NUCLEAR RADIATION

IDEA TO REMEMBER!

Some isotopes are stable, others are unstable.

OBJECTIVE:

Explore the characteristics of different types of radiation and how they interact with absorbing materials. Measure the half-life of a radioactive source.

MATERIALS:

PASCO Interface

Wireless Geiger Counter

Sample Holder w/ Source Tray

Absorber Set

Radioactive Sources

Eluting Solution

Isotope Generator Kit

CONCEPT:

The nucleus of an atom consists of protons and neutrons. The electrical repelling force between each pair of protons tends to make the nucleus fly apart. But there is also a nuclear force between each pair of particles (proton-proton, proton-neutron, neutron-neutron) which tends to hold particles together. The net effect is that some combinations of numbers of protons and neutrons are stable and others are unstable. An unstable nucleus is said to be radioactive. That is, it is active in the emission of radiation. Most elements have both stable and unstable isotopes. Two different isotopes of an element have different numbers of neutrons, as in **Figure (1)**.

When an unstable isotope undergoes radioactive decay, alpha (α), beta (β), and gamma (γ) radiation are the three most common products—each with distinct properties and characteristics including charge, mass, and ability to penetrate materials. (See the table on the next page.)

THINK: Have you had a dental or other medical x-ray? What kind of protective measures were put in place?

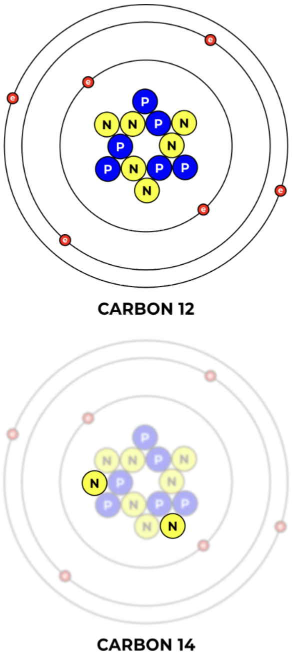

Figure 1

Type of Radiation	Composition	Charge	Penetration
α (alpha)	2 protons, 2 neutrons	+2	paper; a few inches of air
β (beta)	1 electron	-1	skin; a few feet of air
γ (gamma)	photon (light)	N/a	concrete or lead

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FUN FACT: Carbon-12 is stable and far more abundant in nature. Though more rare, Carbon-14 comes in handy in radiometric dating.

For any given radioactive isotope, there is a particular time interval, called a half-life, in which the probability is 50% that each atom will disintegrate. Statistically we expect half of the nuclei to disintegrate during one half-life. Of those which survive one half-life, we expect half to disintegrate during the second half-life, etc.

The number of nuclei that disintegrate per unit time is proportional to the number of nuclei present. The decay of a radioactive isotope is given by the equation

$$N = N_0 e^{-\gamma t} \tag{1}$$

N is the number of radioactive nuclei. The decay *rate* equals the decay constant γ times the number of radioactive nuclei N:

$$\frac{\Delta N}{\Delta t} = \gamma N \tag{2}$$

To solve for half-life, let $N = 1/2\, N_0$ and solve for time:

$$\frac{1}{2}N_0 = N_0 e^{-\gamma t_{half}} \longrightarrow e^{-\gamma t_{half}} = \frac{1}{2} \longrightarrow t_{half} = \frac{-ln\frac{1}{2}}{\gamma} = \frac{0.693147}{\gamma} \tag{3}$$

Real World Applications

- The healthcare industry uses nuclear radiation, specifically X-Ray, for quickly diagnosing various internal injuries. Processes, like CT scans, shoot layers of X-Rays from multiple angles to create a cross-sectional image!
- NASA Astronauts are encouraged to have kids before going to space, since the amount of gamma radiation in space will impact reproductive organs. Astronauts also eat irradiated (sterilized) meat to avoid germs!
- The only stable isotope of Cesium is ^{133}Cs, which was chosen in 1967 to determine the length of a second! The first atomic clocks were available in 1968!

1) What happens when you receive 17 Sieverts of radiation!
2) Who decides how long a second is?

PRECAUTIONS:

The radiation source should be kept in its case or in the sample holder tray. The radiation source is safe for classroom use but contact with it should be minimized. The radioactive source is sealed in the disk and should not be tampered with. Report any spills to your TA.

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CONCEPT & PROCEDURE VIDEOS:

PROCEDURE:

Part 1

1. ☐ Fill out the top information on the worksheet and complete the memory exercise—Questions M1–M3.

2. ☐ REQUIRED: Read the *Concept* section.

3. ☐ Assemble the setup.
   3.1. Press the power button on the side of the Wireless Geiger Counter to turn it on. Connect the Wireless Geiger Counter to PASCO Capstone. *Notes: See Procedure video via the QR code to the right… You can turn off the beeps in the Geiger Counter sidebar menu… If the battery charge LED indicates low battery, plug the Wireless Geiger Counter into the computer via the USB port .*
   3.2. Create a *Graph* in PASCO Capstone: set the y-axis to “Running Count”, and set “Recording Conditions” to have a 60-second time-based “Stop Condition.” You may also find it useful to have a “Digits” display of “Running Count” as well.
   3.3. Place the Wireless Geiger Counter into the top hole of the Geiger Sample Holder.

4. ☐ To collect the control background count, click *Record* in PASCO Capstone to begin counting and wait for the timer to reach 60 seconds. *Note: make sure the Radiation Sources are far away from the Wireless Geiger Counter.*

5. ☐ Record the number of background counts on the worksheet.

6. ☐ Place the Cs-137 radiation source on the Sample Tray, and insert the Sample Tray the into slot “8” in the Geiger Sample Holder.

7. ☐ Click *Record* in PASCO Capstone to begin counting. If you’ve set the stop condition correctly, the counting should end after 60 seconds. Record the number of counts in Table 1 of the worksheet.

8. ☐ Move the Sample Tray to slot “6” and repeat steps 6–7.

9. ☐ Move the Sample Tray to slot “4” and repeat steps 6–7.

10. ☐ Move the Sample Tray to slot “2” and repeat steps 6–7.
11. ☐ Subtract off the 60s background count from each of your 60 s running count values and enter these values in the third column of Table 1.
12. ☐ Using the corrected counts from the third column, find the ratios of each of your 60-s count values with the count from the 8-cm distance.
13. ☐ Answer Questions 1–2 on the worksheet.

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Part 2

14. ☐ Place a β-radiation source (Sr-90) on the Sample Tray, and insert the Sample Tray into slot “4” in the Geiger Sample Holder.
15. ☐ Click *Record* in PASCO Capstone to begin counting and wait for the timer to reach 60 seconds.
16. ☐ Record the number of counts in Table 2 on the worksheet.
17. ☐ Insert the “C” absorber from the Absorber Set into slot “2” in the Geiger Sample Holder.
18. ☐ Click *Record* in PASCO Capstone to begin counting and wait for the timer to reach 60 seconds.
19. ☐ Record the number of counts in Table 2 on the worksheet.
20. ☐ Repeat steps 18–19 for absorbers “D,” “E”, “G”, “J,” and “P” from the Absorber Set.
21. ☐ Repeat steps 14–20 for the γ-radiation source (Co-60).
22. ☐ Take four additional readings (absorbers Q-T) for the γ-radiation source (Co-60).
23. ☐ Plot the number of counts in one minute vs the mass per unit area of the absorber. You’ll show these graphs to your TA.
24. ☐ Answer Questions 3–4 on the worksheet.

Part 3

25. ☐ You’ll be taking an 8-minute reading for this part of the experiment so you’ll need to change your “Stop Condition” to <u>480 seconds</u>.
26. ☐ Ask your TA to prepare a sample of ^{137}Ba for your Sample Tray from the Eluting Solution and Isotope Generator Kit. Place the tray in Slot 2 of the Geiger Counter Holder and immediately start recording counts.
27. ☐ Read precise count values at the times designated in Table 3 by using the Coordinates Tool in the

PASCO Capstone software. Note, you can collect your data while the experiment is running.

28. ☐ Now subtract each count recorded from the previous count to obtain the number of counts per 15 seconds.

29. ☐ With the liquid sample still in the counter stand, obtain a background count by counting for 2 minutes (you may want to change your "Stop Condition" to 120s) and then dividing by 8 to obtain the 15-second background value.Record this value in the “Background per 15s” column in Table 3.

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30. ☐ Subtract the background from the “Counts per 15 s” column to get “Net Counts per 15 seconds.”

31. ☐ Using a graphing program of your choice, plot “Net Counts per 15 s” vs time *t*. *Note: we recommend Excel.*

32. ☐ Determine the half-life of ^{137}Ba using the following methods:
    - 32.1. Ensure that your graph is showing gridlines. *Note: in Excel, right-click on your graph and select “Add gridlines”.*
    - 32.2. Using the (x, y) intersects of the gridlines, select some point on the smooth curve that is near the high-count rate end and record the count rate and time.
    - 32.3. Next, move along the smooth curve until the count rate is one half as great and record the time. The half-life is the difference in these two times. See **Figure (2)**.

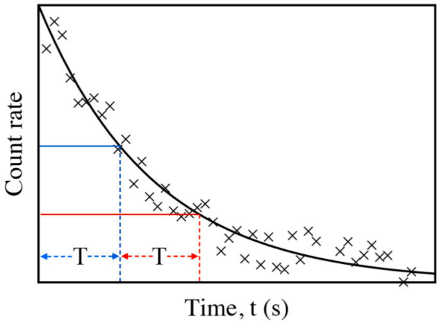

Figure 2

    - 32.4. Select a third point on the smooth curve (like the first) and repeat the procedure to get half-life from this point on the curve. Record and then answer Question 5 on the worksheet.
    - 32.5. Plot the natural log of the net counts for 15 seconds (ln *I*) vs time *t*. *Note: You'll need to create a new column in your spreadsheet. From Equation (3) (see Concept section), notice that a plot of* $\ln I$ *vs* t *is a straight line of slope* $-0:693/T$ *and intercept* $\ln I_0$.
    - 32.6. Choose a linear fit and get the slope from the equation of your straight line. From this slope compute the half-life and answer Question 6 and 7 on your worksheet.

33. ☐ Follow the **Let’s THINK!** instructions on the next page.

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Let's THINK!

- **Ask questions**: What are you learning here?... Why is this Physics concept important and how can it be used?... What do you not understand?... (For more information on this Physics topic, scan the QR codes in the *Real World Applications* and at the start of the *Procedure* section.)
- **Discuss** the concept and demonstration with your partner to help each other understand better. Discussion makes learning active instead of passive!
- For **FULL PARTICIPATION [15 points]** you must call on the TA when you have finished your group discussion to answer some comprehensive questions. If you do not fully understand and the TA asks you to discuss more, you must call on them one more time to be dismissed with full marks.
- **CONCLUSION [10 points]**: In the Conclusion section at the end of the worksheet, write 3 or more sentences summarizing this concept, how this lab helped you understand the concept better, and the real world implications you see. Do you still have questions? If so, write those as well.

Updated Date	Personnel	Notes
2023.11	Bob Swanson, Chase Boone	Reformatted for new lab manual standard. Improved the concept, procedure, and worksheet.

Name: ______________________________ PH1133 Section #: __________

Name: ______________________________ TA Name: ____________________

NUCLEAR RADIATION
Worksheet [70 points]

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Part 1

Background count: ________________ counts [1 point]

Table 1: Impact of distance, using Cs-137 Gamma source [8 points]

Distance (cm)	Count after 60 s	60 s count - background	Count / 8-cm count
8			
6			
4			
2			

1) Describe the expected shape of a graph of count rate on the vertical axis and distance on the horizontal axis. Will the line be straight or curved? If straight, will it have a positive or negative slope? If curved, will the curve go up or down? Make a sketch below to support your answer. [5 points]

2) Compare the count rate at 2 cm to the count rate at 4 cm. About how many times larger is the 2 cm count rate than the 4 cm count rate? [2 points]

Part 2

Table 2: Impact of Absorbers [9 points; 0.5 point per cell]

Absorber	Material	Thickness(in)	Mass per unit area (mg/cm^2)	Sr-90 sample 60-s count	Co-60 sample 60-s count
none					
C	Plastic sheet	0.004	9.6		
D	Plastic sheet	0.008	19.2		
E	Plastic	0.03	76.4		
G	Aluminum	0.02	130.7		
J	Aluminum	0.04	261.4		
P	Aluminum	0.125	814		
Q	Lead	0.032	1031.3		
R	Lead	0.064	1878.3		
S	Lead	0.125	3721.8		
T	Lead	0.25	7413.8		

3) For each of your sources, plot counts vs mass per unit area and show your graphs to your TA. Comment on how well different substances absorb each of these types of radiation. [5 points]

TA Signature: ______________________________

4) While gamma rays from space pose little threat to humans on Earth's surface, they become a concern when planning long-term missions to space. Why are gamma rays hazardous to human health and why would it be difficult to "shield" a spacecraft effectively? [3 points]

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Part 3

Table 3: Half-life [12 points]

Time (sec)	Total Counts	Counts per 15s	Background per 15s	Net Counts per 15s
0				
15				
30				
45				
60				
75				
90				
105				
120				
135				
150				
165				
180				
195				
210				
225				
240				
255				
270				
285				
300				
315				
330				
345				
360				
375				
390				
405				
420				
435				
450				
465				
480				

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Count Rate 1: __________

Time 1: __________

Count Rate 2: __________

Time 2: __________

5) Half-life reading 1 (as measured from Counts vs Time graph): ____________ s

Half-life reading 2 (as measured from Counts vs Time graph): ____________ s

Average half-life: ___________ s [5 points]

6) Half-life value as calculated from slope of *ln I* vs *t* graph (show your calculation): [5 points]

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7) The actual half-life of ^{137}Ba is 153 seconds. Show your calculation for % error below: [5 points]

Conclusion

Write 3 or more sentences summarizing this concept, how this lab helped you understand the concept better, and the real world implications you see. Do you still have questions? If so, write those here as well. [10 points]