α, β, and γ

Nuclear radiation can be broadly classified into three categories. These three categories are labeled with the first three letters of the Greek alphabet: α (alpha), β (beta) and γ (gamma). Alpha radiation consists of a stream of fast-moving helium nuclei (two protons and two neutrons). As such, an alpha particle is relatively heavy and carries two positive electrical charges. Beta radiation consists of fast-moving electrons. A beta particle is much lighter than an alpha, and carries one unit of charge. Gamma radiation consists of photons, which are massless and carry no charge. X-rays are also photons, but carry less energy than gammas.

After being emitted from a decaying nucleus, the alpha, beta or gamma radiation may pass through matter, or it may be absorbed by the matter. You will analyze the effects of distance, shielding, and time on the degree of exposure to a radioactive source.

Part 1: Background Radiation

When a Geiger counter is operated it will usually record an event every few seconds, even if no obvious radioactive source is placed nearby. Where do these counts come from?

Two significant sources are cosmic rays and radon decay products. Cosmic rays, as the name suggests, are fast-moving particles from space that enter the Earth's atmosphere, along with their decay products. Since the atmosphere absorbs some of these particles, the rate of detection of cosmic rays increases with increasing altitude. If you were to take a Geiger counter on a cross-country jet flight, you would observe a marked increase in count rate while at high altitude.

Another radiation source comes not from above us, but from below. The Earth's crust contains, among other radioactive elements, uranium-238 (^{238}U). ^{238}U has a long half-life, but its decay products do not. One of these products is radon gas, or ^{222}Rn. As a result of the long uranium half-life, there is a nearly steady production of radon, which itself decays with a short half-life of 3.8 days. Since radon is a gas, it diffuses out of the soil into the air, and can collect in low enclosed areas such as basements. Radon decays to a series of species including polonium, lead, and bismuth. These decay products precipitate out of the air onto dust particles since they are solids, unlike gaseous radon. The beta and gamma ray emissions as these products decay can be detected using a Geiger counter.

The ^{238}U decay sequence relevant to this experiment is ^{222}Rn (3.8 d) $\rightarrow$ ^{218}Po (3.1 min) $\rightarrow$ ^{214}Pb (27 min) $\rightarrow$ ^{214}Bi (20 min) $\rightarrow$ ^{214}Po (164 μs) $\rightarrow$... The times in parenthesis are the half-lives of each species.

PROCEDURE:

1. Connect the radiation monitor to DIG/SONIC 1 of the computer interface.
2. Prepare the computer for data collection by opening the file "Radiation Lab" from the *Chemistry Handouts* folder in the t:drive/neugebauert/public folder.

3. Begin with no source, to determine the background count rate. Move all sources away from the monitor. Click [Collect] to begin collecting data. While it may appear as if data collection did not start, Logger *Pro* is collecting data. Wait 60 s for the number of counts to appear in the meter. Record the total number of counts in the no-source row of your data table, no shielding.

Question: What are some possible sources of this background radiation?

Part 2: Effect of Shielding

You will arrange for the three classes of radiation to pass through nothing but a thin layer of air, a sheet of paper, an aluminum sheet, cardboard, glass, lead, plastic, and cloth. Will the different types of radiation be absorbed differently by the various types of shields? In this experiment you will use small sources of alpha, beta, and gamma radiation.

MATERIALS

computer
Vernier computer interface
Logger *Pro*
Vernier Radiation Monitor or
  Student Radiation Monitor
Polonium-210 0.1μC alpha source
Strontium-90 0.1μC beta source
Cobalt-60 1μC gamma source
paper sheet
aluminum sheet, about 2 mm thick

PRELIMINARY QUESTIONS – Answer these before starting.

1. More massive particles generally travel more slowly than light particles. Make a preliminary guess as to which radiation type will in general interact most strongly with matter, and therefore would be most strongly absorbed as it passes through matter. Consider electrical charge, mass and speed. Explain your reasons.

2. Which radiation type do you predict would interact, in general, least strongly with matter, and so be less absorbed than others? Why?

3. You will be using various absorbers for the radiation. Which material has the greatest density and so would present more matter to the passing radiation and therefore absorb more? Which material would have less matter?

4. Is your radiation monitor sensitive to all three types of radiation? How can you tell? ***Devise a test and carry it out. If your radiation monitor does not detect one form of radiation, then you will be able to compare the absorption of the remaining two types.*** If a source is not detected, X out the appropriate places in the data table to indicate that no data will be available.

PROCEDURE

1. If you are using the Radiation Monitor (brown plastic case with meter) place the source near the metal screen (5 cm away), and when using an absorber, place the absorber between the source and the screen. Use the same position (5 cm away) for the sources each time, with and without an absorber. The sources are usually mounted in small plastic discs, with the most radiation emitted from the underside of the disc.

2. Using no absorber, place the source near the appropriate region of your radiation monitor, with the underside of the disc facing the monitor. Click Collect to begin collecting data. Wait for Logger *Pro* to complete data collection. Record the total number of counts in the appropriate row of your data table, no shielding.

5. Place a single sheet of paper between the beta source and the monitor, and measure the counts as before. Take care to **keep the source in the same position** (5 cm away) with respect to the radiation monitor. Record the total count rate in the appropriate place.

6. In a similar manner, record the counts for the following used as absorbers for each of the sources:

   a. a single sheet of paper
   b. a single sheet of aluminum
   c. cardboard
   d. glass
   e. lead
   f. plastic
   g. cloth

   Record each count in your data table.

source	No shield	paper	Al sheet	Cardboard	glass	lead	plastic	cloth
none								
alpha								
beta								
gamma								

ANALYSIS

1. Compare the no-source, or background, count with the no-absorber counts for the sources. Is the background count number a significant fraction of the counts from the sources? Do you need to consider a correction for the background counts?

2. Inspect your data. Does the count rate appear to follow your initial guesses for the relative absorption of the various types of radiation by matter? Be specific, considering which source should be the most penetrating (least interacting), and which absorber is more difficult to penetrate.

3. X-rays are photons, just like gamma rays. X-rays carry lower energy, however, and so historically received a different name. If you have had an X-ray film picture of your teeth taken by a dentist, the dentist probably placed a lead-lined apron on your chest and lap before making the X-ray. What is the function of the lead apron? Support any assertion you make from your experimental data.

4. If you were presented with a safe, but unknown, radiation source, and assuming that it emitted only one type of radiation, devise a test that would allow you to tentatively identify the type of radiation as primarily alpha, beta, or gamma. Explain your test.

Part 3: The effect of distance

Scientists and health care workers using intense radiation sources are often told that the best protection is distance; that is, the best way to minimize exposure to radiation is to stay far away from the radiation source. Why is that?

A physically small source of radiation, emitting equally in all directions, is known as a point source. By considering the way radiation leaves the source, you will develop a model for the intensity of radiation as a function of distance from the source. Your model may help explain why users of radiation sources can use distance to reduce their exposure.

PROCEDURE:

1. Place the radiation moniter at one end of a meter stick. Place the source (either gamma or beta) 1 cm away and collect for one minute. Record the counts per minute in the data table below.
2. Repeat the process for distances of 2 cm, 4 cm, and 8 cm.
3. Make a new graph by choosing New under the File tab of the counts per minute (y-axis) versus distance in centimeters (x-axis).

Distance:	1 cm	2 cm	4 cm	8 cm
Counts from Source: ________				

ANALYSIS:

1. As the distance from a radioactive source is doubled, what happens to the amount of radiation detected? Be specific!

2. How does the pattern observed by your graph help explain the behaviors of X-ray technicians?

Part 4: Effect of Time

1. Choose ONE of your radiation sources. Place the source near the appropriate region of your radiation monitor, with the underside of the disc facing the monitor. Set the collection time for 5 minutes by going to Experiment/Data Collection and changing the collection length from 60 seconds to 300 seconds. Click [▶ Collect] to begin collecting data. Wait for Logger *Pro* to complete data collection.

2. Record the number of counts at 1 minute, 2 minutes and 5 minutes in the data table below.

Counts recorded at:	1 minute (60 seconds)	2 minutes (120 seconds)	5 minutes (300 seconds)
Source: ________			

Question: Is there an advantage to remaining near a radiation source for the shortest possible time? Explain.

Question: Explain the behavior of x-ray and dental technicians that you have observed based on your response to the previous question.