Unit 5: Age of the Earth

Objective:

E5.3e Determine the approximate age of a sample, when given the half-life of a radioactive substance (in graph or tabular form) along with the ratio of daughter to parent substances present in the sample.

E5.3f Explain why C-14 can be used to date a 40,000 year old tree but U-Pb cannot.

Radioactive Isotopes

Rocks generally contain small amounts of radioactive material that can act as natural clocks. Atoms of the same element that have different numbers of neutrons are called isotopes. **Radioactive isotopes** have nuclei that emit particles and energy at a constant rate regardless of surrounding conditions.

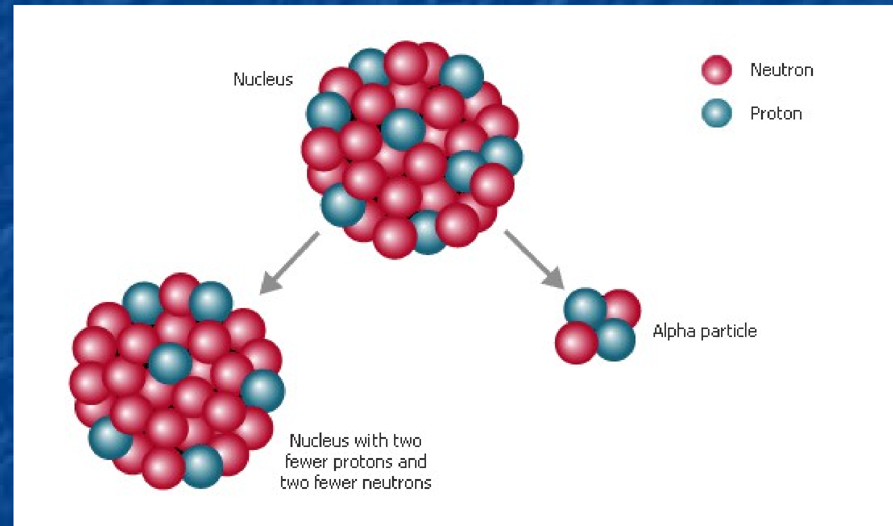
Uranium Ore

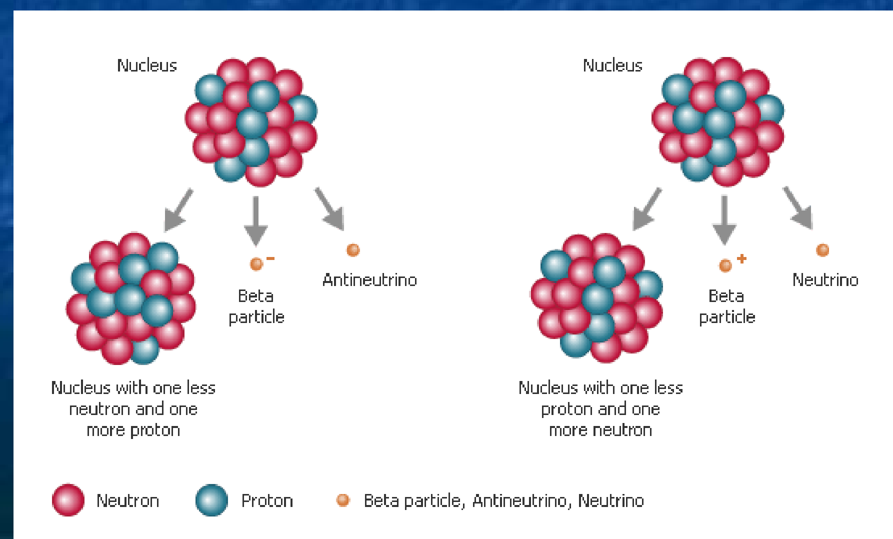
Radiometric Decay

Alpha decay and beta decay are two forms of radioactive decay. In all forms of radioactive decay, an atom emits particles and energy.

Scientists use this natural breakdown of isotopes to accurately measure the **absolute age** of rocks.

The method of using radioactive decay to measure absolute age is called **radiometric decay**.

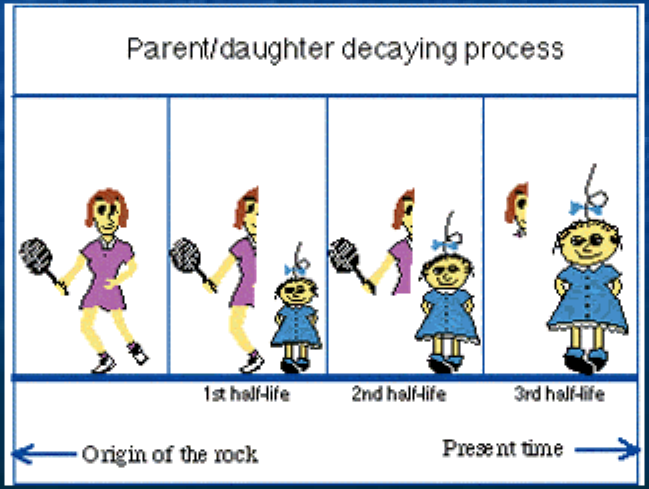




Parent / Daughter Isotopes

As an atom emits particles and energy, the atom changes into a different isotope of the same element or an isotope of a different element. Scientists measure the concentrations of the original radioactive isotope (known as the **parent isotope**), and of the new formed isotopes (known as the **daughter isotope**).

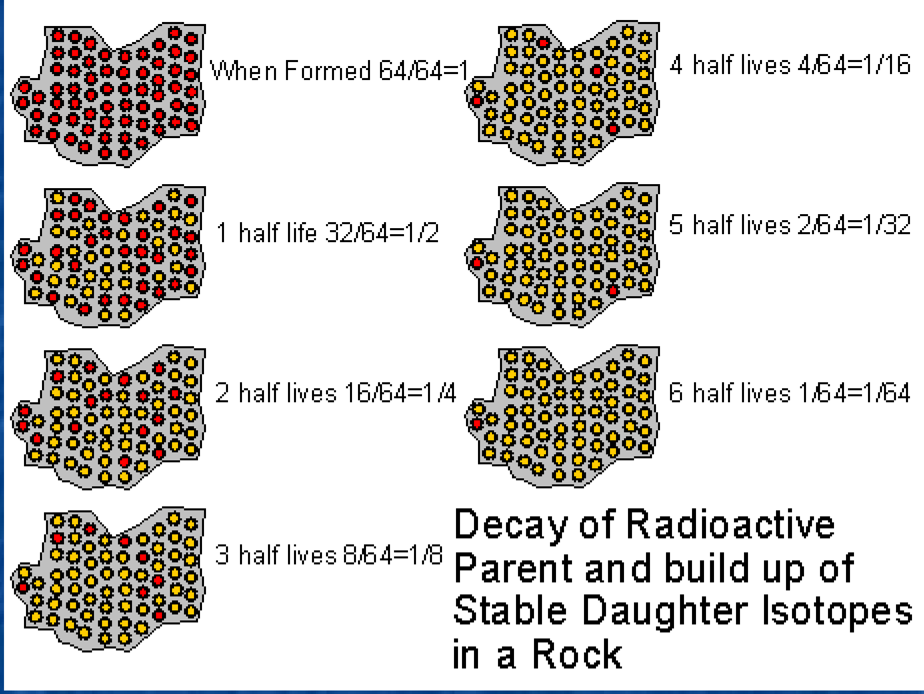
Using the known decay rate, the scientists compare the proportions of the parent and daughter isotopes to determine the absolute age of the rock.



Half-life*

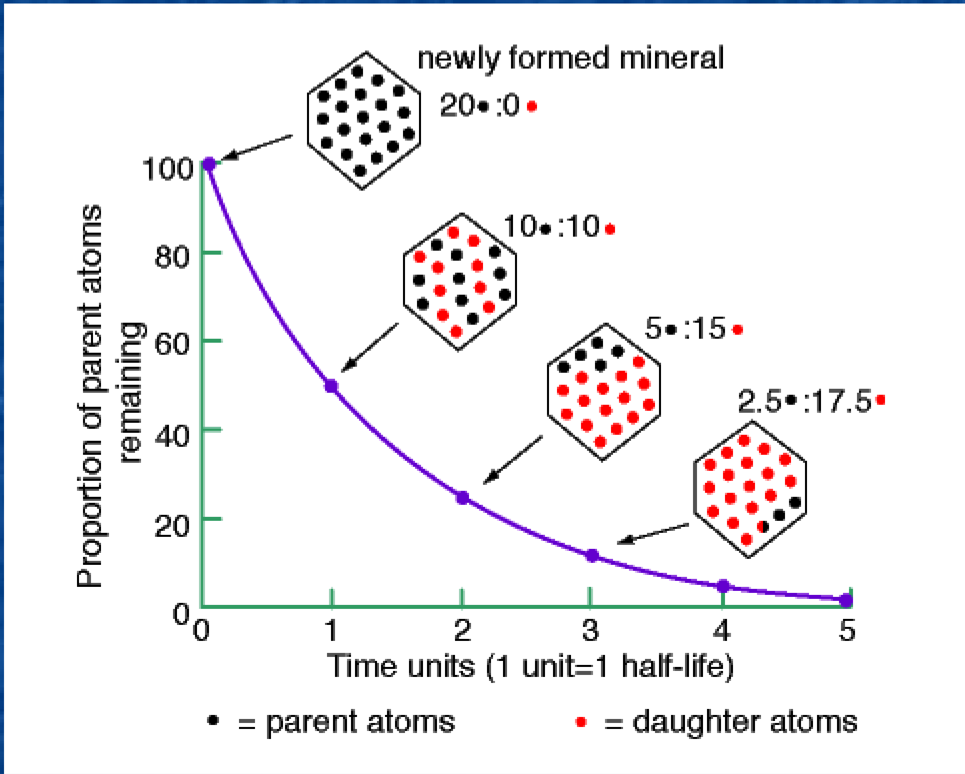
Radioactive decay happens at a relatively constant rate that is not changed by temperature, pressure, or other environmental conditions. Scientists have determined that the time required for half of any amount of a particular radioactive isotope to decay is always the same and can be determined for any isotope.

Therefore, a **half-life** is the time it takes half the mass of a given amount of radioactive isotope to decay into its daughter isotopes.



Calculating Half-life*

If you begin with 20 g of a parent isotope, you would have 10 g of that isotope after one half-life of that isotope. At the end of a second half-life, you would have 5 g of that isotope. At the end of a third half-life, you would have, one-eighth, or 2.5 g of the original isotope remaining. At that point, three-fourths of the sample would now be the daughter isotope.

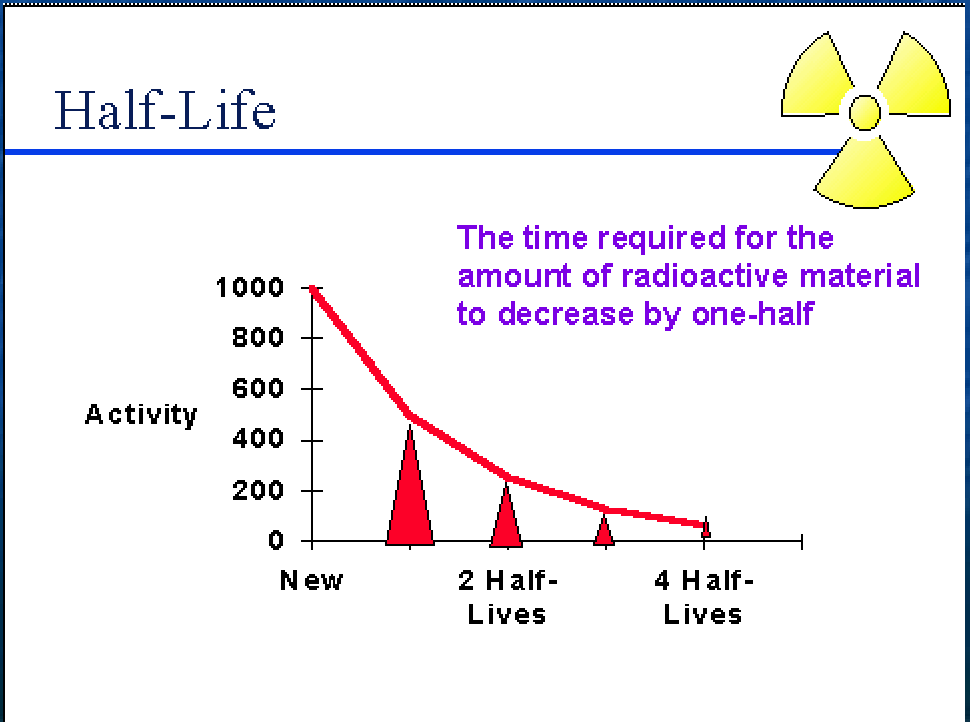


$$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8}$$

Half-life

By comparing the amounts of parent and daughter isotopes in a rock sample, scientists can determine the age of the sample. The greater the percentage of daughter isotopes present in the sample, the older the rock is.

But comparing parent to daughter isotopes only works when the sample has not gained or lost either parent or daughter isotopes through leaking or contamination.



Radioactive Isotopes

The amount of time that has passed since a rock formed determines which radioactive element will give a more accurate age measurement. If too little time has passed since radioactive decay began, there may not be enough of the daughter isotope for accurate dating. If too much time has passed, there may not be enough of the parent isotope left for accurate dating.

URANIUM 238 (U238) RADIOACTIVE DECAY

type of radiation	nuclide	half-life
α	uranium-238	4.47 billion years
β	thorium-234	24.1 days
β	protactinium-234m	1.17 minutes
α	uranium-234	245000 years
α	thorium-230	8000 years
α	radium-226	1600 years
α	radon-222	3.823 days
α	polonium-218	3.05 minutes
β	lead-214	26.8 minutes
β	bismuth-214	19.7 minutes
α	polonium-214	0.000164 seconds
β	lead-210	22.3 years
β	bismuth-210	5.01 days
α	polonium-210	138.4 days
	lead-206	stable

Radioactive Isotopes

Uranium-238 has an extremely long half-life of 4.5 billion years. It is most useful for dating geologic samples that are more than 10 million years old, as long as they contain uranium.

Other isotopes are also used to date rock samples. Potassium-40 has a half-life of 1.25 million years. Potassium-40 occurs in mica, clay, and feldspar and is used to date rocks that are between 50,000 and 4.6 billion year old.

Rubidium-87 has a half-life of about 49 billion years. Rubidium-87 commonly occurs in minerals that contain potassium-40, so it can be used to verify the age of rocks previously dated by using potassium-40.

Math Skills – Half-life

A sample contains 1000 g of an isotope that has a half-life of 500 years. How many half-lives will have to pass before the sample contains less than 10 g of the parent isotope?

After 1 half-life (500 years), 500 g of the parent isotope will remain.

After 2 half-lives (1000 years), 250 g of the parent isotope will remain.

After 3 half-lives (1500 years), 125 g of the parent isotope will remain.

After 4 half-lives (2000 years), 62.5 g of the parent isotope will remain.

After 5 half-lives (2500 years), 31.25 g of the parent isotope will remain.

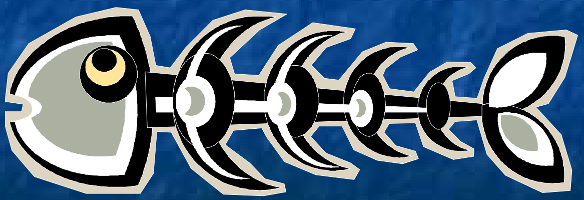
After 6 half-lives (3000 years), 15.625 g of the parent isotope will remain.

After 7 half-lives (3500 years), 7.8125 g of the parent isotope will remain.

Carbon Dating*

Younger rock layers may be dated indirectly by dating organic material found within the rock. The ages of wood, bones, shells, and other organic remains that are included in the layers and that are less than 70,000 years old can be determined by using a method known as **carbon-14** (or **radiocarbon**) **dating**.

The isotope carbon-14 combines with oxygen to form radioactive carbon dioxide. Most carbon dioxide in the atmosphere contains nonradioactive carbon-12. Only a small amount of carbon dioxide in the atmosphere contains carbon-14.



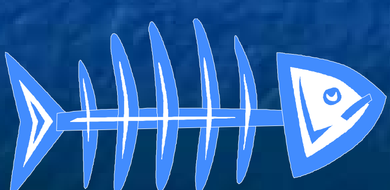
Carbon Dating

Plants absorb carbon dioxide which contains either carbon-12 or carbon-14 during photosynthesis. Then, when animals eat the plants or the plant-eating animals, the carbon-12 and carbon-14 become part of the animals' body tissues. Thus, all living organisms contain both carbon-12 and carbon-14.

Carbon Dating*

To find the age of a small amount of organic material, scientists first determine the ratio of carbon-14 to carbon-12 in the sample. Then, they compare that ratio with the ratio of carbon-14 to carbon-12 known to exist in a living organism. While organisms are alive, the ratio of carbon-14 to carbon-12 remains relatively constant.

When a plant or an animal dies, the ratio begins to change. The half-life of carbon-14 is only about 5,730 years. Because the organism is dead, it no longer absorbs carbon-14 and carbon-12, and the amount of carbon-14 in the organism's tissues decreases steadily as the radioactive carbon-14 decays to nonradioactive nitrogen-14.



$$\frac{\chi\alpha\rho\beta o\nu-14}{\chi\alpha\rho\beta o\nu-12}$$

Radiometric Dating

Now that you have learned about the different radiometric dating methods (isotopes), can you explain why carbon-14 can be used to date a 40,000 year old tree, but uranium cannot?

The 40,000 year old tree is/was a living organism. Remember, all living organisms contain both carbon-14 and carbon-12. Thus, radiocarbon dating would be an appropriate method to use to determine the date of the tree. Uranium is used to date rock samples that are more than 10 million years old.