EXPERIMENTS FOR NUCLEAR CHEMISTRY

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OBJECTIVE

The object of this experiment is to understand the properties of radioactive substances including the difference between alpha, beta and gamma emitters, the concept of shielding, the effect of the Inverse Square Law, and some applications of nuclear chemistry

INTRODUCTION

All matter is made up of small particles which we call atoms. The atoms of each element are composed of two parts, a nucleus, at the center of the atom, and energy levels around the nucleus. The main subatomic particles that make up the atoms are protons and neutrons, found in the nucleus, and electrons which occupy the energy levels outside the nucleus.

Each chemical element has a unique identity that is determined by the number of protons in its nucleus. Since protons have a positive charge, and like charges repel each other, to hold the protons together there are neutrons which are also located in the nucleus. For most light elements, the number of protons and neutrons are approximately equal, but as the nuclear charge of the atoms increase, the number of neutrons increases by a larger amount in order to stabilize the nucleus. For example, an atom of helium normally contains 2 protons and 2 neutrons in its nucleus, an atom of potassium normally contains 19 protons and 20 neutrons in its nucleus, and an atom of uranium usually contains 92 protons and 146 neutrons in its nucleus.

There is a large number of atoms of elements that have the same number of protons, but different numbers of neutrons in their nuclei. Such atoms are known as *isotopes*. Isotopes of an element generally have the same physical and chemical properties, except they have a different atomic mass. Some of the isotopes of some atoms, however, are not stable and, within some time period, which can range from microseconds to millions of years, their nucleus will fall apart, or disintegrate, losing a small piece. Such atoms are said to be *radioactive*.

No matter what the element is, when natural nuclear disintegration takes place, two types of particles are most commonly emitted: alpha particles (α) or beta particles (β). These are usually accompanied by a third type of radiation in the form of gamma (γ) rays.

Alpha particles, α, are positively charged and are identified as helium nuclei. They are relatively large in mass and interact strongly with matter, being absorbed by as little as a sheet of paper.

Beta particles, β, are negatively charged and are identified as fast electrons. They are small in mass and interact less with matter than α particles and can easily penetrate paper and cardboard, but are absorbed by metal sheets.

The third type of radiation, gamma rays, γ, are not particles but very high energy photons, similar to x-rays, but more energetic. They interact with matter much less strongly than do alpha and

beta particles and consequently their penetrating power is very high.

You will determine the penetrating power of radiation using laboratory safe standards of α, β, and γ radiation with various shielding materials to discriminate against the radiation.

The instrument used in this experiment is a computer-interfaced Geiger counter. Your instructor will demonstrate the use the instrument.

SAFETY PRECAUTIONS for Handling Radioactive Materials

All the samples and materials used in this experiment are low level radioactive emitters and are considered to be safe quantities of radioactive substances.

For safe handling, use, and disposal, these materials must be handled with respect, taking all the proper safety precautions needed for any radioactive material.

Do not handle radioactive materials unless you are required to do so. They should be removed from their containers when needed for a procedure, taken to the work area, and then returned to their containers when the procedures are completed.

Always handle radioactive materials with extreme care using the smallest quantity necessary for your experiment. Remember that you cannot see or feel the radiation coming from that innocent looking sample, you will only feel the effects at a later time - then, it is too late!

Always wear gloves and any other applicable safety clothing when working with radioactive materials. For these procedures, disposable gloves will be used.

Any pregnant students, or individuals who are trying to become pregnant, should avoid radioactive materials, no matter how safe they claim to be. Please inform your instructor so you may be excused from the laboratory for this experiment.

When removing disposable gloves, hold them at the cuff and remove them turning them inside out so that any traces of radioactive materials are on the inside of the glove. Do not reuse the gloves. Dispose of the gloves as directed.

Do not eat, drink, chew gum, or wear cosmetics when working with radioactive materials. All edible materials are banned from areas where radioactive materials are used.

Any cut or wound arising during work with radioactive materials should get immediate medical attention.

All radioactive wastes should be stored in appropriately labeled containers until properly stored or disposed of.

All personnel must wash their hands and face and survey their person for any contamination before leaving the laboratory.

The laboratory should be surveyed for any contamination after cleaning up.

DISPOSAL

All materials must be returned to their containers after use.

All waste materials must be placed in the properly labeled containers in the laboratory.

All glassware used to hold radioactive isotopes must be placed in the location provided near the waste containers.

EXPERIMENT 1. Determination of the Background Radiation

There is radiation all around us. It comes from the sun, from distant stars or other sources in space, from radioactive isotopes in the air, and from radioactive isotopes in the soil. This radiation will vary with your location on the Earth, but no place is 100% nuclear radiation free. All this radiation is known as *background radiation*. In order to measure radioactivity of our samples, the background radiation must be determined.

Figure 1. Aware Electronics Model RM-60 Geiger tube.

Materials Needed:
Aware Electronics Geiger counter tube interfaced with a laboratory computer. (See Figure 1.)
Stand for the Aware Electronics Geiger tube. (See Figure 2)

Procedure:
Remove all radioactive materials from your work area.

Set the Geiger tube apparatus in a stand.

Using the computer program for the Geiger tube, set the time interval for 60 seconds. (Your instructor will provide instructions on using the program.)

Start recording radiation counts. Record background activity for at least 3 minutes.

The average background rate is determined by taking the total number of counts recorded and dividing by the number of minutes.

Record the background radiation value.

Figure 2. Geiger tube with stand.

EXPERIMENT 2. Determination of the Half-Life of a Radioactive Isotope

The half-life of a radioactive isotope is the time it takes for one-half of the atoms present to decay. The half-life can range from a fraction of a second to millions of years. It is not necessary to wait the full half-life to determine its values. Taking reading over a period of time will allow the half-life to be calculated.

SAFETY PRECAUTIONS for Handling the ^{137}Cs/^{137}Ba Isogenerator
Wear disposable gloves to handle the Isogenerator and any containers with eluted ^{137}Ba solution.

If you are not sure how to elute the ^{137}Ba solution, ask your instructor for assistance.

Report any spills of the ^{137}Ba solution immediately.

Materials Needed:

Radioactive source: $^{137}Cs/^{137}Ba$ Isogenerator (see Figure 3) or other source of radiation.
Eluting solution for Isogenerator
Syringe for eluting solution
Aware electronic Geiger counter interfaced with a laboratory computer.
Stand for Geiger tube
10 mL beaker
Wash bottle with distilled water
Disposable rubber or vinyl gloves

Procedure:

NOTE: If you are using the $^{137}Cs/^{137}Ba$ Isogenerator, DO NOT ELUTE any isotope from the Isogenerator until you are ready to start your measurements.

Remove all radioactive materials from your work area.

Using the computer program for the Geiger tube, set the time interval for 60 seconds.

Enter a file name, but do not start your measurements.

Put on a pair of gloves.

Obtain your radioactive source and place it under the Geiger tube mounted on a stand.

If you are using the isotope from the $^{137}Cs/^{137}Ba$ Isogenerator , elute 2 mL of $^{137}Barium$ into a 10 mL beaker. Quickly, but carefully, take the beaker and place it under the Geiger tube and start your measurements.

Start recording. Record the radioactivity measurements for at least 6 minutes.

Correct all recorded counts for background radiation by subtracting the average background counts from each measurement. Record the corrected counts per minute.

Plot the counts per minute (cpm) vs time in minutes. (see sample graph in Figure 4)

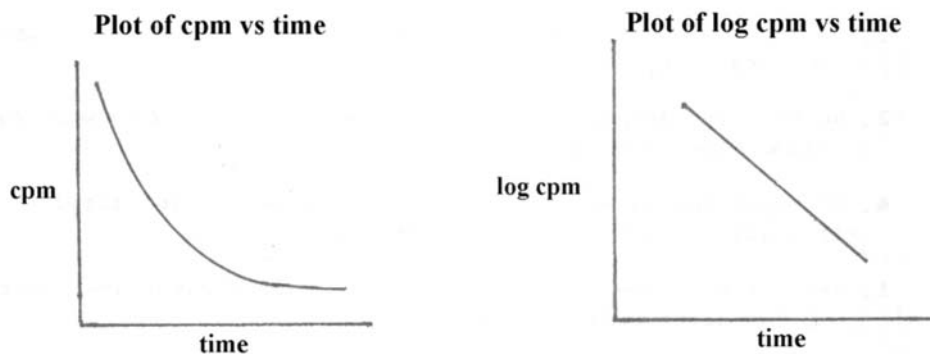Plot log cpm vs time. (Use regular or semi-log paper)   (see sample graph in Figure 4)

Calculate the value of the decay constant, k, for the radioactive element using:

$$\ln \frac{A_t}{A_0} = -kt$$

Where: A_t is the activity (counts per minute) at some time t
A_0 is the activity at time 0 (initial activity)
t   is the time in minutes
k is the decay constant

Figure 3. The $^{137}Cs/^{137}Ba$ Isogenerator

Figure 4. Graph of cpm vs. time (left) and log cpm vs. time (right)

Although you can use any set of values for A_t, A_o, and t, it is usually best to use the data for minute 1 (A_0) and minute 6 (A_6) or later. You will need to use logs to solve. Scientific calculators are available from the stockroom.

Use the value of the decay constant, *k*, to calculate the half-life, $t_{1/2}$ of the radioactive isotope.

$$t_{1/2} = \frac{0.693}{k}$$

EXPERIMENT 3. Determination of the Type of Radiation From a Source

In the introduction to this series of experiments, it was explained that radioactive materials decay to produce alpha particles (α), beta particles (β), and/or gamma (γ) rays. In this experiment, you will determine what kind of radiation is emitted from common materials such as smoke alarms, camping lantern mantles, radium dial clocks, "Lite" salt (KCl), water filters, bricks, rocks, etc.

Materials Needed:
Radioactive sources such as smoke alarms, camping lantern mantles, radium dial clocks, "Lite" salt (KCl), water filters, bricks, rocks, etc.
Aware electronic Geiger counter interfaced with a laboratory computer.
Stand for Geiger tube
Assorted absorbing (shielding) materials
Disposable rubber or vinyl gloves

Procedure:
Remove all radioactive materials from your work area.

Set the Geiger tube on a stand. Make sure the opening to the internal probe is centered over the stand.

Place the radioactive source at least two slots down from the Geiger tube on the stand. You will need the slot closest to the Geiger tube for your shielding material.

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Using the computer program for the Geiger tube, set the time interval for 60 seconds.

Record the number of counts for 3 time intervals. Record the average value for each series of measurements (corrected for background).

Place a single sheet of paper in the slot beneath the Geiger tube. Record the count rates and the average.

Repeat this procedure with two different shielding materials of different thickness. Record the count rates and the average. NOTE: If the count rate of the shielded sample is close to the background rate, it is not necessary to do another series of measurements.

Based on the type of shielding that was effective in absorbing the radiation, what type of radiation was emitted by the various samples, α, β, or γ?

EXPERIMENT 4. Absorption of Gamma Photons (Shielding)

Different materials will absorb radiation to differing degrees. Some materials are more effective at shielding, or blocking radiation than others. In this experiment, you will determine the effective shielding of various materials for γ radiation.

Materials Needed:
    Radioactive source
    Aware electronic Geiger counter interfaced with a laboratory computer.
    Stand for Geiger tube
    Assorted absorbing (shielding) materials, lead sheets, and/or assorted metal foils.
    Disposable rubber or vinyl gloves

Procedure:
    Remove all radioactive materials from your work area.

    Set the Geiger tube on a stand. Make sure the opening to the internal probe is centered over the stand.

    Place the radioactive source at least two slots down from the Geiger tube on the stand. You will need the slot closest to the Geiger tube for your shielding material.

Figure 5. A set of standard shielding materials for radioactivity measurements.

Using the computer program for the Geiger tube, set the time interval for 60 seconds.

Record the number of counts for 3 time intervals. Record the average value for each series of measurements (corrected for background). This value is I_0.

Place a single sheet of shielding material in the slot beneath the Geiger tube. Record the count rates for 3 60-second intervals and determine the average value (corrected for background).

Replace the sheet of shielding material with a thicker sheet. (If using sheets of lead or other metal

foils, you may add a second sheet of the lead or metal.) Record the count rates for 3 60-second intervals and determine the average value (corrected for background).

Continue to add thicker shielding or additional sheets of metal and recording the count rates until the average value (corrected for background) is less than ½ the original count rate.

Plot the average (corrected) cpm vs. thickness of metal shielding in cm. (See Figure 6)

Plot the log of average (corrected) cpm vs. thickness of metal shielding in cm. (See Figure 6)

Plot of cpm vs. thickness   **Plot of log cpm vs. thickness**

cpm   **log cpm**

Thickness, cm   **Thickness, cm**
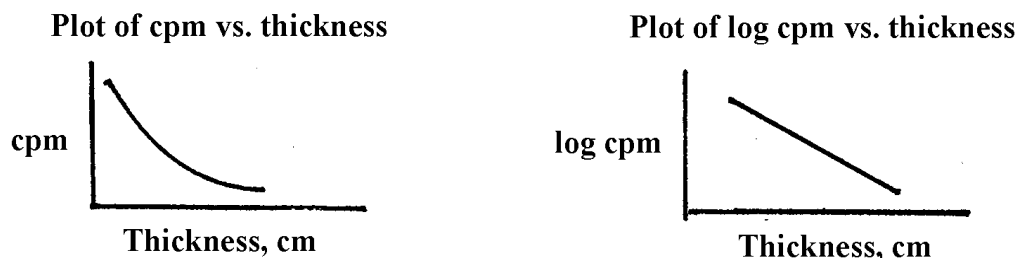
Figure 6. Plot of cpm vs. thickness of metal shielding (left) and log cpm vs. thickness (right)

From the graph of log of average (corrected) cpm vs. thickness of metal shielding in cm, determine the thickness of the shielding which reduced the radioactivity to ½ of the original, non-shielded value, I_0. This thickness is $x_{1/2}$.

Calculate the linear absorption coefficient, μ, of the shielding material using the formula:

$$\mu = \frac{0.693}{x_{1/2}}$$

       where: μ is the linear absorption coefficient
              $x_{1/2}$ is the thickness of shielding material that reduces the activity to ½

Compare the value of the linear absorption coefficient you obtained with those obtained by others in the class for the different types of shielding used in the experiment.

NOTE: Once the linear absorption coefficient is known for a material, the results of this experiment can be used to determine the thickness of an unknown material. This is useful in an industrial setting where thickness of materials need to be monitored on a continuous basis.

EXPERIMENT 5. Inverse Square Law

The intensity of γ radiation varies inversely with the square of the distance from the source. This statement is known as the **Inverse Square Law** and is defined by the equation:

$$I = \frac{k}{d^2}$$

where I is the intensity or count rate, k is a constant, and d is the distance between the radioactive source and the detector.

According to this law, if the distance between the source and the detector is doubled, the count rate is reduced to ¼. If the distance is tripled, then the rate is reduced to 1/9.

Materials Needed:
Radioactive source: $^{137}Cs/^{137}Ba$ Isogenerator or other source of radiation.
Aware electronic Geiger counter interfaced with a laboratory computer.
Disposable rubber or vinyl gloves
Ruler or meter stick

Procedure:
Place the radioactive source 2 cm from the detector. Set the time interval to 60 seconds, and measure the activity for 3 intervals. Record the average measurement corrected for background.

Move source to a position 4 cm from the detector and measure the activity for 3 intervals. Record the average measurement corrected for background.

Repeat the procedure placing the source at positions of 6 cm, 8 cm, 10 cm, etc., from the detector until activity equals or is close to the background.

Plot activity (corrected for background) (y-axis) vs. distance in cm (x-axis).

Using your graph, does the inverse law apply to your measurements?

Acknowledgement:

EXPERIMENTS FOR NUCLEAR CHEMISTRY
Data and Results

Name(s) _____ Date of Exp. _____

EXPERIMENT 1. Determination of the Background Radiation

First **60** second interval   _____ Counts

Second **60** second interval   _____ Counts

Third **60** second interval   _____ Counts

Average number of counts   _____ Counts

EXPERIMENT 2. Determination of the Half-Life of a Radioactive Isotope

Radioactive source used: _____

Time in minutes	Counts	Counts corrected for background	log counts corrected for background
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Graphs: Plot the counts per minute (cpm) vs time.
          Plot log cpm vs time.

EXPERIMENT 3. Determination of the Type of Radiation From a Source

Sample used _____

No shielding material

First **60** second interval _____ Counts

Second **60** second interval _____ Counts

Third **60** second interval _____ Counts

Average number of counts _____ Counts

Paper used as shielding

First **60** second interval _____ Counts

Second **60** second interval _____ Counts

Third **60** second interval _____ Counts

Average number of counts _____ Counts

Shielding material used _____

First **60** second interval _____ Counts

Second **60** second interval _____ Counts

Third **60** second interval _____ Counts

Average number of counts _____ Counts

Shielding material used _____

First **60** second interval _____ Counts

Second **60** second interval _____ Counts

Third **60** second interval _____ Counts

Average number of counts _____ Counts

What type of radiation did your sample give off? Explain your answer.

EXPERIMENT 4. Absorption of Gamma Photons (Shielding)

Sample used _____

No shielding material used

First **60** second interval   _____ Counts

Second **60** second interval   _____ Counts

Third **60** second interval   _____ Counts

Average number of counts   _____ Counts

Shielding material used (include thickness) _____

First **60** second interval   _____ Counts

Second **60** second interval   _____ Counts

Third **60** second interval   _____ Counts

Average number of counts   _____ Counts

Shielding material used (include thickness) _____

First **60** second interval   _____ Counts

Second **60** second interval   _____ Counts

Third **60** second interval   _____ Counts

Average number of counts   _____ Counts

Shielding material used (include thickness) _____

First **60** second interval   _____ Counts

Second **60** second interval   _____ Counts

Third **60** second interval   _____ Counts

Average number of counts   _____ Counts

Graphs:
   Plot the average (corrected) cpm vs. thickness of metal shielding in cm.
   Plot the log of average (corrected) cpm vs. thickness of metal shielding in cm.

Calculate the linear absorption coefficient, μ, of the shielding material you used.

What is the value of $x_{1/2}$ (the thickness of shielding material that reduced the activity to ½) for the shielding material you used?

Compare the value of the linear absorption coefficient you obtained with those obtained by others in the class for the different types of shielding used in this experiment.

EXPERIMENT 5. Inverse Square Law

You may use the same sample from Experiment 3 or 4 for your first set of distance data.

Sample used _____

Distance _____cm

First **60** second interval _____ Counts

Second **60** second interval _____ Counts

Third **60** second interval _____ Counts

Average number of counts _____ Counts

Distance _____cm

First **60** second interval _____ Counts

Second **60** second interval _____ Counts

Third **60** second interval _____ Counts

Average number of counts _____ Counts

Distance _____cm

First **60** second interval _____ Counts

Second **60** second interval _____ Counts

Third **60** second interval _____ Counts

Average number of counts _____ Counts

Distance _____cm

First **60** second interval _____ Counts

Second **60** second interval _____ Counts

Third **60** second interval _____ Counts

Average number of counts _____ Counts

Distance _____cm

First **60** second interval _____ Counts

Second **60** second interval _____ Counts

Third **60** second interval _____ Counts

Average number of counts _____ Counts

Graph:
   Plot activity (corrected for background) (y-axis) vs distance in cm (x-axis).

Using your graph, does the inverse law apply to your measurements?