PHYSICS 176

UNIVERSITY PHYSICS LAB II

Experiment 13

Radioactivity, Radiation and Isotopes

Equipment: ST-360 Counter with GM Tube and stand, shelf stand, and a source holder with isotopes.

Historical overview:

Radiation was discovered in the late 1800s. Wilhelm Röntgen observed undeveloped photographic plates which had become exposed while he worked with high voltage arcs in gas tubes. Unable to identify the electromagnetic wave energy, he called them "X" rays. The following year, 1896, Henri Becquerel observed that while working with uranium salts and photographic plates, the uranium seemed to emit a penetrating radiation similar to Röntgen's X-rays. Madam Curie called this phenomenon "radioactivity". Further investigations showed that this property of emitting radiation is specific to a given element or isotope of an element. It was also found that atoms producing these radiations are unstable and emit radiation at characteristic rates to form new atoms.

Atoms are the smallest unit of matter that retains the properties of an element (such as hydrogen, carbon, or lead). The central core of the atom, called the nucleus, is made up of protons (positive charge) and neutrons (no charge). The third part of the atom is the electron (negative charge), which orbits the nucleus. In general, each atom has an equal amount of protons and electrons so that the atom is electrically neutral. The atom's size is on the order of an angstrom (1 Å), which is equivalent to $1x10^{-10}$ m while the nucleus has a diameter of a few femtometers (1 fm $=1x10^{-15}$ m). This means that the nucleus only occupies approximately 1/10,000 of the atom's size. Yet, the nucleus controls the atom's behavior with respect to radiation. (The electrons control the chemical behavior of the atom.)

Radioactivity

Radioactivity is a property of certain atoms to spontaneously emit particles, such as alpha particles and beta particles, or electromagnetic waves such as x-rays. These unstable atoms are called radioactive atoms or isotopes. When radioactive (or unstable) atoms adjust, it is called radioactive decay or disintegration. A material containing a large number of radioactive atoms is called either a radioactive material or a radioactive source. Radioactivity, or the activity of a radioactive source, is measured in units equivalent to the number of disintegrations per second (dps) or disintegrations per minute (dpm). One unit of measure commonly used to denote the activity of a radioactive source is the Curie (*Ci*) where one Curie equals thirty seven billion disintegrations per second. 1 *Ci* = 3.7x1010 dps = $2.2x10^{12}$ dpm. The SI unit for activity is called the Becquerel (*Bq*) and one Becquerel is equal to one disintegration per second. 1 *Bq* = 1 dps = 60 dpm.

Alpha (α) particles. These particles consist of 2 neutrons and 2 protons that are bound together without any accompanying electron

Beta (β) particles. These are high speed single electrons which are emitted from the nucleai.

Radiation

Radiation is energy emitted from radioactive atoms, either as electromagnetic (EM) waves or as particles. Radioactive materials that we find as naturally occurring were created by:

1. Formation of the universe, producing some very long lived radioactive elements, such as uranium and thorium.
2. The decay of some of these long-lived materials into other radioactive materials like radium and radon.
3. Fission products and their progeny (decay products), such as xenon, krypton, and iodine.

Man-made radioactive materials are most commonly made as fission products or from the decays of previously radioactive materials. Another method to manufacture radioactive materials is activation of non-radioactive materials when they are bombarded with neutrons, protons, other high-energy particles, or high-energy electromagnetic waves.

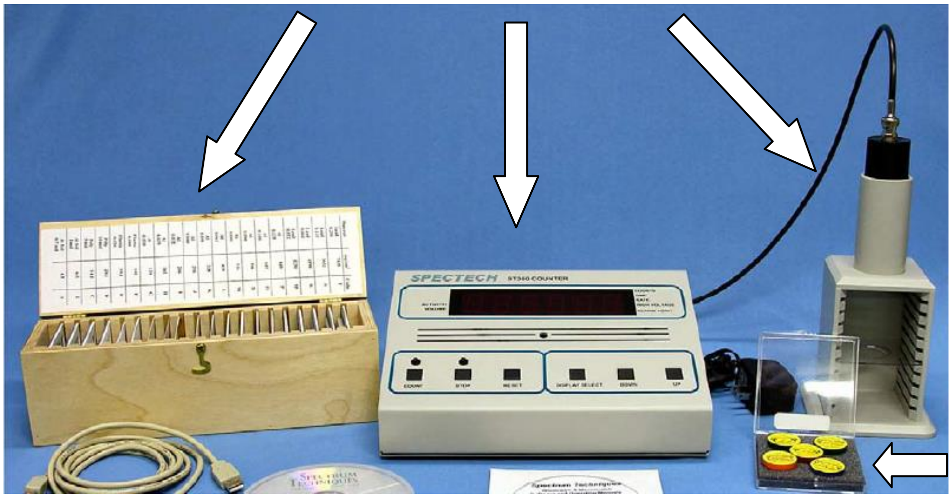
Exposure to Radiation

Everyone on the face of the Earth receives background radiation from natural and man-made sources. The major natural sources include radon gas, cosmic radiation, terrestrial sources, and internal sources. The major man-made sources are medical/dental sources, consumer products, and other (nuclear bomb and disaster sources). Radon gas is produced from the decay of uranium in the soil. The gas migrates up through the soil, attaches to dust particles, and is breathed into our lungs. Cosmic rays are received from outer space and our sun. The amount of radiation depends on where you live; lower elevations receive less while higher elevations receive more. Terrestrial sources are sources that have been present from the formation of the Earth, like radium, uranium, and thorium. These sources are in the ground, rock, and building materials all around us. The last naturally occurring background radiation source is due to the various chemicals in our own bodies. Potassium is one of those. Background radiation can also be received from man-made sources. The most common is the radiation from medical and dental x-rays. There is also radiation used to treat cancer patients. There are small amounts of radiation in consumer products, such as smoke detectors, some luminous dial watches, and ceramic dishes (with an orange glaze). The other man-made sources are fallout from nuclear bomb testing and usage, and from accidents such as Chernobyl. Without overloading you with too much information, the government mandates that the safety level for radiation is three times below the level of exposure for biological damage to occur. So just living another year (celebrating your birthday), you may receive about 7% of the government regulated radiation exposure. If you have any more questions, please ask your instructor.

Isotopes

Isotopes are variants of a particular chemical element which differ in neutron number. All isotopes of a given element have the same number of protons in each atom. Some isotopes are radioactive, and are therefore referred to as radioisotopes or radionuclides, whereas others have never been observed to decay radioactively and are referred to as stable isotopes or stable nuclides. That decay happens regularly like a clock. The rate at which a radioactive isotope decays is measured in half-life. The term half-life is defined as the time it takes for one-half of the atoms of a radioactive material to disintegrate. For carbon, the decay happens in a few thousand years (5,730 years). Some elements take longer, and others have a decay that happens over a period of minutes. Archeologists are able to use their knowledge of radioactive decay when they need to know the date of an object they dug up. When locked in an object from thousand years ago, C-14, that is an isotope of carbon, would decay at a certain rate. With their knowledge of chemistry, archeologists can measure how many thousands of years old an object is. This process is called carbon dating**.** Here we will use *Po-201* (half-life of 138 days), *Cs-127* (half-life of about 30 years), *Sr-90* (half-life of about 29 years), *Co-60* (half-life of 272 days), and *Tl-204* (half-life of 3.8 years) isotopes. The isotopes are sealed in capsules strong enough to maintain leak tightness under the conditions of use in this Lab, and also under foreseeable mishaps.

Equipment: overall view: **Absorbers** **Counter** **GM tube**



Sources

Figure 1. Setup for the Lab with sources, absorbers, GM tube and counter.

GM Tube

Geiger-Mueller tubes produce electrical pulses when ionizing radiation events occur within their sensitive volume. To improve sensitivity, GM tubes have extremely thin entrance windows, which require careful handling. Keep the protective caps in place when the tube is not in its stand and never touch the window. All Geiger-Müller (GM) counters do not operate in the exact same way because of differences in their construction. Consequently, each GM counter has a different high voltage that must be applied to obtain optimal performance from the instrument.

Modes of operation of the Radiation Counter.

COUNT Control

The *COUNT* button starts the timer and event data acquisition. The corresponding LED indicates when the unit is counting.

STOP Control

The *STOP* button stops the timer and event data acquisition. The corresponding LED indicates when the unit has stopped counting.

RESET Control

The *RESET* button only functions when counting is stopped. It is used to reset the time and counts to zero.

DISPLAY SELECT Control.

Pressing *DISPLAY SELECT* button cycles through each mode in the following order: *COUNTS*, *TIME*, *RATE*, *HIGH VOLTAGE*, *ALARM POINT*, *SPEAKER VOLUME*, then back to *COUNTS*, etc… On the right side of the display, a corresponding LED will indicate the selected mode unless the unit is in *SPEAKER VOLUME* mode for which there is no indication LED.

DOWN and UP Controls

The *DOWN* and *UP* buttons are used for setting the preset time, high voltage, alarm point and speaker volume.

Procedure- Experiment 13

Warnings: It is strictly forbidden to store or consume any kind of food or beverage in your working area. The sources of radiation used in the Lab are an exempt source, which means that they give off very little radiation compared to what the government (NRC – Nuclear Regulatory Council) deems dangerous sources. Yet, use common sense during the Lab session. In particular, do not attempt to open the sources up.

Data Sheet - Experiment 13 Name:
Section #

Experiment 1: Determining the operating voltage of the GM tube

The correct operating voltage for the Geiger-Mueller tube has to be determined using *Cs-137* radioactive source, unless your instructor advises you to use another one. A properly functioning tube will exhibit a "plateau" effect, where the counting rate remains nearly constant while the high voltage is increasing linearly. A plateau chart is obtained by counting a source for several *runs* using a constant preset time, while increasing the high voltage by a constant amount.

1. Place the radioactive source in a fixed position close to the window of the GM tube.
2. Set high voltage to 600 V.
3. Set the *Preset Time* to 10 seconds and press *COUNT*.
4. When the *Preset Time* expires, record the counts. Repeat three times and average out the readings. Record the averaged value for counts and the voltage setting.
5. Increase the high voltage by 20 volts and press *COUNT* again.
6. Repeat steps 4 and 5 until the high voltage reaches 1.15 kV.
7. Create an X-Y graph of the data, with "Y" being the Counts, and "X" being the voltage. The graph should look-like the one shown in Figure 2. Determine the operating voltage for the GM tube and operate the tube at that voltage throughout the Lab.

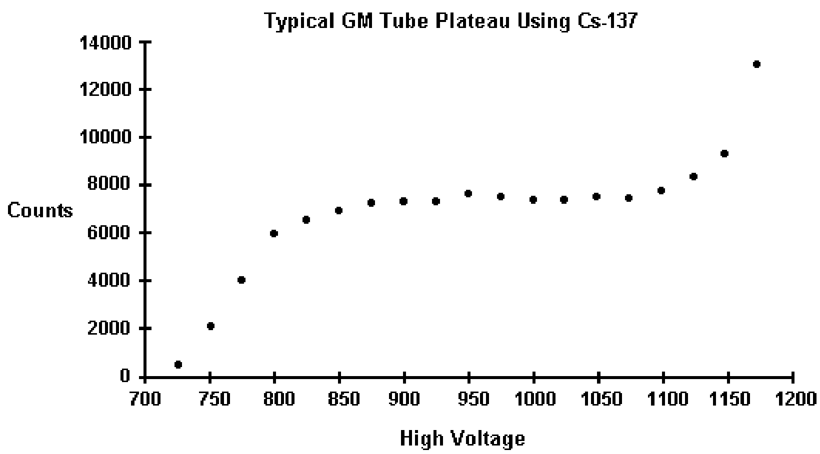


Figure 2. A typical GM tube plateau. Notice that the counts form a relatively *flat* region on the graph between 850 and 1150 volts. The center of this area is at approximately 950 volts and is the recommended operating voltage for this detector. However, any voltage in this *flat* region would be acceptable. Also, notice that the counts increase rapidly as the high voltage nears its upper limit. This indicates that the tube is entering its breakdown region.
Do not continue to operate the tube in this region !

Data table for the GM tube plateau.
Repeat every measurement 3 times, average and only then enter a data point in the table.

Voltage	Counts	Voltage	Counts

The best operating voltage for the tube = Volts.

Would the functional dependence/plot “Counts vs Tube Voltage” change if the experiment is done using another radioactive source ? Explain:

Experiment 2: Determining the relationship between the distance and intensity of radiation

As a source is moved away from the detector, the intensity, or amount of detected radiation, decreases. It is like the farther you move away from a light source, the harder it is to see. Here you will determine the exact dependence of the registered intensity on the distance between the GM tube/detector and the particular source. The experiment can be done using *Sr-90* source.

1. Setup the Geiger counter as you did it in the previous experiment. Set the *Voltage* of the GM tube to its optimal operating voltage, which should be around 950 Volts.
2. Set *Preset Time* to 30.
3. First do a run without a radioactive source to determine the background level.
4. Next, place the radioactive source in the top shelf and begin taking data. In this position, the source is 2 cm from the GM tube's actual detector components.
5. Move the source down one shelf each time and take another data point. You should see the intensity decreasing. Record the measured intensities in the Table below. After all ten shelves have been used, *correct* the intensities for the background and plot them vs the respective distances.

Data table for the intensity vs distance dependence. Repeat every measurement 3 times, average and only then enter a data point in the table.

Counts	Corr. Counts	Distance

What is the dependence of the measured intensity on the distance between the GM tube/detector and the radioactive source, that is, no dependence, linear dependence, exponential dependence or …? Explain:
Hint: Think of how light and sound intensity diminishes with the distance from the source.

Experiment 3: Absorption of gamma rays

Gamma radiation unlike alpha and beta radiation, consists of electromagnetic waves. Gamma rays are emitted as photons, or little "packages" of energy called quanta, which travel at the speed of light (c = 3.0 x 10^8 m/s). One significant difference between x-rays and gamma rays is their origin. X-rays are produced in the electron shells, while gamma rays are produced in the nucleus. X-rays are created when electrons undergo a deceleration or jump to lower energy levels. Gamma rays are created by energy transitions in the nucleus. In this experiment, we are mostly concerned with gamma rays, because any x-rays present will be shielded by air and matter acting as absorbers.

When a beam of gamma rays impinges on a sheet of absorbing material, some of the radiation will be absorbed or scattered. As the thickness of the absorber is increased, the fraction of the radiation passing through will decrease. When exactly half the radiation passes through the absorber (and the other half is absorbed or scattered), the thickness of the absorber is called the half thickness, $X_{1/2}$.

Since the intensity of radiation is reduced by 50% by passing through one $X_{1/2}$, it will be reduced by another 50%, or only to 25% of the original intensity, in passing through a second $X_{1/2}$ of absorber. A linear relationship is obtained if the data are plotted using semi log paper or if the logarithm of the activity is plotted as a function of the absorber thickness.

The attenuation (or absorption and scattering) of gamma rays is exponential in nature, which is shown by the equation:

$$I = I_o e^{-\mu X} \qquad (1)$$

where I is the intensity of the beam after passing through X amount of absorbing material, I_o is the original intensity, μ is the mass attenuation coefficient, and X is the mass thickness. Since the intensity of the gamma rays is cut in half after passing through $X_{1/2}$, we can rewrite Equation 1 as

$$\frac{1}{2} I_o = I_o e^{-\mu X_{1/2}} . \qquad (2)$$

The I_o terms cancel giving

$$\frac{1}{2} = e^{-\mu X_{1/2}} , \qquad (3)$$

which can again be rewritten by taking the natural logarithm of both sides

$$\ln\left(\frac{1}{2}\right) = -\mu X_{1/2} . \qquad (4)$$

Using the rules of exponents, we know that ln(1/2) = -ln(2), so that gives

$$\ln(2) = \mu X_{1/2} . \qquad (5)$$

One final rearrangement gives us a value of the mass attenuation coefficient

$$\mu = \frac{\ln(2)}{X_{1/2}} = \frac{0.693}{X_{1/2}} . \qquad (6)$$

During your data analysis, you will find a value for μ , and thus one for $X_{1/2}$

1. Setup the Geiger counter as you have in the previous experiments. Set the *Voltage* of the GM tube to its optimal operating voltage, which should be around 900 Volts.
2. Set *Preset Time* to 60.
3. First do a run without a radioactive source to determine your background level. Use *Cs-137* isotope.
4. Next, place the radioactive source in <u>the second shelf from the bottom</u> and begin taking data.
5. Place an absorber piece in <u>the top shelf</u> and take another run of data.
6. Repeat this using at least 4 absorbers (e.g. Pb) of increasing thickness. <u>Also, do not forget to repeat every measurement 3 times, average and only then enter a data point in the table.</u>

Plot your data as a function of absorber thickness. Use semi-log paper/scale if necessary.

Counts	Corr. Counts	Mass thickness (mg/cm^2)	ln (Counts)

Equation for line:
y= ______________________

μ= ______________________ cm^2/mg

OR μ= ______________________ cm^2/g

Calculate $x_{1/2} = \ln(2)/\mu$

$x_{1/2}$ = g/cm^2

Is your data linear / if not, why ? Can we be completely shielded by gamma rays ? If not, then why bother ?

When the Lab session is over, PLEASE
i) reduce the voltage of the GM tube to zero MANUALLY and *then*
ii) turn the power off using the push button on the back of the counter.

Appendix A – Common Radioactive Sources

Isotope	*Activity*	*Half-Life*	*Emissions*	*Energies*
Ba-133S	**1 µCi**	**10.7 years**	**Gamma**	**81.0, 276.3, 302.7, 355.9, 383.7**
Cd-109S	**1 µCi**	**453 days**	**Gamma**	**88.0**
Co-57S	**1 µCi**	**270 days**	**Gamma**	**122.1, 136.4**
Co-60S	**1 µCi**	**5.27 years**	**Gamma, Beta**	**1173.2, 1332.5, ß317.9**
Cs-137S	**1 µCi**	**30.1 years**	**Gamma, Beta**	**32, 661.6 ß511.6, ß1173.2**
Cs-137S5	**5 µCi**	**30.1 years**	**Gamma, Beta**	**32, 661.6 ß511.6, ß1173.2**
Cs/ZnS	**1 µCi**	**Mixed**	**"Unknown"**	**32, 661.6, 1115.5**
Eu-152	**1 µCi**	**13.5 years**	**Gamma**	**Multiple**
Mn-54S	**1 µCi**	**312 days**	**Gamma**	**834.8**
Na-22S	**1 µCi**	**2.6 years**	**Gamma**	**511.0, 1274.5**
Po-210S	**0.1 µCi**	**138 days**	**Alpha**	**5304.5**
Sr-90S	**0.1 µCi**	**28.5 years**	**Beta**	**546.0**
Tl-204S	**1 µCi**	**3.78 years**	**Beta**	**763.4**
Zn-65S	**1 µCi**	**244 days**	**Gamma**	**1115.5**