

Activity 11 Solutions: Ionizing Radiation II

11.1 Additional Sources of Ionizing Radiation

1) Cosmic Rays

Your instructor will show you radiation events in a cloud chamber. Look for vapor trails that do not seem to come from one of the radioactive sources.

What could be the source for events that occur away from any of the radioactive sources?

Cosmic rays from space, which consist mostly of very high energy protons.

2) X-Rays

a) What are X-rays?

X-rays are high energy photons that are slightly less energetic than gamma particles.

b) How are X-rays produced?

X-rays are produced when a beam of electrons strikes a piece of metal. As the electrons slow down, some of their kinetic energy is converted into X-ray photons.

c) How do we know that X-rays are a form of ionizing radiation?

X-ray expose photographic film by ionizing molecules in the film, which causes a chemical reaction.

d) How does ionizing radiation differ from other types of radiation, such as microwaves, infrared radiation, or visible light?

Radiation is a general term that refers to anything, such as energy or particles that radiate outward from a source. Ionizing radiation is radiation that causes atoms in its path to be ionized, or stripped of one or more electrons. Ionizing radiation can be particularly damaging to living things.

11.2 How Are All Types of Ionizing Radiation Detected?

3) Detection of ionizing radiation

a) What do film badges do?

Photographic film can be exposed by ionizing radiation. Radiation workers wear film badges that contain pieces of film in light-tight plastic holders. Every month the film in the film badge can be developed and checked for exposure to radiation. Provided the badge is always worn by the radiation worker, this can reveal the radiation exposure of the worker.

b) List three ways we've seen in class to detect ionizing radiation.

Geiger counter, cloud chamber, film badge

11.3 What Is the Strength of Ionizing Radiation?

4) The strength of ionizing radiation

- a) Use the Geiger counter and a timer to find the background radiation in the room by counting the number of Geiger counter clicks per minute. _____

The background level is usually about 25 to 30 counts per minute.

- b) What is the source of this background radiation?

Naturally-occurring radioactive particles in building materials and cosmic rays from outer space.

- c) Your instructor will bring you a weak radioactive source. Attach the Geiger counter detector to a ring stand. Place the source 10 cm from the open side of the detector and record the number of counts per minute. _____
How many counts per minute result from this source? _____

- d) Place the source 20 cm from the detector and record the number of counts per minute. _____ How many counts per minute result from this source? _____

- a) Place the source 40 cm from the detector and record the number of counts per minute. _____ How many counts per minute result from this source? _____

- b) What effect does increasing the distance have on the count?

The number of counts decreases as the distance from the detector increases.

5) The Penetrating ability of ionizing radiation

Test the penetrating ability of beta and gamma sources by placing the sources, one at a time, approximately 10 cm from the open side of the Geiger counter detector. Try shielding each source with pieces of cardboard, aluminum, and lead. Write "yes" or "no" in the table below to indicate which materials shielded each source.

Does the shielding material significantly reduce the ionizing radiation recorded?

Shielding material	alpha	beta	gamma
a) cardboard	__yes__	__no__	__no__
b) one aluminum sheet	__yes__	__no__	__no__
c) multiple aluminum sheets	__yes__	__partially__	__no__
d) one lead sheet	__yes__	__yes__	__no__
e) multiple lead sheets	__yes__	__yes__	__partially__

- f) Compare the penetrating ability and the ionizing ability of alpha, beta, and gamma radiation.

Of the three types, alpha radiation is the least penetrating since it has the most ionizing ability. Beta radiation is more penetrating than alpha and has less ionizing ability. Gamma radiation is the most penetrating of the three and has the least ionizing ability.

11.4 What Are Natural Sources of Radioactivity?

6) Radiation exposure

- a) What factors determine the extent of our exposure to ionizing radiation?

Radiation exposure is a function of the count rate (the number of ionizing particles/min), the energy of the particles, and the time exposed to them. The effect of exposure to radiation depends upon how penetrating that form of radiation is.

- b) What is the average person's annual dose of ionizing radiation?

Exposure to radiation can be measured in units of rems. An average person's annual exposure is 200 millirems. For comparison, one hour of arms-length exposure to a gamma source like the Cobalt-60 we use in class would add up to about 0.001 mrems of radiation exposure.

- c) How does the radiation exposure of a typical chest X-ray compare to the average annual exposure?

While X-rays may give doses as low as 6 mrems, the average is about 20 mrems per X-ray. (Averages depend upon many factors and should not be taken as absolute numbers.)

7) Radioactivity in household products

Your instructor will show you some natural and man-made radioactive sources.

- a) List these sources and the results when you place a Geiger counter detector near each source.
- i) **Potassium iodide (salt substitute) gives a count above background of about 30 counts/min.**
 - ii) **When the smoke detector is opened and its shield is removed, it gives a count of about 25 counts/min.**
 - iii) **The uranium and thorium ores are all only slightly above background levels (maybe 50 counts/min) except uraninite (pitchblende), which is very detectable at over 200 counts/min.**
 - iv) **The radium paint off of the radium clock hand is nearly gone, but it still measures 325 counts/min.**
 - v) **The old Fiestaware plate gives the highest reading (approx. 6000 counts/min). The orange glaze contains uranium oxide.)**
- b) Does your exposure to these products constitute a danger to your health?
- Since your exposure to each is very limited in everyday life it is unlikely that they would significantly affect your average annual radiation exposure. However, if you wore an radium wristwatch 16 hours a day, this could have an impact.**

- c) The radiation exposure from an old orange Fiesta ware plate is about 0.002 mrem/hour. Estimate the annual radiation exposure of a person who ate 3 meals a day using a Fiesta ware plate. What percent is this exposure from the plate of the 200 mrem annual exposure of the average person?

Assuming the Fiesta ware dishes were used for three 30 minute meals per day (including exposure time during dish washing), a person might be exposed to them 1.5 hours per day or roughly 500 hours per year.

0.002 mrem/hour X 500 hours = 1 mrem per year

This is 1/200 th or 0.5% of the average person's annual dose.

8) Radiation or phosphorescence?

Watch the flash bulb/glow-in-the-dark stickers demonstration.

- a) Are glow-in-the-dark stickers radioactive? **_No_**
 b) What makes them glow?

The phosphorescent stickers are NOT radioactive. High energy (ultraviolet) photons are absorbed by the stickers knocking electrons in the atoms to higher energy levels. As those electrons fall back down to normal ground state energy levels, they emit lower energy photons (visible light) and this is what we see as glowing.

- c) How are glow-in-the-dark stickers different from radium glow-in-the-dark clocks manufactured years ago?

Glow-in-the-dark clocks manufactured years ago had a radium based paint. The radioactive decay of radium provided the energy to knock the electrons to higher energy levels.

9) Radon

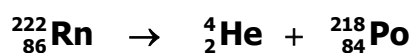
- a) What is radon?

Radon is a radioactive gas. Radon-222 gas comes from the radioactive decay of uranium-238.

- b) What is a "radioactive daughter"?

The daughter of a radioactive element is the element that forms from the decay of the radioactive element. A series of radioactive daughters may form in the decay of a radioactive element. For example, uranium-238 goes through a series of 14 different reactions and produces 13 generations of radioactive daughters before finally decaying into a stable isotope of lead.

- c) Radon-222 (${}^{222}_{86}\text{Rn}$) decays by emitting an alpha particle (${}^4_2\text{He}$). Write the reaction that occurs when radon-222 decays.



- d) How long do you have to leave a radon test kit in a location to determine if you have a radon problem?

Several days, since radon-222 has a half-life of 3.8 days. Radon levels may fluctuate greatly during the course of the day so you need a device that measures the levels over a period of several days.

- e) Can you use a Geiger counter or similar device to check if you have a radon problem? Why or why not?

No. As we have seen, alpha particles have low penetrating ability. They cannot easily penetrate a Geiger counter.

- f) Why are radon daughters dangerous?

The radioactive daughter products adhere to dust particles. If these radioactive dust particles are inhaled, they can emit alpha and beta radiation inside the lungs. Though alpha particles cannot penetrate skin, they are dangerous if they are being emitted by a radioactive source inside your body, since they have a high ionizing ability.

- g) Why is radon of particular concern in locations like central Ohio?

Homes built on soil with uranium deposits may have high level of radon gas seeping through cracks in the basement floor and walls. Shale deposits are particularly likely to contain radon-producing materials. Shale is the bedrock of portions of central Ohio.

- h) What can be done to correct a radon problem in a building?

Radon gas in can be removed through ventilation pipes installed under the basement floor. Fans draw the radon gas outside of the building.

11.5 A Model of Radioactive Decay

Your instructor will explain how to use a board that simulates radioactive decay with circuit elements and a capacitor.

10) Finding the half-life of a radioactive source

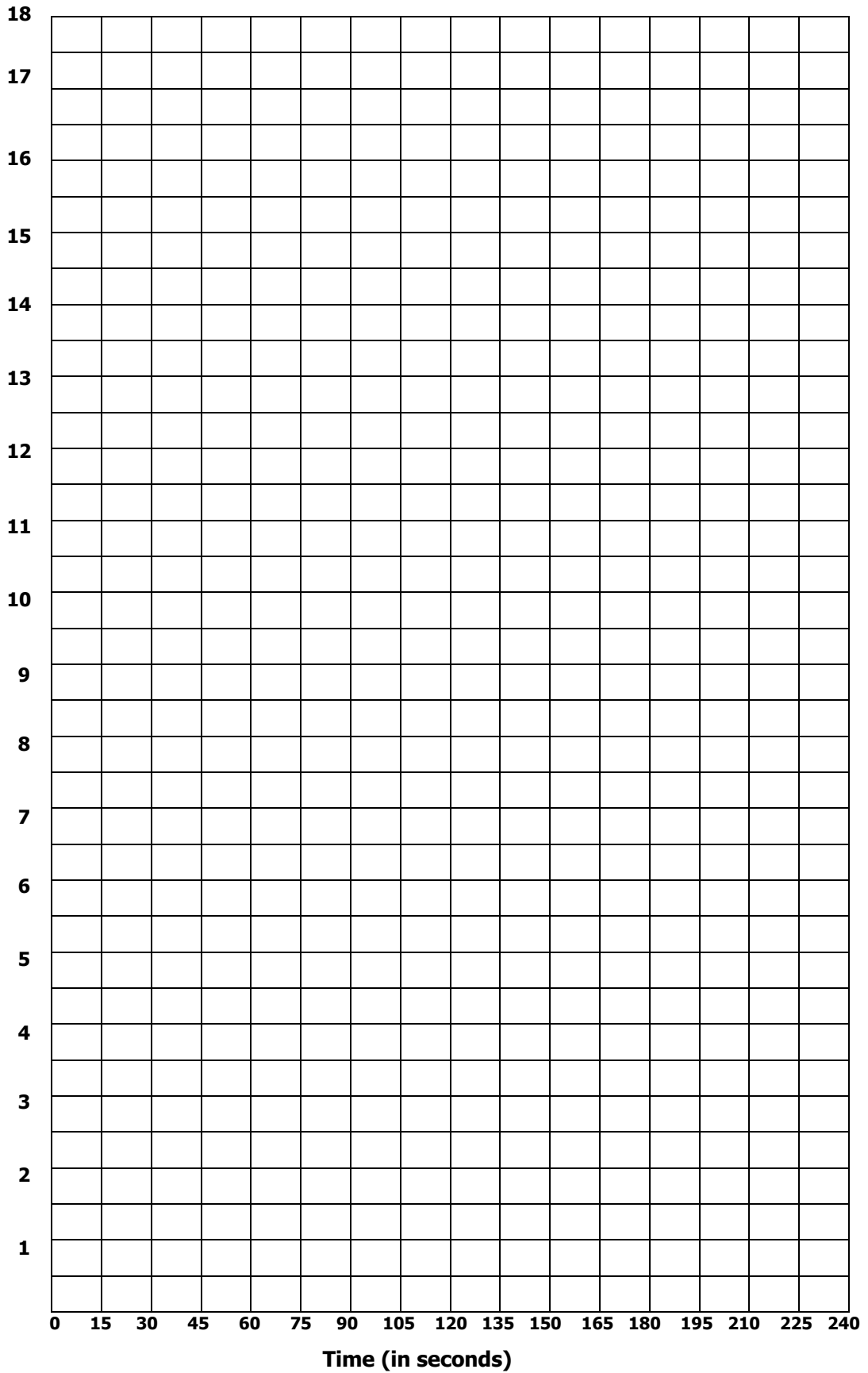
- a) What is the half-life of a radioactive source?

The half-life of a radioactive source is the time required for half of the unstable nuclei to decay. After one half-life, the number of the original nuclei remaining will be only half what it was originally, and the material will be only half as radioactive. After 2 half-lives, only one fourth of the original radioactive material will remain.

- b) After charging the capacitor, flip the switch to the right to allow the capacitor to discharge through the resistor. At the same time, start the timer. Measure the voltage with a multimeter set to measure DC voltage ($V \Rightarrow$) every 15 seconds for four minutes. Record your measurements in the table below.

Time elapsed (Min: Sec)	Voltage (volts)		Time elapsed (Min: Sec)	Voltage (volts)
0:00			2:15	
0:15			2:30	
0:30			2:45	
0:45			3:00	
1:00			3:15	
1:15			3:30	
1:30			3:45	
1:45			4:00	
2:00				

- c) Make a graph on the grid below of the voltages you measured versus time elapsed.



- d) What is the smallest voltage reading you obtained? **___ approximately 3 volts___**
- e) What does this voltage represent? Why didn't your graph decrease further?
This voltage represents the background radiation.
- f) Would your graph decrease below this voltage if you had measured the voltage for a longer time? Why or why not?
No, the background radiation (in this case, background voltage) is always present.
- g) From your graph, find the half-life represented by the capacitor's discharge. To do so, you must subtract the background radiation (the background voltage), find the time for the radiation (the voltage) to decrease by $\frac{1}{2}$, and then add in the background radiation (background voltage).

Pick a data point on your graph as your starting point for the voltage. Subtract the background voltage. Divide the result in half. Then add back in the background voltage. This gives $\frac{1}{2}$ the original voltage, corrected for the background. Find this voltage on your graph. The time elapsed between this point and your original point is the half-life – the time it took for $\frac{1}{2}$ of the capacitor's charge to be released.

11.6 Radiocarbon Dating

11) Carbon-14

- a) What common radioactive isotope is used for archeological dating?

The carbon-14 isotope ($^{14}_6\text{C}$)

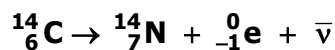
- b) Why is this isotope unstable?

Carbon-14 is a small nucleus (only 6 protons) with an unequal number of protons and neutrons.

- c) What change to a $^{14}_6\text{C}$ nucleus would make it a more stable nucleus?

If one neutron decayed into a proton, the nucleus would have equal numbers of neutrons and protons (7 of each type of nucleon).

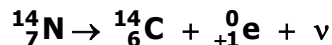
- d) Write a nuclear equation to show how a $^{14}_6\text{C}$ nucleus decays to become a more stable nucleus. What type of ionizing radiation is emitted during this decay?



Since changing a neutron into a proton adds one positive charge, a negatively charged electron (β^- particle) must be emitted to conserve electric charge. An antineutrino is also emitted whenever an electron is given off.

- e) Where does carbon-14 come from? Write a nuclear reaction to show the formation of $^{14}_6\text{C}$.

The energy from cosmic rays can turn stable nitrogen-14 in the air into carbon-14. One proton in the nitrogen atom turns into a neutron. An antielectron (a positron) and a neutrino are emitted.



12) Carbon Dating

- a) How long does it take for one-half of the carbon-14 nuclei in a sample to decay?

5,730 years

- b) How can the half-life of carbon-14 allow us to determine the age of an archeological object?

Both stable carbon-12 and unstable carbon-14 isotopes are present in the atmosphere (in carbon dioxide). Living organisms absorb both isotopes of carbon in the process of respiration. After an organism dies, it no longer absorbs any new carbon-14, and the carbon-14 within it decays. We can accurately estimate the time of an organism's death, if we know the ratio carbon-12 to carbon-14 in the atmosphere at the time the organism died, the present ratio of Carbon-12 to carbon-14 in the fossil, and the half-life of carbon-14.

- c) A sample of bone from an archeological site was found to contain only one-sixty fourth ($1/64$) the amount of carbon-14 that would have been present in living bone at the time this organism was alive. What is the age of this bone?

Since $\frac{1}{64} = \frac{1}{2^6}$ we know that 6 half-lives have passed since this organism died.

$$6 \text{ half lives} \times \frac{5,730 \text{ years}}{\text{half life}} = 34,380 \text{ years}$$

- d) Group Discussion Question: An archeological team works in a dig they believe to be around one million years old. Would carbon-14 dating be appropriate to determine the age of this site? Why or why not?