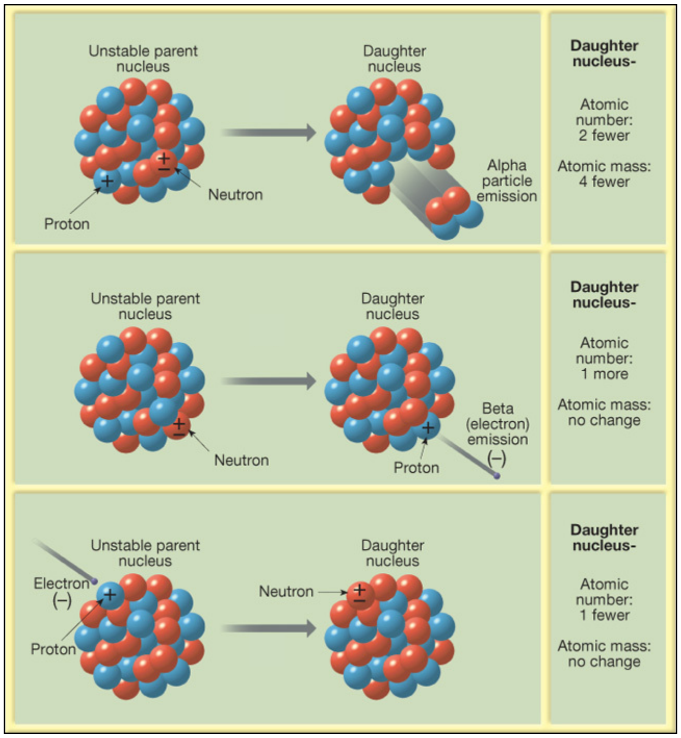
Radioactive Decay



Introduction

All atomic nuclei with more than 82 protons are inherently unstable. The electrostatic repulsions between pairs of protons are so large, that even the addition of many more neutrons than protons cannot create sufficient nuclear attraction to stabilize the nucleus. However, you cannot predict exactly which atomic nucleus will decay or exactly when, and some nuclei may decay in more than one way.

Objectives

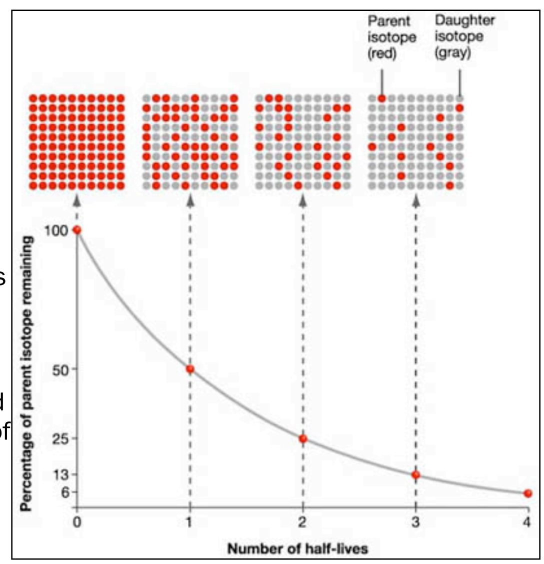
- Simulate the radioactive decay of a sample isotope
- Construct a graph to illustrate the exponential decay
- Determine the radioactive half-life of the isotope
- Examine the process of radiologic dating and calculate the age of a sample using this method
- Use a Geiger Counter to compare the radiation emitted from beta and gamma sources
- Distinguish between naturally occurring background radiation and sample source radiation emission

Experimental Equipment

- Container of dice
- Beta and Gamma radiation sources
- Polyethylene and lead shielding
- Container of multi-colored beads
- Student Radiation Monitor (Geiger Counter)

Activity 1: Simulating Radioactive Decay

The idea of the radioactive half-life cannot tell you precisely *which* nuclei have decayed, but can tell you how much time it will take for exactly *half* of the atoms in your sample to decay. Half-lives vary between different elements, and from isotope to isotope of the same element. Half-lives can be very accurately calculated by measuring instantaneous rates of decay, using a radiation detector. The shorter the half-life, the faster the rate of decay.



The nuclei in a sample of a radioactive isotope decay into other isotopes at a certain rate. One way to quantify this rate is to determine the amount of time it would take to be left with only half the nuclei you started with. This elapsed time is called half-life.

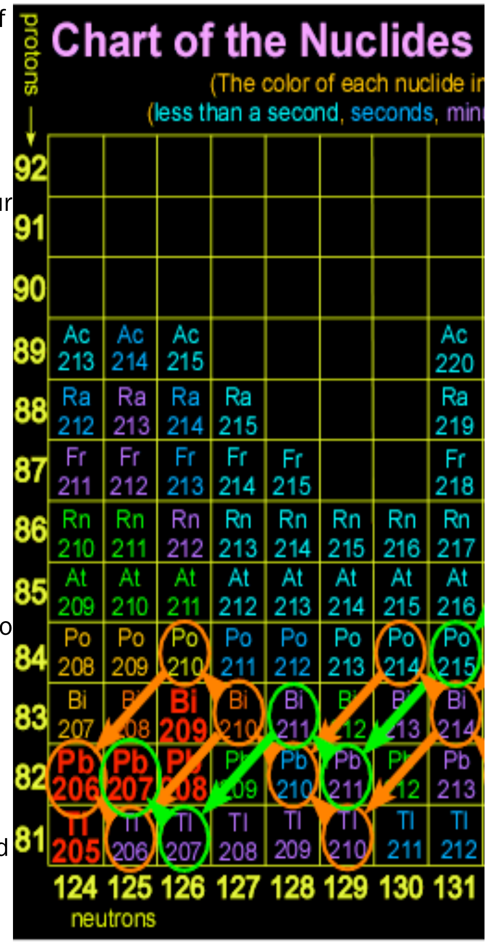
- Examine your container and count the number of dice (there should be 56, but count them to be sure). Each die represents one atom of our sample isotope.
- Roll all 56 dice and remove only the dice that come up either as sixes or ones. These will count as decayed isotopes.
- Record the number of dice you have left. These are the undecayed isotopes.
- Repeat this process until you are left with either one or zero dice.

Trial	Number of Decays	Number of Remaining Dice
0		
1		
2		
etc.		

Questions

1. Construct a graph showing the rate of decay of the dice isotopes. On the x-axis, plot the trial number. On the y-axis, the number of undecayed or remaining dice. Use the entire page, scale your axes carefully, and plot your points accurately. Note that your first data point will be at (0, 56) because before you throw the dice for the first time, none of the isotopes have decayed. Draw a smooth curve (do not connect the dots) to fit the data.
2. On the y-axis of your graph, go to exactly half the total number of dice. Draw a perfectly horizontal line straight across to the curve you sketched, then draw a perfectly vertical line from the point where it intersects down to the x-axis. Where does your line intersect the x-axis?

3. What is the radioactive half-life of your sample, in units of trials or rolls of the dice? This represents the rate at which the atoms of the isotope decay, regardless of where they are found.
4. When one atom of an actual isotope decays, what happens to it? Is it still the same type of atom after the decay? Compare what happens specifically to Bismuth. On the Chart of Nuclides shown on the right, locate Bismuth–210 ($_{210}$Bi, row 83, column 127). If you need to, use your text to recall the difference between *alpha* and *beta* decay.



Activity 2: Radiological Dating

Since a sample of a radioactive isotope decays into other isotopes at a certain rate, one can use this as a clock to measure the ages of certain things.

For example, image that a volcano made a rock a long time ago. If that rock originally contained one-hundred atoms of isotope–X, then over time the isotope–X atoms will decay, and therefore there will be fewer and fewer isotope–X atoms as the rock ages. After one half-life there would be only 50 left. After another half-life there would be only 25 left. And so on, until eventually there would be no more isotope–X atoms left in the rock.

An isotope that gets used to measure really old rocks is Rubidium-87 which decays into Strontium-87. By comparing the number of Rubidium-87 atoms to the number of Strontium-87 atoms one can determine the age of the rock given the half-life of Rubidium-87 is 4.8×10^{10} years.

Where N_{Sr} is the number of Strontium-87 atoms and N_{Rb} is the number of Rubidium-87 atoms.

- Examine your cup of beads. The green beads represent Rubidium-87 atoms and the red beads represent Strontium-87 atoms.
- Count the number of each type of atom present in the sample and record those numbers.

Questions

5. Use those numbers and the equation on the right to determine the age of the sample:

$$age = \left(\frac{4.8 \times 10^{10}\,\text{years}}{0.7}\right)\ln\left(1 + \frac{N_{Sr}}{N_{Rb}}\right)$$

6. If this sample represents a rock that formed when the solar system first formed, then how old is the solar system (and the Earth) in billions of years (1 billion = 10^9)?

Activity 3: Measuring Low-level Radiation Sources with a Geiger Counter

The *Student Radiation Monitor* contains a Geiger tube that can detect beta, x-ray, and gamma radiation. Each time radiation hits the Geiger tube the radiation monitor will chirp when turned to AUDIO. Various types of radiation are naturally present in the environment. Some of this naturally occurring background radiation comes from space (some from the Sun, some from cosmic rays). Some of the radiation comes from isotopes found in the Earth's crust. This is separate from the radiation of our sources.

- Turn the radiation monitor on AUDIO and measure the number of radiation detections it detects in 15 seconds. Record this as the background radiation level.
- Put the radiation monitor above one of the beta radiation sources. Record approximately how many detections in 15 seconds.
- Place polyethylene or lead barriers in front of the beta source until the radiation detections are reduced to the background level. Record the minimum thickness of polyethylene or lead necessary.
- Repeat this process for one of the gamma radiation sources.

Questions

7. Subtract the background count from the total radiation count to get the number of decays attributable to each source. Why can we subtract the same background even though the sources are different? Unshielded, which source had more decays?
8. Compare the amount of shielding required to block each source. From this observation, explain which type of radiation is more energetic.