LABORATORY VIII
NUCLEAR PHENOMENA

Radioactive decay is the emission of particles such as photons, electrons, neutrons, or even other nuclei when atomic nuclei go from a high energy state to a lower energy state. This lower energy state is usually a nucleus of a different element. The particles emitted from the nucleus, given the generic name of radiation, often have a high enough energy to penetrate materials such as organic tissue. This energy is transferred to any object with which the particles collide, including the cells of your body. Radioactive materials are used to kill diseased cells inside a living organism that cannot be reached by other means, as tracers to analyze fluid flow in the body, and in imaging the body's interior. They are also used in industry to examine potential defects in materials. When the particles from radioactive decay collide with cells in a living organism, the resulting collision damages the cell. If enough cells are damaged, the effect can be to overwhelm the organism's repair mechanisms or to cause a mutation. Some food products are treated with radiation to kill existing microorganisms without altering the molecular structure of the food as would happen with heating or chemical treatment.

We live in an environment of particles with energies as high or higher than those produced by radioactive decay. Our bodies are built of some naturally occurring radioactive nuclei such as potassium 40. In addition the earth is bombarded by high energy protons which collide with the atmosphere and produce showers of high energy particles which continuously collide with our cells. Almost all of the common materials in our environment, e.g. carbon or iron, contain radioactive nuclei. This sea of radiation in which we live is usually called background. This radiation constantly kills or alters the cells in our body and our bodies have evolved to handle the repair at the cellular level. Significantly higher levels of radiation however can overwhelm this cellular self-repair mechanism.

In this laboratory, you will solve problems related to the nature of interactions between particles produced by radioactive decay and matter. You will also determine the rate of background radiation for comparison.

OBJECTIVES:

Successfully completing this laboratory should enable you to:

- Quantitatively determine the level of background radiation.
- Understand the statistical nature of radioactive decay and the process of counting.
- Predict the relationship between distance from a radioactive source and the count rate.
- Determine the different types of particles emitted by radioactive decay by the effects of different shielding material.
- Understand how the effectiveness of radiation shielding depends on the shielding thickness, for different shielding materials and different types of radiation.
- Test for relationships among measured quantities by producing a linear graph with data with an non-linear functional dependence.

PREPARATION:

Before you come to lab, read Sections 3-5 of Chapter 30 in Serway and Jewett. You should:

- Set up and solve the equation that describes the lifetime of a radioactive nucleus.
- Use graphical techniques to determine the parameters in that equation.

PROBLEM #1:
DISTANCE FROM THE SOURCE

You have a job working in a cancer treatment facility that prepares radioactive isotopes. Although you take great care to handle them properly, you know that some body parts are more sensitive to radiation than others. After all, you may want to have children some day. To address your worry, you decide to use geometry to calculate how the rate of particles emitted from a radioactive source going through a sensitive area of your body depends on the distance from the source. You will test your calculation in the laboratory using a small radioactive source and a Geiger counter to detect the emitted particles. Is this relationship different for different types of particles?

EQUIPMENT

The equipment consists of a Radiation Monitor, also called a Geiger counter, connected to the LabPro Interface device. Data will be collected using computer software called Vernier Logger Pro.

You will also have three different radioactive sources: an alpha source, a beta source, and a gamma source.

PREDICTION

Use geometry to calculate how the particle count rate varies with distance from a small radioactive source. On what assumptions is your calculation based?

WARM-UP

Read Serway & Jewett: sections 30.3, 30.4.

1. Draw a large sphere centered on a small radioactive source. Write down the fraction of the particles produced by the source that pass through the surface of that sphere. Write down the equation for the surface area of that sphere.

2. On the surface of the sphere you've drawn, sketch an area representing a small particle detector. If the source emits radiation evenly in all directions, write an equation for the fraction of its radiation that would pass through the particle detector as a function of the area of the detector and the radius of the sphere.

3. Now draw another even larger sphere still centered on the radioactive source. Draw the same particle detector on the surface of the larger sphere. Now write an equation for the fraction of the source's radiation that would pass through the particle detector as a function of the area of the detector and the radius of the new sphere. Is the rate of particles passing through the detector when it is on the surface of the larger sphere higher or lower than its rate when it is on the smaller sphere?

4. Write an equation for the relationship of a detector's counting rate and its distance from radioactive source. Sketch a graph of this relationship. What assumptions does this relationship require?

EXPLORATION

WARNING: The radioactive sources available for this problem provide low intensity radiation, and are safe if handled with respect for short amounts of time. Do not remove them from the laboratory, and do not attempt to open the plastic disks containing the sources. **If a disk breaks open inform your TA immediately, do not touch it.**

Make sure you read *Appendix D* to understand the operation of the Geiger counter before trying to operate it. Place a radioactive source near the detector, turn on the counter. Try the controls, and make sure every group member understands how to operate it. Try each of your sources to make sure the equipment is functioning
.

With the detector working you now need to determine how to make your measurement uncertainty as small a practical. Start by using the detector to measure the number of counts from a radioactive source in some short time interval, say 10 or 15 seconds. Repeat this measurement several times, recording the number of counts occurring in each fixed time interval. Compute the average number of counts per second and the difference of each trial from that average. Calculate the average of these differences for all of your trials. That average difference represents your counting uncertainty for the measurement. Now increase your time interval by a factor of 4 and repeat the same number of trials and the same calculation. In which case is the measurement uncertainty a smaller fraction of the measurement? By approximately what factor did the average measurement change when you increased the counting time by a factor of 4? What does this tell you about the time period necessary when taking data? Keep measurement uncertainty in mind when deciding how much time is "enough" to allow comparisons among count rates under different conditions.

Since we live in a “sea” of radiation, you need to determine how that effects your measurements. Remove all radioactive sources from the vicinity of your detector. Record the count rate from the detector for a significant amount of time. You will need to subtract the count rate due to this background radiation from your future measurements. Measure the background rate, and estimate the uncertainty in your measurement.

Try different orientations of each source relative to the detector. Do you achieve a greater counting rate with the label facing up or facing down? Repeat this test for each type of radioactive source.

Come up with a measurement plan that will allow you to accurately determine the relationship between counting rate and the distance between the detector and the source. Your plan should take background radiation into account and a plan to minimize the measurement uncertainty.

MEASUREMENT

Carry out your measurement plan, and adjust if necessary to obtain useful data for each source. You may find Microsoft Excel (available on the computer at your lab station) to be a very useful tool for recording data, doing calculations, and making plots. Be sure to keep copies of your measurements as electronic files (or on paper printouts).

ANALYSIS

Make a plot to show how the particle rate through the detector depends on the distance from the source. If this is not a linear relationship, use your prediction to determine a set of axes that should make your graph as straight line. Make this graph (see *Appendix C*).

To see if your predicted relationship fits the data better than some other possibilities, try at least one other linearization that you think might also fit the data.

Whenever your graph is a straight line, record the equation of the best fit line for that graph. Solve that equation for the counting rate as a function of distance from the detector.

CONCLUSION

Describe the relationship between the particle rate from a radioactive source and distance from that source to the detector.

Does your predicted relationship match the relationship you found? If not, can you explain why not?

PROBLEM #2:
SHIELD POSITION

As a member of a radiation medicine research group, you are constantly reminded that it is important to limit your dose of radiation. One day while at Starbucks for a coffee break you overhear your coworkers discussing shielding efficacy. One person says that radiation shielding is most effective when it is placed near the radiation source. Another person contends that shielding is most effective when it is worn on the body, which places it as far from the radiation source as possible. Yet a third person states that material of a particular thickness should absorb a certain fraction of incident radiation so the shield's distance from the source is irrelevant. Based on your ideas of what happens when a particle passes through material, you decide which person you believe and explain why. You also decide to test your idea in the laboratory. Since the result might depend on the type of radiation, you use three different sources which each emit alpha (He nuclei), beta (electrons), or gamma (photons) radiation. It is also possible that result depends on the type of shielding so you try several different kinds of material.

EQUIPMENT

The equipment consists of a Radiation monitor, also called a Geiger counter (see *Appendix D*) connected to a LabPro Interface device. Data will be collected using computer software called Vernier Logger Pro. You will also have three different radioactive sources: an alpha source, a beta source, and a gamma source., as well as a variety of shielding materials.

PREDICTION

Do you think that radiation is shielded more effectively by material that is closer to the radiation source or closer to the detector? How does your conclusion depend on the type of radiation? How does it depend on the type of shielding material? On what do you base your prediction?

WARM-UP

Read Serway & Jewett: sections 30.3, 30.4.

1. Sketch two pictures showing a radioactive source that emits radiation in all directions. Add a detector at the same distance from the source in each diagram. Finally, add identical shielding material in each diagram; place the shield near the source in one picture, and near the detector in another diagram. The shielding material should be wider than the detector, so that radiation emitted in a range of directions from the source will have a chance to interact with the shield.

2. Imagine that each shield absorbs half of the radiation incident on it. Show the paths of some example radiation particles in your pictures for this case. How should the count rates for the situations shown in each picture compare to one another? How should the count rates compare to a situation in which no shielding is present?

3. Imagine a situation in which some particles that interact with the shielding material are scattered (leave the shield in a new direction). Add examples of scattered radiation particles to

your pictures. Could scattering affect count rates, compared to the situations in which particles are only absorbed? Could scattering cause the count rates to depend on the position of the detector?

4. Imagine a situation in which some particles that interact with the shielding material produce several new particles. Add this example to your pictures. Could this cause the count rates to depend on the position of the detector?

5. If no scattering or particle production occurs, do you expect the count rate to change when the position of the shield is changed? If not, why not? If so, do you expect the count rate to be greater when the shield is closer to the source or closer to the detector? Explain.

EXPLORATION

WARNING: The radioactive sources available for this problem provide low intensity radiation, and are safe if handled with respect for short amounts of time. Do not remove them from the laboratory, and do not attempt to open the plastic disks containing the sources. **If a disk breaks open inform your TA immediately, do not touch it.**

Make sure you read *Appendix D* to understand the operation of the Radiation Monitor before trying to operate it. If you did not do Lab VII, Problem 1 today, do the exploration section of that problem to make sure you can get meaningful results from this specific Radiation Monitor equipment.

For each source, try different shielding materials and thicknesses until you can reduce the counting rate by a significant fraction. Devise a plan to qualitatively determine whether the position of the shielding material (closer to the radiation source or closer to the detector) has an effect on the counting rate.

MEASUREMENT

Carry out your measurement plan, and adjust if necessary to obtain useful data for each source. Measure counting rates for at least three different shield positions for each source.

ANALYSIS

Compare your results for different types of radiation and different types of shielding. Be careful with your logic since there are a lot of materials, radiation types, and distances. To be able to reach any conclusion make sure that only one quantity changes at a time.

Be sure to take the statistical uncertainty in your data into account. If you graph your data (regardless of whether you used a spreadsheet), don't forget to add error bars!

CONCLUSION

Does your data support your prediction? Why or why not?

Does your data support the assertion that the position of a radiation shield has no effect on the count rate? If there is an effect, how does it depend on the type of incident radiation? Does your data allow you to make any firm statements about whether scattering or particle production occurs for each type of radiation?

PROBLEM #3:
SHIELD THICKNESS

You are working for a company interested in irradiating turkeys for long-term storage. The management has asked your team for preliminary estimates of the minimum dose of the radiation necessary to kill enough of the microorganisms to retard spoilage. You quickly realize that the radiation dose to be determined is the minimum necessary at the center of the turkey. Of course, turkeys come in different sizes so your first task is to calculate how the radiation dose varies with depth inside the turkey. Your team decides to test your calculation in the lab by modeling the turkey with sheets of shielding material, as they are easier to handle than slabs of raw turkey meat. Since the company has not decided between using beta or gamma radiation for the process, you will have to test your idea on both types of radiation.

EQUIPMENT

The equipment consists of a Radiation monitor, also called a Geiger counter (see *Appendix D*) connected to a LabPro Interface device. Data will be collected using computer software called Vernier Logger Pro.

You will also have a beta source and a gamma source, as well as a variety of shielding materials.

PREDICTION

Write down a mathematical function that describes the effect of material thickness on the intensity of radiation that passes through that material. Describe the reasoning that leads you to that function.

WARM-UP

Read Serway & Jewett: sections 30.3, 30.4.

1. Draw a diagram with a source of radiation, a detector, and several identical sheets of equal thickness material between them.

2. Imagine that you measure the amount of radiation incident on the first sheet of material and the fraction that passes through that sheet. The surviving radiation now passes through a second sheet of material. Based on your first set of measurements, write an expression for the amount of radiation that passes through the second sheet. Continue this procedure for a third sheet. You should be able to continue for any number of sheets.

3. Try some numbers. Suppose that the initial radiation was 1000 particles and only half of the incident particles pass through each sheet of material, calculate the number of particles that survive the first sheet. How many survive the second sheet? The third sheet? On what quantity(ies) does the number of particles surviving a sheet of material depend? Make a graph of the number of surviving particles versus the number of sheets of material. Since each sheet is a specific thickness of material, you now have a graph of how the surviving amount of radiation depends on the thickness of material. Try to guess what functions could represent this graph. Check your guesses by graphing them to see if they match your points.

4. Imagine that all of the sheets of material are very thin and are pushed together to make one thick piece of material. As the particles pass through a thin sheet, the number entering the next sheet is reduced. On what quantity(ies) does this change in the number of particles depend? Write an equation for the change of the number of radiation particles per small amount of thickness (dN/dT). Solve this equation for the surviving number of particles as a function of material thickness. Check to see if this function matches your graph in question 3.
5. Compare the mathematics for your hypothetical description of the shielding of radioactive particles by material to that of radioactive decay described in your textbook. How are they similar? Different?

EXPLORATION

WARNING: The radioactive sources available for this problem provide low intensity radiation, and are safe if handled with respect for short amounts of time. Do not remove them from the laboratory, and do not attempt to open the plastic disks containing the sources. **If a disk breaks open inform your TA immediately, do not attempt to touch it.**

Make sure you read *Appendix D* to understand the operation of the Radiation monitor before trying to operate it.

If you did not do Lab VIII, Problem 1 today, do the exploration section of that problem to make sure you can get meaningful results from this specific equipment.

Take a new background count rate.

Try different types and thicknesses of material for the beta and gamma sources while noting the counting rates. Find a material that gives a noticeably different counting rate as you add more sheets? How many sheets will you need to get a good enough graph to check your prediction?

Some of the material, such a lead sheets, may not be able to support themselves when you stack them. If you use such material, be sure that the support system you devise will not significantly affect your measurement.

Decide as a group how long you will count for each increment of material thickness.

Come up with a measurement plan that will allow you to do this.

MEASUREMENT

Carry out your measurement plan, and adjust if necessary to obtain useful data. Don’t forget to include measurements that will help you determine your uncertainties.

ANALYSIS

Make a graph of the number of particles entering your detector (corrected for background count rate) vs. material thickness for each source. Match the data to your prediction for each type of radiation on a graph.

If it is difficult to tell whether or not a graph supports your predicted function, linearize the graph (see *Appendix C*) based on your prediction. Also try at least one other linearization of another function that might represent the data.

CONCLUSION

Describe the relationship between radiation survival and material thickness. Does this relationship hold for both types of radiation?

Does your data support your prediction? Why or why not?

PROBLEM #4:
HALF LIFE

You work for a nuclear medicine company that uses radioactive isotopes to diagnose and treat cancers and other diseases. Because certain radioisotopes are attracted to specific organs, their emissions can provide information about a particular disease or cancer. Nuclear techniques can provide data about the function of organs, not just their structure. One consequence of nuclear medicine is a plethora of contaminated waste: syringes, glass, gloves, and vials of radioactive pharmaceuticals. Unlike defense-related waste, most refuse from nuclear medicine won't be radioactive for millennia. For example, one radioactive isotope of indium, ^{111}In, is used as a "tracer" to identify tumors and has a half-life of 2.8 days, much shorter than that of plutonium. In this exercise, you and your partners will look at the relationship of time and radioactivity on a short lived isotope.

EQUIPMENT

The equipment consists of a Radiation monitor, also called a Geiger counter (see *Appendix D*) connected to a LabPro Interface device. Data will be collected using computer software called Vernier Logger Pro.

You will also have a Cs/Ba-137m isotope generator kit.

PREDICTION

Write down a mathematical function that describes the half life of a radioactive sample.

WARM-UP

Read Serway & Jewett: sections 30.3, 30.4.

1. Write an expression that represents the number of counts for a source with an unknown decay constant and a specified number of radioactive nuclei to start with.

2. Set the number of counts equal to half the original amount. Can you solve for the decay constant? Can you think of a way to determine the decay constant from the actual counts of a sample?

3. Solve your decay equation for the time when the number of counts is half the original amount. This is referred to as the “half-life” of the radioactive material.

4. How is the half-life of a material related to its decay constant? If a material has a very long half-life, is the decay constant large or small?

EXPLORATION

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Make sure you read *Appendix D* to understand the operation of the Radiation monitor before trying to operate it.

MEASUREMENT

Place the sample as close to the screen of the radiation monitor as possible. Do not move the sample until you have completed taking data.

When you and your partners are done taking measurements, you must ascertain how many radioactive events occurred in each one-minute interval.

ANALYSIS

Plot your results on a graph of counts vs. time. You should discover that, as you took your measurements, the radioactivity of the sample decreased. Also make a graph of (*ln* counts) vs. time. From your prediction equation, what does the slope of this line represent? Record this value. Is the value of this slope positive or negative?

Use your prediction equation to calculate the half-life of the radioactive sample.

CONCLUSION

Report the value for the half-life you measured. How certain are you of the result? What is the uncertainty in your measurements and analysis? How does the half-life of this compare to other radioactive wastes?

PHYSICS 1202 LABORATORY REPORT

Laboratory VIII

Name and ID#: ____

Date performed: ________________ Day/Time section meets: ______________________

Lab Partners' Names: ____

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Problem # and Title: ____

Lab Instructor's Initials: __________

Grading Checklist	Points
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:*	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to <u>rewrite that section only</u> and return it to your lab instructor within two days of the return of the report to you.