Radioactivity

The term radiation literally means "that which moves radially." This means that radiation usually emanates from a point and moves away along a radius of the sphere which has its center at that point. The **inverse square law** describes the relationship between the **intensity** *(I)* of a certain radiation and the **distance** *(r)* from the source: $I \mu \frac{1}{r^2}$. But why is the intensity proportional to the inverse of the square of the distance? The answer is actually pretty simple.

The units for intensity are particles per second per unit area, i.e.:

$$[\, I \,] = \frac{[\text{ particles }]}{[\text{second}]\,[\text{area}]}$$

On average, a certain point source emits a certain number of particles per second. These particles move away from the source in arbitrary directions, and they move *radially*. Statistically speaking, the trajectories of the particles will be evenly distributed over all the possible radial directions. Let's say that a source emits X particles every second and that they all travel away from the source at the same speed. If you put a sphere around the source with the source at the center, there will be X particles per second passing through the surface area of the sphere because the sphere completely encloses the source. If you use a sphere of a greater radius (but with the center still at the source), X particles per second still pass through the sphere, but they will pass through a greater surface area, and the intensity will be less (because there are fewer particles per second passing through *each unit* of area). The relationship between the area *(A)* of a sphere and the radius *(r)* is as follows:

$$A = 4 \pi r^2$$

Therefore, for a source *radially* emitting X particles per second, the intensity will be:

$$I = \frac{X}{4 \pi r^2}$$

and we see the inverse square relationship.

In the past laboratories, we have been observing a type of radiation called visible-light electromagnetic radiation. The particle which carries this type of radiation is called the **photon**, and is emitted or absorbed when electrons move from one energy level in the atom to another. Other types of radiation called **nuclear radiation** also exist. These are composed of basically three types of particles* , the alpha (α), the beta (β), and the gamma (γ). The α is a high energy helium nucleus which is released in a nuclear decay in which the He^{+2} (two neutrons and two protons) is ejected from the nucleus, lowering the atomic number of an atom by two and the mass number by four. The β is a high energy electron which is emitted when a neutron in the nucleus decays into a proton and an electron, raising the atomic number by one and leaving the mass number unchanged. The γ is a high energy, high frequency, ultra-short wavelength photon which is released when the protons and neutrons change energy states in the nucleus, a process which is analogous to the manner by which ordinary photons are released when the electron changes states in the atom. While all three types of nuclear radiation are harmful, only β and γ radiation can penetrate deep into the body.

In this lab, we will be studying a very weak source of nuclear radiation, and how the intensity (counts/second•area) relates to the distance from the source.

Procedure:

The Geiger-Muller (GM) Tube.

The GM tube is a device which is used to measure the presence of alpha, beta, and gamma radiation. It consists of a rarefied (low density) gas at a low pressure contained in a sealed tube between two high voltage electrodes. When radiation enters the tube, it ionizes on of the molecules of the gas, giving it a charge. The charged particles are then accelerated through the voltage produced by the electrodes until they strike the electrodes, causing a spike in the current. This spike corresponds to a single particle which is detected and is called a **count**. Only certain voltages may be placed between the two electrodes for the GM tube to function properly. The *starting voltage* is the minimum voltage below which no detection will occur. The *operating voltage* is the optimal voltage for maximum detection. If the voltage is increased to the *avalanche voltage*, the rarefied gas will become ionized, large currents will be produced, and the tube may be damaged. The individual pulses or counts can then be sent through an electronic circuit which time-averages them to determine the number of "counts per second". *Since the area of the window of the GM tube is constant, the intensity will be directly related to this quantity.* Normally the operating voltage must be determined for an individual tube, but this has already been done previous to this experiment.

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* Neutrons and neutrinos are also emitted in nuclear reactions, but they are difficult to detect and will not be treated in this lab.

We will be using the GM tube and a simple ruler to measure *I* and *r*, and testing if the inverse square law is indeed applicable.

Preliminary procedure:

A preliminary examination of the GM tube should reveal the following:

1. It has an on-off , volume control switch with which the volume of the audible clicks (counts) may be controlled. Also, there is an indicator light which will flash when counting occurs.
2. The device has a range selector which allows the single meter to read a wide range of counts per minute (CPM). Note the two scales, one ending at 1000 and the other ending at 3000. You will need to multiply the meter reading by the respective power of ten to get the actual reading. For instance, if the range is set on the 0-30,000 range, you will read the 0-3000 scale and multiply by 10.
3. There is a red button which when pressed, causes the meter to read the tube voltage on the red scale.
4. There is a vertical cm scale with zero at the end of the GM tube.
5. The GM tube fits between two clamps at the end of the cm scale and should be positioned with its window facing upward and centered on the scale.
6. The radiation source is very weak and is not of any danger to you. The source is imbedded in a plastic disc and the radiation is emitted through a hole in the aluminum mount. The radiation from the hole is emitted in a hemispherical distribution. The magnet on the mount allows it to be placed anywhere along the cm scale.
7. The response control has three settings: slow, medium, and fast. The slow setting will yield a very accurate reading of counts / sec but it will take a long time to get the reading. The fast reading will give a less accurate reading, with the needle showing visible fluctuations. You should use the slow or medium settings.

Data Collection:

1. Do not turn on the counter yet! Set the tube voltage to zero by turning the voltage control counter-clockwise to its zero setting. Now you may turn on the counter. Press and hold down the red button and turn up the voltage until the value reaches the V_0 listed at the top of the counter.
2. Since the Earth is constantly bombarded by cosmic radiation, you will need to record the value of the CPM with no sources present. This will give you the reading of the **background radiation**. You will need to repeat this several times throughout the experiment. This background CPM should be subtracted from all subsequent readings.

3. With the selector on the 0-10,000 range, move the source close to the GM tube until the reading on the meter is nearly full-scale. Record I and r.
4. Move the source away at 0.5 cm increments, recording I and r for every position. When the reading is below 3000, you can change the range setting to get a more accurate reading of the intensity.

Analysis:

Since the intensity is proportional to the inverse of the distance squared, the product of intensity and distance squared should be constant. For each data pair, compute Ir^2.

Plot all your intensity/ distance data on a graph and turn it in with your report.

Conclusions:

1. Summarize your results for this experiment.
2. Are the values Ir^2 constant? Did the inverse square law apply here?
3. Did you notice any pattern to the clicks on the counter, any rhythm? Since the particles are emitted radially, what do you think about the direction each individual particle is emitted? Is it predictable?
4. Look at your graph. Does it have a smooth inverse square curve? Are there any anomalies? What happens when the source is especially close to the tube? Would the inverse square law apply here? What would happen if the GM tube's reading were not linear (that is, not directly proportional to the actual CPM)?

Error Analysis:

Describe any major sources of possible error and deviation from the inverse square law.

Radioactivity

Name:_______________________ Section:_________

Abstract:

Data:

r	r^2	I	$I\ r^2$

Calculations: (Use back if necessary)

Conclusions:

Error Analysis: