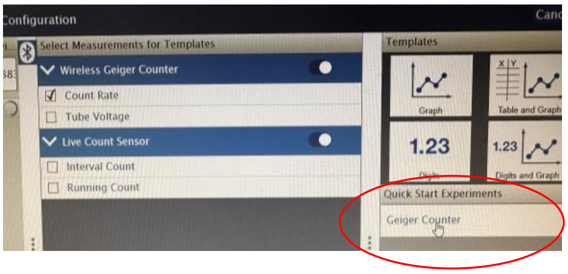
Procedure

1. Turn on the power of the table (see the dashboard of the table - by your right leg, when you sit in front of the computer) - turn the red "knob" in the direction of the arrows (it should pop out), turn the key as in a car and let go.
2. Turn on the computer

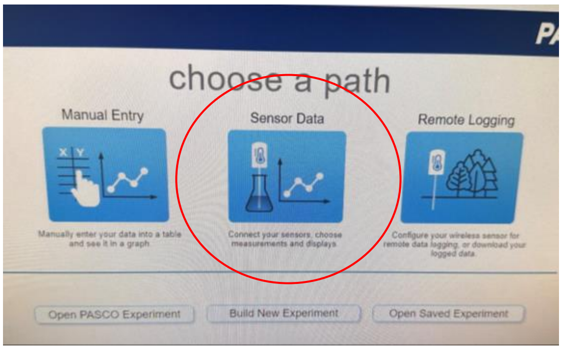
3. Turn on the **Geiger counter**, place 4.5 cm from the floor of the desk (counting from the lowest part).

4. Choose a **SPARKvue** icon.

5. Connect it to the data collection system (**Geiger-counter 030-830**).



6. Choose a path: **Sensor Data** (in the middle).

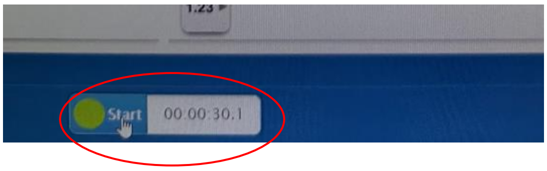


7. The beeps can be silenced by pressing the on button for about a half second or by unchecking the Enable Beeps box in the software.

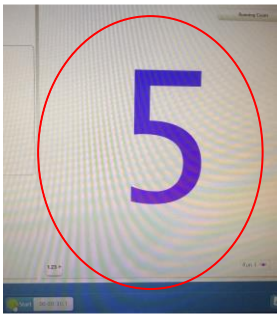
8. Create a digits display of Running Count.

9. Make sure the natural radiation sources are far from the Geiger counter. See Figure 1.

10. Set the sample interval **to 30 s** and check the **Record only one interval** box in the software.



11. Start recording data. Data recording will stop automatically after 30s. Record the count below.



This is called **the background count** because there was no radioactive source nearby. The background radiation is produced by small amounts of radioactive elements in the environment and radiation produced high in the Earth's atmosphere when cosmic rays collide with atoms.

12. Place selected natural radioactive source under the Geiger counter.

13. Start data collection and wait for data collection to stop after 30 seconds.

14. Subtract the background count from the measurement. Record the result as **the through air counts** for the each source in Table 1. The background count should be subtracted from the all the remaining measurements before recording them. If this results in a negative number, record the value as zero. To make this easier, create a digits display of a calculation that subtracts the background from the measurement.

15. Place the different materials above the different natural radiation sources according to the table. Measure and record the counts in Table 1.

Questions to answer in final report:

1. The 3 most common types of ionizing radiation are called alpha, beta, and gamma. They are called ionizing radiation because they have enough energy to knock electrons off atoms, therefore ionizing them. When radiation was first discovered the types were distinguished by their ability to penetrate materials. Alpha radiation had the least ability to penetrate materials. Beta radiation was the next most penetrating. Gamma radiation was the highest penetrating.
   a) Based on collected data in Table 1 and Table 2 below, identify the type of radiation coming from each natural radioactive source and explain your reasoning.
   b) Identify low or high LET type of radiation in your results and write in the table.

Table 2:

Radioactive sample	**Through Air (counts/30s)**	**Through Paper (counts/30s)**	**Through Al shield (counts/30s)**	**Through plastic dish (counts/30 s)**	**Through water in a plastic dish (counts/30s)**	**Through wood (counts/30s)**	**Type of radiation**
Cs-137	771	98	107	157	105	119	**γ**
Sr-90	99	97	61	85	33	53	**β**
Co-60	33	31	22	28	26	27	**γ/β**

2. Alpha radiation consists of 2 protons and 2 neutrons. It is a fast-moving helium nucleus. Beta radiation is a fast-moving electron. Gamma radiation is a photon. The mass, charge, and average energy of each type of radiation is shown in Table 3 below. Based on the data in Table 1 and Table 4, what factor(s) are more important for predicting the ability of radiation to penetrate material? Explain your reasoning.

Table 3: Radiation types

Radiation Type	**Mass (AMU)**	**Charge (e)**	**Average Energy (MeV)**
Alpha	4	+2	~5
Beta	0.00055	-1	< 1
Gamma	0	0	~1

3. The natural radioactive samples used in this lab are safe for student because of their low activity. A large amount of radioactive material is used in some medical equipment. Would it be more effective to protect medical workers and patients using shielding or distance? Does the answer depend on the type of radiation being produced? Explain your reasoning.