Experiment 3
Radioactivity: Effect of Distance and Absorbers

Textbook Reference: Chemistry Matter and Its Changes, Chapter 22 by Brady and Senese.

Discussion

Radioactivity is the emission of high-energy particles from unstable nuclei and was discovered in 1896 by Henri Becquerel. Ernest Rutherford later discovered that there are three common types of radioactivity: α (alpha particles), β (beta particles), and γ (gamma rays). In this experiment we will study the properties of radioactive emissions and their interactions with matter. http://www.physics.isu.edu/radinf/natural.htm http://www.darvill.clara.net/nucrad/

Particle	Symbol	Mass Number	Charge	Description
alpha (α)	${}^{4}_{2}He^{2+}$	4	+2	helium nucleus
beta (β)	${}^{0}_{-1}e$	0	-1	electron
gamma (γ)	${}^{0}_{0}\gamma$	0	0	photon

Consider the emission of a beta particle from strontium-90:

β-emission ${}^{90}_{38}Sr \rightarrow {}^{0}_{-1}e + {}^{90}_{39}Y$

In this process the nucleus emits an electron and is converted into a yttrium-90 nucleus. Both mass number and charge number are conserved in the process. This conservation is represented in the nuclear equation.http://www.fordhamprep.org/gcurran/nuceqex.htm
http://www.wwnorton.com/chemistry/concepts/chapter2/ch2_2.htm

Another decay process is the emission of a beta particle from cobalt-60:

$${}^{60}_{27}Co \rightarrow {}^{60}_{28}Ni^{*} + {}^{0}_{-1}e$$

The product of the decay of cobalt-60 is nickel-60. But this isotope is said to exist in an excited state. It possesses a large amount of energy. It is analogous to atom in which an electron is in an excited state. It will emit a photon and relax to a lower energy state. The photon is a gamma ray and possesses a large quantity of energy:

$${}^{60}_{28}Ni^{*} \rightarrow {}^{60}_{28}Ni + {}^{0}_{0}\gamma$$

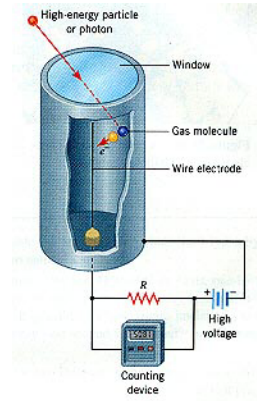
So cobalt-60 emits two types of particles, beta and gamma.

The ability of a particle emitted by nuclear decay to move through material without being stopped is an important issue. For example, alpha particles generally cannot penetrate through most materials (like paper or skin). But gamma rays can. An important factor in the ability of a particle to penetrate through material is its energy. A particle with a high energy possesses a greater capacity to pass through matter than a particle with a small amount of energy. In this experiment we will compare the abilities of beta and gamma rays to pass through materials of different compositions.

The Measurement of Radioactivity

The emission of high-energy particles by radioactive nuclei can be detected using a Geiger-Muller tube. http://home.clara.net/darvill/nucrad/detect.htm

The Geiger-Muller tube is typically a metal cylinder filled with an inert gas like argon through which runs a metal wire with a high voltage applied. When an alpha, beta, or gamma particle enters through the window (a thin piece of mica) it collides with many atoms in the gas. These collisions ionize the gas as electrons are stripped from the gas particles. The wire has a positive voltage applied. So the electrons are attracted to the wire. The electrons flow through the wire and are measured as individual pulses. An electronic counter displays each pulse as a count. The number of pulses (counts) is often expressed in units of counts per minute (cpm) or counts per second (cps).



In nature, we find that there is always some level of radiation due to natural and human-made sources. This radiation is called **background radiation**. Its sources include radiation from space (cosmic rays), the radiation found in terrestrial materials, and nuclear testing. Geiger counters are sensitive to background radiation. If we measure a radioactive source we must subtract the background radiation from the measurement.

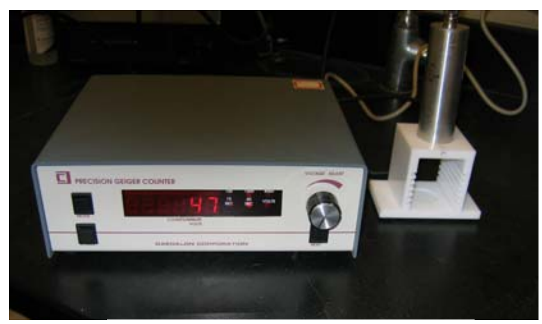
$$\text{Source} = \text{Measured} - \text{Background}$$

where Source is the count rate due to the source being studied, Measured is the measured count rate, and Background is the background count rate.

Apparatus

Geiger tube and counter, meter stick, planchet holder, a planchet of strontium-90 ($^{90}_{38}\text{Sr}$), a planchet of cobalt-60 ($^{60}_{27}\text{Co}$), and a set of absorbers.

The absorber set contains absorbers of different materials of varying thickness: Paper, polyethylene, aluminum, and lead.



Counter and Geiger tube

Procedure

Work in groups of two to three as assigned by your instructor. The voltage setting for the Geiger tube should be near 900 V.

Part A. Determining the Background Radiation Count

1. All planchets not being counted should be kept at least 6 ft from any Geiger tube in the class. Then switch on the counter.
2. Press the RESET button to set the count.

3. Set TIME to 60 sec. Now press RESET to measure the background for one minute. Record the counts in Data Table 1.

4. Repeat this process four more times so that you have five background measurements. Calculate the average of these five measurements and use the average in future calculations.

Part B. Determining the Effect of Distance
In this part of the experiment we will measure the effect of distance (r) on radiation counts.

1. Using a meter stick and a cobalt–60 source place the cobalt–60 planchet 12.0 cm from the Geiger tube. Measure the counts for sixty seconds and enter the number in Data Table 2a.

2. Repeat this process four more times and calculate the average count rate. Move the source to 10.0 cm and measure the count rate as you did for 12.0 cm.

3. Measure the count rate at 12.0 cm, 10.0 cm, 8.0 cm, 6.0 cm, 5.0 cm, and 4.0 cm. Enter all numbers in Data Table 2a.

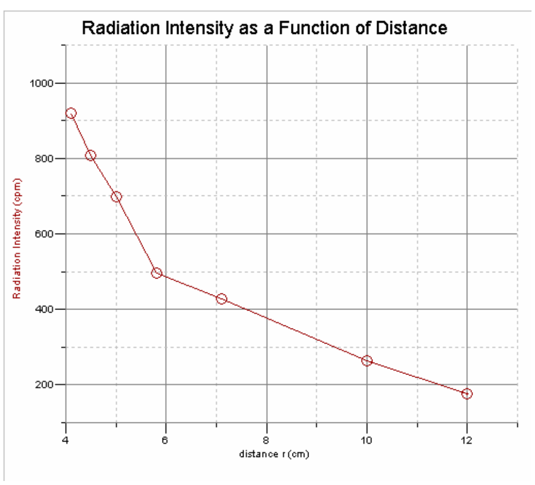
4. Subtract the average background value from the distance–dependent data and enter the results in Data Table 2b.

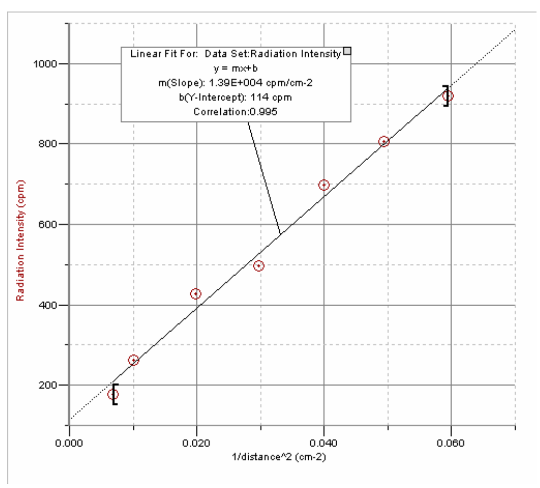
5. Calculate $1/r^2$, and Enter in Data Table 2b.

6. Plot cpm vs r and $1/r^2$ as separate graphs using Graphical Analysis as described:

It should be clear that the plot of cpm versus r is not a straight line so for this plot only, just connect the points by checking Connecting Lines in the Graph menu. For the other three plots, disable the connecting lines and perform a linear regression. A typical graph for the $1/r^2$ plot is shown. Note carefully how the axes are labeled. The caret (^) is used to denote an exponent in Graphical Analysis. For example, cm^2 means cm^2.

Be sure to save your graph to a 3 1/2 inch diskette or a USB flash drive.





Part C. Determining the Effect of Type of Absorber

In this section we will test the ability of different materials to absorb the emission of from cobalt-60 and strontium-90.

1. The Geiger tube will be re–positioned at the top of the planchet holder. Place the shelf of the planchet holder in the bottom notch. Don't touch the window of the Geiger tube. It is very fragile and costs a lot.

2. Place a planchet of cobalt–60, symbol side facing the Geiger tube on the shelf of the planchet holder. Keep the unused planchets at least 6 feet away from the Geiger tube when making this and all succeeding measurements. Be sure that the planchet is in the depression of the shelf. This way, it will be directly below the window of the Geiger tube.

3. You will use five absorbers, one of which is air. The other choices are polyethylene, cardboard, aluminum, and lead. Select two absorbers of the same nonmetal with different thicknesses. Select one metal with different thicknesses.

4. Measure the emission from cobalt-60 for each of the absorbers: Air, the two nonmetals, and the two metals. Enter the data in Data Table 3.

5. Repeat the measurements using strontium-90 as the source with the same five absorbers.

***Data Table 1–Background**

	counts (60 s)
Run 1	
Run 2	
Run 3	
Run 4	
Run 5	
Average	

***Use this value for the background correction in Data Tables 2a, 2b, and 3 below.**

Data Table 2a–Counting at Different Distances using cobalt-60

	12.0 cm	10.0 cm	8.0 cm	6.0 cm	5.0 cm	4.0 cm
Run 1						
Run 2						
Run 3						
Run 4						
Run 5						
average						
ave.– background						

Data table 2b

r (cm)	$\left(\frac{1}{r}\right)^2$ (cm^{-2})	cpm – background
12.0		
10.0		
8.0		
6.0		
5.0		
4.0		

Data Table 3 – Effect of Absorbers * (Distance is 5.0 cm for all runs.)

Nonmetal ________________________ Metal_____________________

Thickness 1________________ Thickness 1________________

Thickness 2________________ Thickness 2________________

Cobalt-60					
	air	Nonmetal (thickness 1)	Nonmetal (thickness 2)	Metal (thickness 1)	Metal (thickness 2)
Run 1					
Run 2					
Run 3					
Run 4					
Run 5					
average					

Strontium-90					
	air	Nonmetal (thickness 1)	Nonmetal (thickness 2)	Metal (thickness 1)	Metal (thickness 2)
Run 1					
Run 2					
Run 3					
Run 4					
Run 5					
average					

The Report
Your report should include: Completed data tables, two graphs of the distance dependence of radiation intensity with linear regression performed on the $1/r^2$ graph, and answers to the questions on the next page neatly typed on a separate piece of paper.

For the effect of distance on counts per minute (From Data Table 2b).

1. From your plots of cpm vs. r and $1/r^2$: Is the intensity of the radiation proportional to r or $1/r^2$? (Note: Only one choice is correct.) Explain how you arrived at your answer based on the discussion below. Hint: If two variables are proportional to one another, then a plot of one against the other yields a straight line.

2. From your observations, what is the difference between the two different emissions as far as their penetrating power is concerned. Discuss the different way that each emission is absorbed aluminum and lead. Air absorbs essentially none of the radiation. Note that if one planchet gives out more counts per minute than the other one, all that indicates is that the radioactivity of the source is greater. Also, you cannot draw any conclusions about how air absorbs the radiation from this number of counts.

   Information regarding questions 3–5 can be found in the Discussion section, textbook, and the web.

3. What is it about the nature of β and γ rays that leads to the differences described in question 2?

4. If the light emitted was blue light instead of γ rays, what qualitative difference would you expect from the γ ray data you collected? Think about what would happen if you held up the polyethylene or lead absorber to a source of blue light. Would you see any blue light coming through? Discuss the relative energies of the photons from γ rays and blue light rays in discussing your conclusions. What region of the spectrum they are in?

5. What would you predict the ability of the β particles to pass through materials to be if they were ejected at speeds much less than that of near-light speeds? Note: β particles never travel at the speed of light. Only photons can travel at the speed of light.

6. Write a one-page report discussing the procedure and your results.