Introduction

This lab relates to material in Serway 7th ed., Chapter 29. In particular please review sections 29.3, 29.4 and 29.5. **IT IS IMPERATIVE THAT YOU READ CHAPTER 29!** In this lab you will measure the radioactive properties of low-activity beta and gamma sources using a Geiger counter. It is a good idea to read all the steps in each part before you start. Radioactive isotopes are used extensively in medical treatments, and a general fear of radioactivity has entered the public perception. The sources you use in this lab present very low levels of activity and can do you no damage unless you eat them. However, before you start, read the warning below on procedures for handling radioactive materials.

Information on the Use of Radio Isotopes in the Physics Lab

- *General Warning:* Radioactivity is not to be feared but to be respected. In today's scientific laboratories many people constantly work with and handle radioactive materials. These people are required to abide by a set of safety rules and regulations for protection against the hazards of radiation. Either through ignorance or carelessness of the experimenter, it is possible for radioactive material to gain entrance into the body via the hands to the eyes, nose, or mouth and then continue its dangerous activity from within the human body.

- Materials usually made available to students taking elementary courses are encased in a plastic capsule of some type. However, it is still possible for a capsule to leak or be partially opened by some means. Students should exercise caution and handle the radioactive sources carefully and only as necessary. The radiation received from any source in this laboratory during the course of an experiment will be small and does not represent any danger.

- Eating, drinking, and the use of cosmetics in the laboratory are not permitted while working with radioactive materials.

- Check with your laboratory instructor on the procedure for checking out and returning your radioactive source. All sources must be fully accounted for before leaving the laboratory.

- Never pipette radioactive solutions by mouth suction. Special suction devices are available for this purpose.

- All wounds, spills, and other emergencies should be reported to the instructor immediately.

- If, in the course of work, any personal contamination is suspected, ask your instructor for a survey with a suitable meter. If contamination is found, follow the cleansing instructions given by your instructor.

- All radioactive sources and contaminated materials are to be retained with the laboratory.

- Use gloves when handling the samples and the lead shielding.

- Personal warnings about working with radioactive materials:

    (a) Do not rub your eyes, nose, ears, or mouth.
    (b) Do not put your pencil in your mouth.
    (c) Be sure to wash your hands after checking in the sources used and before leaving the laboratory.

Pre-Lab Questions:

1. When first discovered α, β and γ radioactivity were referred to as α–rays, β-rays and γ-rays. Now we refer to α-particles and β-particles, but still use the term γ-rays. What type of particles are α and β commonly known as? What type of ray is γ commonly known as?

2. What is the mass (in kg) of the α-particle? What is the mass (in kg) of the β-particle? Which particle (α or β) is more massive? Do all (α, β, γ) carry energy? Do they all carry momentum?

3. When a charged particle moves through matter it loses energy primarily to excitation and ionization of the atoms in the medium. It also loses some energy due to collisions with nuclei in the medium. As it loses energy, it moves more slowly and eventually stops. The distance it travels is called its **range**. The range depends on many parameters that include the charge, mass and initial energy of the particle, and the density, ionization potential and atomic number of the atoms in the medium. In this experiment, you will use cardboard, copper foil, aluminum plate and lead sheet to block β particles. If you had equal thicknesses of each substance, which would be most effective blocker? Which would be the least effective blocker?

4. Write "I checked my grades online". (Please, actually check them on webct.ucsd.edu. And if you have some problems then it would be better to solve them with your TAs during the last lab instead of emailing them during finals week.)

Activity A: Statistics of a Radioactive Decay

Radioactive nuclei spontaneously decay to a more stable nuclide. Radioactive decay is a probabilistic phenomenon (decay probability $= P$), therefore it exhibits an exponential decay with a characteristic decay constant ($\lambda = -\ln(1-P)$) and half-life ($T_{1/2}$). The number of particles you should have at any instant of time t is given by: $N(t) = N_o\, e^{-\lambda t}$. The half-life for radioactive nuclei is given by: $T_{1/2} = \ln(2)/\lambda$. The activity is the rate of decay and is given by: (either λN or $-\Delta N/\Delta t$)

In this activity you will be exploring the statistical nature of radioactive decay. You should have 25 pennies, a cup, your whiteboard and graph paper for this activity. Also, someone from your group should be designated the recorder who reports the values for each round to the TA who will be keeping the entire class tally on front whiteboard.

1. Lets take the probability of some nucleus decaying in a given time interval, $\Delta t = T$, to be 1/2. If you have 150 nuclei, how many of them would you predict would decay in a time T? How many *undecayed* nuclei do you predict will be left after the time T? How many *undecayed* nuclei do you predict will be left after time 2T?

2. For the nuclei discussed in 1) what is the decay constant (the units of time are T so what are the units of the decay constant)? What is the half-life in units of T? What is the initial activity? What is the activity after one-half life has elapsed? What is the activity after two half-lives have elapsed?

3. Make a graph of N vs t (t in units of T out to 6T) on a sheet of the graph paper provided and on your white board. Mark each half-life on the horizontal axis.

Each table will keep track of twenty-five unstable nuclei, each with a 1 in 2 chance that it may decay in the next time interval, T. (There should be a total of 150 nuclei in the entire lab section at the start, so make sure that your table has 25 total nuclei (*i.e.* pennies).

- When told by your TA, flip your decay probability generators (aka your pennies in a cup), one penny for each nucleus that has NOT decayed.

- "heads" is an unlucky result, and means that a nucleus has decayed. This nucleus cannot ever be flipped again—do not cheat death.

- "tails" means that a nucleus has survived. This nucleus can flip again next time.
- Report the number of decays **from your table** to the TA for each round.
- One Volunteer will tally t, $N_i(t)$, $\Delta N(t)$ for each group, and the new $N_f(t)$, where $N_i(t)$ is the initial number of nuclei for the round and $N_f(t)$ is the final number of nuclei for the round.

After all results are tallied, plot the experimental values of $N_f(t)$ on the same graph you previously made. Answer the following questions

1) Why do the experimentally determined values of N not fall exactly on the graph you previously plotted?
2) Would you find the exact number of decays predicted even if you had one-million nuclei? Does the discrepancy in the number of decays at each step found experimentally get bigger or smaller as the number of nuclei increases? Hint: think about how far off the number of decays happening in the third time interval might be if you had two nuclei and compare to how far off it might be if you had a million nuclei.
3) What measured quantity do you expect would get closer and closer to the calculated number as the number of nuclei increases?
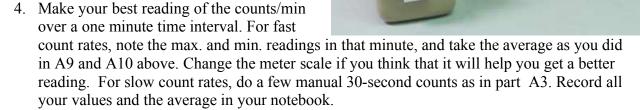
Activity B: Background Radiation

A Geiger counter is an instrument that allows you to count nuclear particles. It contains a tube of gas with a thin metal wire through its center. The wire is held at about 1000 V relative to the tube. A thin "window" at the end lets particles into the tube. When a nuclear particle enters the tube it has enough energy to tear electrons off atoms in the gas. The electrons released move toward the wire. Along the way they collide with more gas atoms, releasing more electrons in a "cascade" process. As the electrons arrive at the wire, they make a detectable pulse of current. This pulse is amplified to make an audible beep. When the particle arrival rate is low it can be measured by counting pulses. When the arrival rate is high, a meter on the instrument shows the average current flowing to the wire. The sensitivity setting (0.1X, 1X, 10X or 100X) shows the factor you need to use to get counts per minute. (E.g., if the meter shows 1K CPM and the sensitivity knob is at 10X, the count rate is 10,000 CPM). The "Fast/Slow" switch (showing the hare and the tortoise) controls the time constant of the meter. It is best to use the fast mode when you select the 0.1X and 1X scales and the slow mode for the 10X and 100X scales.

1. Put your Geiger Counter on the lab bench. Make sure all of the radioactive sources are far away from your counter (the far end of the table is good enough). Turn on the GC to battery test. The batteries are OK if the meter reads within the range of values shown for "BAT

TEST". Next turn to the "1X" setting, and turn the audio on so you can hear clicks. Can you hear clicks? Are they equally spaced in time?

2. Put one of the beta or gamma sources close to the sensor and listen to the rate of clicks. Move the source away, what happens? Try other sources.

3. With all sources at the far end of the bench, count clicks for 30 seconds. Repeat three times more to get four measurements in total. This is a measure of the *background radiation*. Background radiation arises from the sun and stars, from elements in our surroundings and from within ourselves (i.e., from the elements in the human body). For each reading calculate the counts per minute (CPM).

4. Are your four measurements all the same? Why might they not be the same? Would you expect the average of your measurements to be the same as the average measured by the group at the next lab bench?

5. On the lab whiteboard enter the four numbers for your lab bench for background counts per minute in the table. Add your data to the histogram on the whiteboard to accumulate data from the whole class.

6. Did every group get exactly the same number of counts per minute? What is the average counts per minute for your lab section? What is the spread of values of the background CPM? If you made ten times more measurements, would the spread of the values get ten times smaller, ten times larger or stay the same?

7. If you needed to make a very precise measurement of background radiation (for example, to compare the background radiation in the 1CL lab with that at some other place,) how would you proceed? Is one measurement enough? If so, how would you make that measurement? If many measurements are needed, suggest how they should be done.

8. If you hold the GC close to a banana or to a bottle of potassium chloride, do you detect radiation at a rate that is higher than background? If so, by how much and with what cause?

9. Finally examine the readings indicated by the Geiger Counter scale. When the events arrive so fast that it is not feasible to count them, the meter is useful. Bring one of the beta or gamma emitters close enough to make a reading of about 1000 CPM. Hold the source still at this point. Is the meter reading stable? Watch for one minute, and record the maximum and minimum readings.

10. Using the maximum and minimum values you just obtained, calculate the difference (i.e., max.-min.) reading in your 1-minute sample to get the expected range, or spread, of readings. Also calculate (max.+min.)/2 to get the average reading.

Experiment C: Radiation Shielding

1. Place one of the β or γ sources in an aluminum holder on the table next to the ring stand. Note the source you are working with in your notebook.

2. Carefully place the Geiger Counter tube into the clamp, positioning the end of the tube about 3 cm above the source. ***Do not over-tighten the clamp.***

3. You may need to adjust the sensitivity of the scale by turning the sensitivity knob. Select 0.1X, 1X, 10X or 100X as appropriate. Remember to use "*fast"* for the 0.1X and 1X settings and "*slow"* for the other settings.

4. Make your best reading of the counts/min over a one minute time interval. For fast count rates, note the max. and min. readings in that minute, and take the average as you did in A9 and A10 above. Change the meter scale if you think that it will help you get a better reading. For slow count rates, do a few manual 30-second counts as in part A3. Record all your values and the average in your notebook.

5. Each table should have a sample of all types of materials being investigated. They are cardboard, aluminum foil, thick copper foil, aluminum sheet, and lead plate. Identify the type of each sample. Place each sample over your source (be careful not to move the source) to see which absorb strongly. Your lab bench should have four sheets of one of the materials for your experiment. Each group will be using different materials, and data will be shared for the lab section. Record what material your group is using.

	Material _____ β-source	**Material _____ γ-source**
0 sheets		
1 sheet		
2 sheets		
3 sheets		
4 sheets		

6. Place one sheet of your material on top of the source and repeat step 4. Make a table like the one shown, and fill-in your measurements

7. Add a second sheet and repeat step 4.

8. Add a third sheet and repeat step 4.

9. Add a fourth sheet and repeat step 4.

10. Repeat this process (steps 6 to 9) using the other source type (i.e., use a β source if you started with γ, and *vice versa*).

11. Enter your numbers in the tables on the lab's whiteboard. Be careful to enter the data for the correct source. Which material (s) are the strongest absorbers? Which are the weakest absorbers? Is the strongest absorber for β also the strongest for γ rays?

12. If your group did not investigate the aluminum plate, copy into your lab book the data for this material from the whiteboard. Your TA will tell you whether to use the β or the γ data. Make a graph showing the number of layers on the horizontal axis and CPM on the vertical axis. Draw a smooth line through your data points, and estimate the number of layers and the total thickness of aluminum needed to reduce the counts by a factor of two. This is called the "*half value thickness*".

13. Make a final whiteboard entry of your half value thickness. Compare the half value thickness for aluminum for γ and for β. Are they the same?

14. What generalization can you make about the effect of thickness of the shielding material on the count rate?

15. What generalization can you make about the effect of density of the shielding material on the count rate?

Experiment C: Checking the Inverse Square Law

You have seen inverse square laws in both Physics 1A and 1B. In Physics 1A, you saw the gravitational force was

$$F_{\mathrm{G}} = \frac{GMm}{r^2}$$

and that the intensity of sound, *I*, in W/m^2, is related to the power, *P*, of the source and the distance by

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

In Physics 1B, you saw the electrical force was

$$F_{\mathrm{E}} = \frac{kq_1 q_2}{r^2}$$

In this experiment, you will determine if the inverse square law holds true for nuclear radiation. Put the radiation source in one of the aluminum holders so that placing heavy objects on it will not crack the housing.

1. Place the *β* or *γ* source under the Geiger tube, and carefully measure and record the distance from the top of the source to the bottom of the tube. Start at about 3 cm distance. You do not

have to try to hit this distance exactly. Set it approximately at 3 cm then measure and record the actual distance. You can be up to 5 mm over or under the target and still obtain good data.
2. Make your best reading of the CPM. Use the same technique as you used in experiment B3 (for low count rates) or B9 and B10 for higher count rates.
3. Move the Geiger tube 1cm further away from the source (4 cm) and measure the CPM in the same way.
4. Continue moving the Geiger tube and taking readings for distances of 6 and 12 cm.
5. Make a table of the average, max. and min. counts/minute at each distance.
6. Make a new column on your table for 1/(distance)^2. Calculate these values and enter them in the table.
7. Make a graph of count rate vs. 1/(distance)^2.
8. Add error bars to each point by considering the max and min values of CPM in your table.
9. Looking at your graphs, do the γ or β sources follow the inverse square law? How do you know?

Based on this experiment, what could you do to protect yourself from a broken container of radioactive material?