Department of Medical Physics, Tabriz School of Medicine

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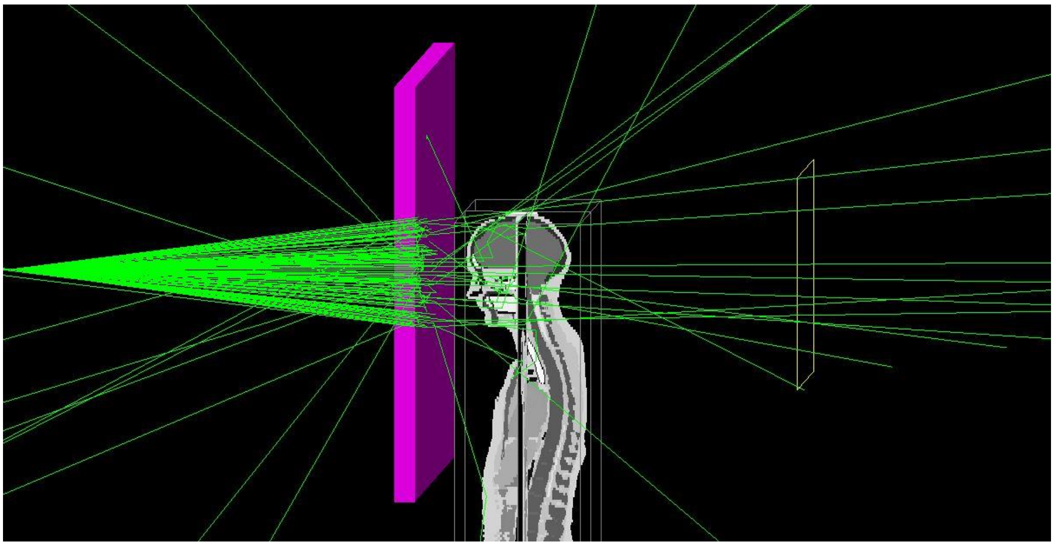
Experiment No. 8

Studying the dependence of the linear attenuation coefficient on the type of absorbing material and the energy of gamma rays



The purpose of this experiment is measuring the linear attenuation coefficient and half value layer thickness of lead for shielding the radioactive source (Co-60).

Required materials

Geiger-Muller detector, lead shields with different thicknesses, clamp, and radioactive source.

Experimental theory

In 1896, Becquerel succeeded in discovering the natural occurring radiation-emitting elements. He discovered three different types of radiation with different physical properties. These radiations were later named alpha, beta, and gamma by an English physicist, Ernest Rutherford, using the first three letters of the Greek alphabet. Ionizing radiation passes through a medium and produces negatively and positively charged particles that pass through materials. The sources of ionizing radiation can be radioactive materials in the Earth's crust that emit particle (particle radiation) or pure energy without mass and electric charge (electromagnetic radiation), cosmic rays from the sun, or human-made constructs.

Radioactivity

In general, elements that spontaneously transform into another nucleus are called radioactive. This means that if the number of protons and neutrons is not equal, they will not be stable in a stable state. Rather, it tends to equalize the number of protons and neutrons and stabilize itself. In such materials that have an unstable nucleus, they can be stable via radiation, so they are called radioactive elements. In this state, for example, one of its extra neutrons converts itself into an electron and a proton and emits an electron.

When a beam of monenergistic gamma rays (single energy) with a constant intensity N_0 passes through an absorbing medium, the transmitted beam intensity is determined according to the Beer-Lambert exponential law.

$$(1)\ N = N_0 e^{-\mu X}$$

In this equation, N is the intensity of the transmitted beam through thickness X, N_0 is the initial beam intensity, and μ is a known constant called the linear attenuation coefficient. The linear attenuation coefficient is defined as the fraction of the initial beam that is absorbed or scattered in passing through each unit thickness of the absorbing material. Usually, μ is expressed in (cm -1). The linear attenuation coefficient (μ) is complicatedly depended on the atomic number (Z) of the absorbing material and the energy (E) of the radiation.

If we take the natural logarithm of equation (1), we have:

$$(2)\ \mathrm{Ln(N)} = \mathrm{Ln}(N_0 e^{-\mu X}) \rightarrow \mathrm{Ln\ (N)} = \mathrm{Ln}N_0 - \mu\mathrm{X}$$

This means that if we plot the Ln (N) graph against X, we will obtain a straight line with a slope equal to μ, which can be calculated.

Half-Value Layer (HVL)

Another quantity defined in this regard is the half-value layer, which is the thickness of an absorbing material that reduces the intensity of radiation by half and is related to μ and can be calculated from the Beer-Lambert formula. In other words, if we replace N with 1/2(N) and X with X_ (1/2) in equation (1), and take the natural logarithm on both sides, we will have:

$$(3)\ X_{\frac{1}{2}} = 0.693/\mu$$

Therefore, by substituting μ in this equation, we can obtain the value of the half-value layer X_ (1/2). The advantage of determining this layer is that it is used in radiology to determine the thickness of protective layers and express the quality of radiation. By knowing the thickness of this layer for each element in terms of radiation protection principles, an appropriate shield can be designed to prevent the passage of ionizing radiation to adjacent areas and protect personnel and patients from diagnostic radiation. According to the recommendations of the International Atomic Energy Agency, by selecting a thickness of approximately 3.5 times the half-value layer, it can be ensured that the corresponding ionizing radiation is blocked to the required extent.

Geiger-Muller Detector

To determine the initial intensity of the radiation N_0 and the transmitted intensity through a material (N), a device that called Gamma counter (γ −counter) is used, which is also known as a Geiger-Muller (GM) detector. The GM tube is cylindrical, and its inner wall acts as the cathode and has a thin wire as the anode along the axis of the cylinder. The inside of the tube is filled with a mixture of an inert gas like argon and a small amount of a halogen gas or ethyl alcohol.

The radiation ionizes the gas inside the detector and creates positive and negative ions. If there is no potential difference between the anode and cathode, no force will conduct the ions created to the electrodes, and therefore, these ions will recombine with each other and no current will pass through the resistance. If a weak potential is applied to the electrodes (v), an eV force will drive the positive and negative ions towards opposite poles, resulting in less recombination and a weak current passing through the circuit. The magnitude of this current depends on the number of ionizations, which is the amount of energy transferred from radiation to the gas inside the detector. This voltage range is called the recombination region.

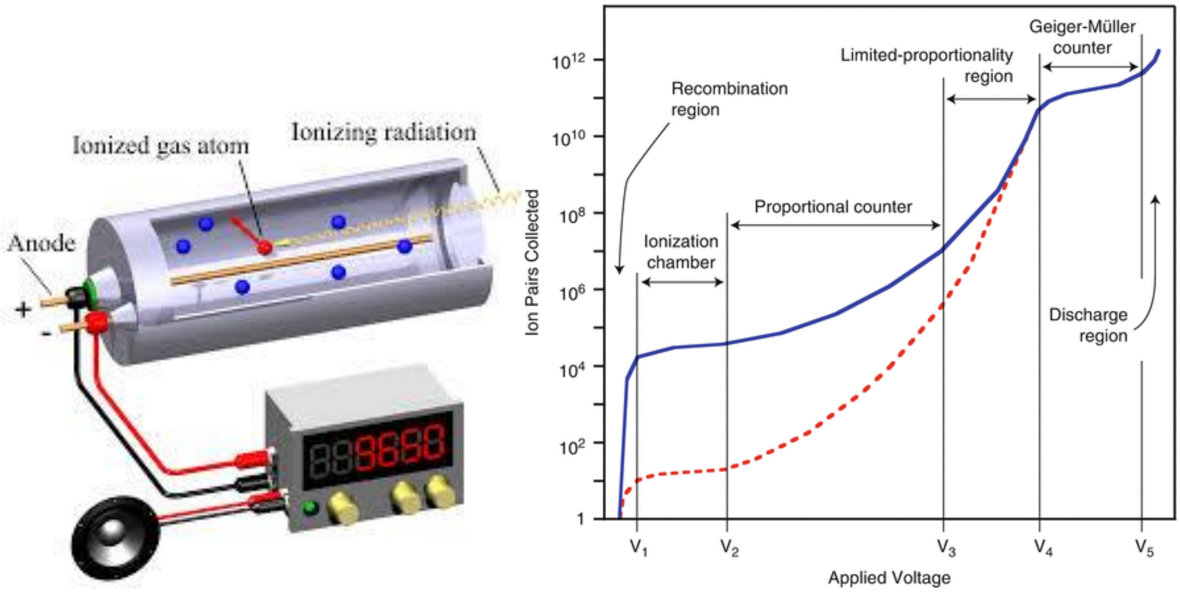


Figure 1 Geiger-Mueller detector structure and voltage region

With an increase in voltage, the possibility of recombination disappears until all the charges created reach the anode and cathode, which is called the saturation region. Ionization chambers operate in this region. With further voltage increase, secondary ionization or multiplication occurs, so that the energy of accelerated ions is sufficient to ionize neutral atoms as well. With an increase in the number of collected ions, the height of the resulting pulse at the output increases. Here, the amount of energy passing through the circuit and therefore the output voltage has a linear relationship with the amount of energy transferred from the radiation to the detector (the number of initial ionizations) and the voltage between the anode and cathode, which is called the proportional region. In the limited proportional region, the linear relationship between the current magnitude and the number of initial ionizations disappears. Finally, in region 5, the current or pulse height reaches its maximum due to complete gas discharge near the anode, which consists of the number of initial ionizations. In this region, known as the Geiger-Muller region, the avalanche of electrons expands near the central wire. Increasing the discharge voltage further inside the chamber can cause damage to the detector even without radiation.

Radioactive sources

The radioactive material used as a gamma source in this experiment is either Co-60 or Cs-137. Cobalt-60 emits beta radiation followed by two gamma rays with energies of 1.17 and 1.33 million electron volts converts to the Ni element. Cesium-137 emits a beta ray and a gamma ray with an energy of 662 kilo electron volts, which is converted to barium. Gamma rays are counted by the detector device. The decay constants for these two radioactive materials are shown in the figure below.

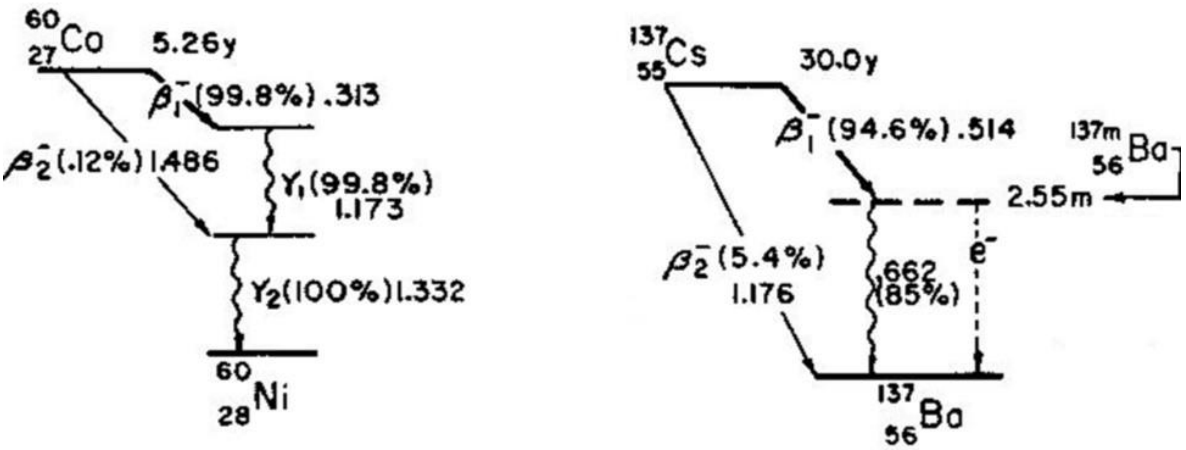


Figure 2. Decay diagram of Cobalt-60 and Cesium-137 radioactive sources

Experimental description

Turn on the device and set the gamma counter voltage, which should initially be at zero, to 700 volts. Press the CR button on the device to start counting background radiation caused by cosmic rays and natural sources in the laboratory environment, and after a specified time (120 seconds), the device will automatically stop counting. Place the Co-60 source in front of the counter window at a fixed distance for an appropriate amount of time for counting the radiation. Place lead absorbers between the source and the counter based on the thickness values given in the table on the next page and count for 120 seconds each time. Repeat each count twice and take the average. Correct the averages obtained for background radiation and write this as the corrected counting in the table. Then, perform the same experiment for different thicknesses of aluminum and make the corresponding tables and plot the curve of changes in count as a function of absorber thickness (inch) or mass thickness (or surface density) (gr/cm^2) on semi logarithmic paper, then calculate the linear attenuation coefficient and half-value layer.

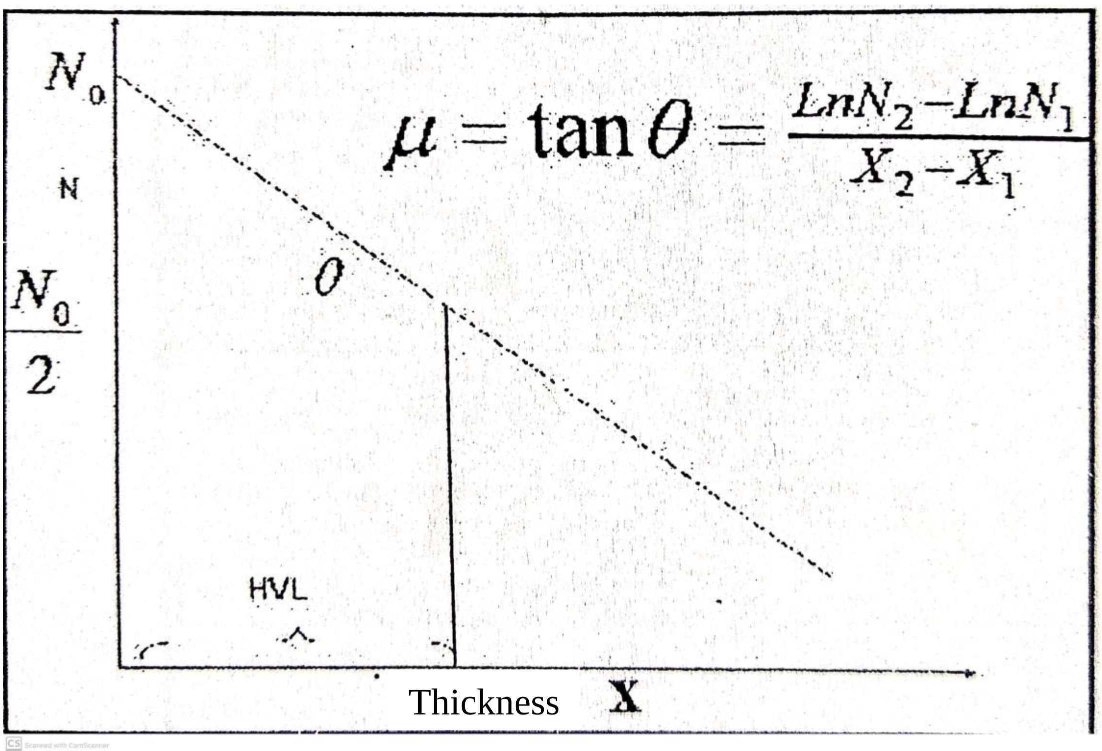


Figure 3. The slope of the plotted graph is equivalent to the value of the linear attenuation coefficient.

Thickness of Absorbent (inch)	First counts	Second counts	Average counts	Corrected counts
Background count				
Without absorbent				
0.125				
0.25				
0.375				
0.500				
0.625				
0.750				
0.875				
1				

Table 1. The table that is completed during the experiment.

value	Ln	value	Ln	value	Ln	value	Ln
36	3.58	192	5.26	617	6.42	3455	8.15
45	3.81	208	5.34	855	6.75	3479	8.15
53	3.97	216	5.38	1145	7.04	3610	8.19
79	4.37	224	5.41	1400	7.24	4126	8.33
85	4.44	230	5.44	1416	7.26	4257	8.36
89	4.49	235	5.46	1547	7.34	4400	8.39
114	4.74	260	5.56	1711	7.44	5111	8.54
115	4.74	266	5.58	1842	7.52	5155	8.55
117	4.76	269	5.59	2000	7.60	5255	8.57
131	4.88	290	5.67	2032	7.62	5286	8.57
133	4.89	305	5.72	2145	7.67	5966	8.69
140	4.94	317	5.76	2163	7.68	6017	8.70
147	4.99	332	5.81	2255	7.72	6025	8.70
150	5.01	335	5.81	2469	7.81	6143	8.72
162	5.09	353	5.87	2600	7.86	6880	8.84
163	5.09	377	5.93	2600	7.86	7000	8.85
176	5.17	423	6.05	2930	7.98	7855	8.97
180	5.19	459	6.13	3000	8.01	S199	9.13
190	5.25	581	6.36	3061	8.03	10054	9.22

Table 2. The closest number to our value can be selected using the above table, and then, we can obtain the Ln value of it.

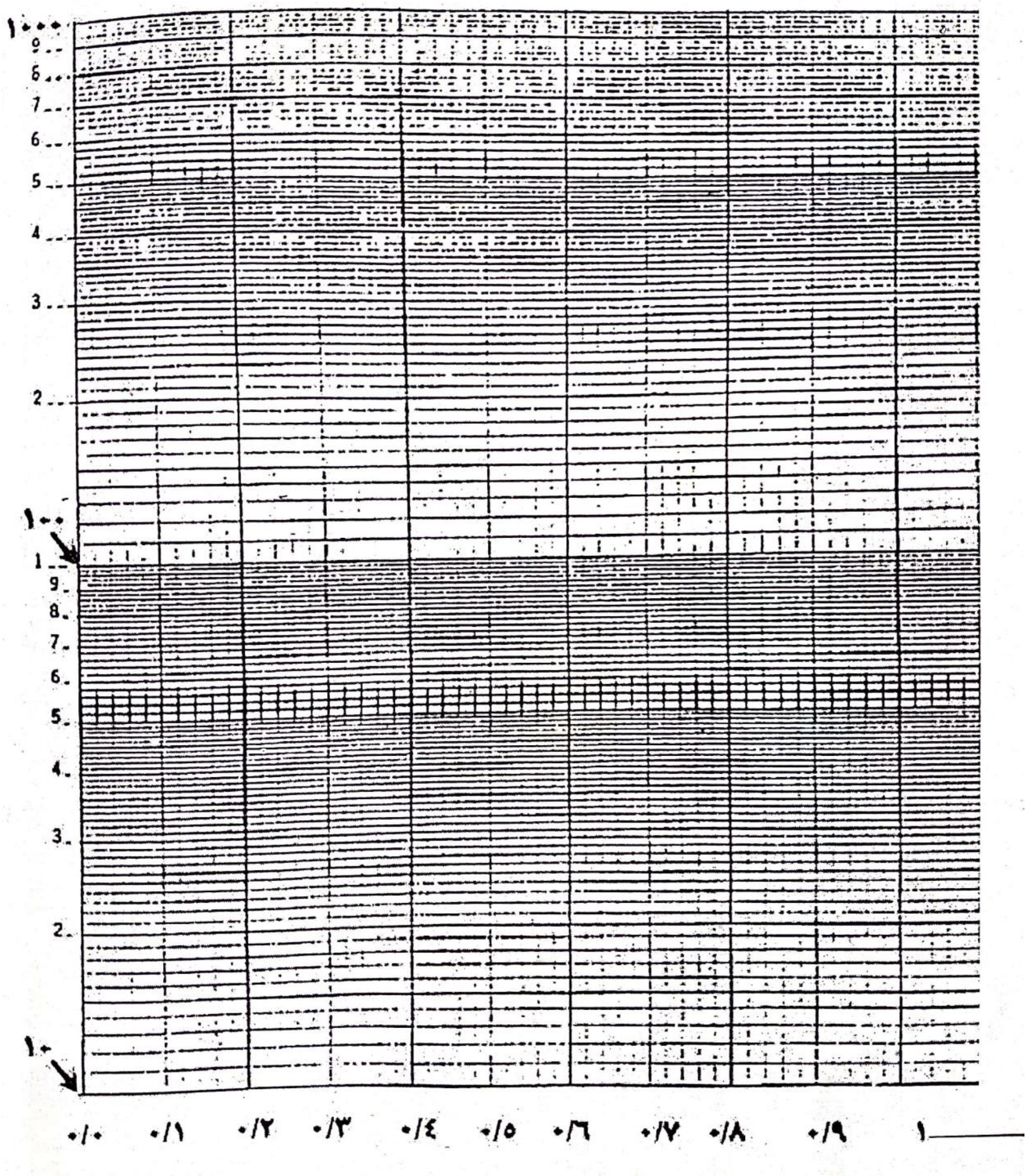


Figure 4. Semi-logarithmic curve for graphing

Questions

1. Draw the graph using the table of counts and then determine the linear attenuation coefficient of lead under Co-60 radiation from the graph.
2. Obtain the HVL for lead under Co-60 radiation.