# Introduction to Radioactive Decay

Processes governed by quantum mechanics are fundamentally random.

For example, we can't know where the next particle will land in the two-slit experiment. We can only predict the pattern we will get if there are many, many particles.

Another example of this inherent randomness is...

radioactive decay of atomic nuclei

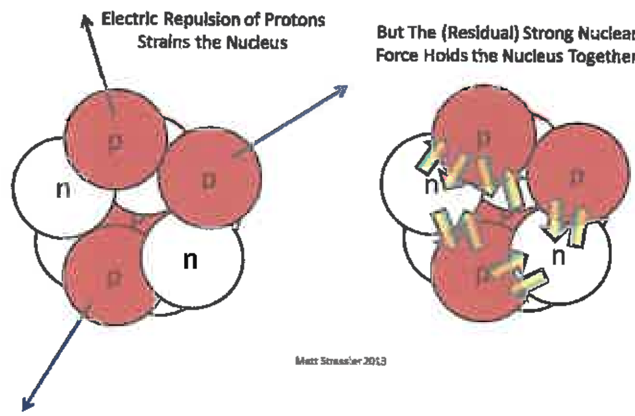
First, some background! The atom is comprised of three subatomic particles:

+ve charged protons and neutral neutrons in nucleus

-ve charged electrons orbiting around nucleus

Of the four known forces in nature, three are important inside the nucleus:

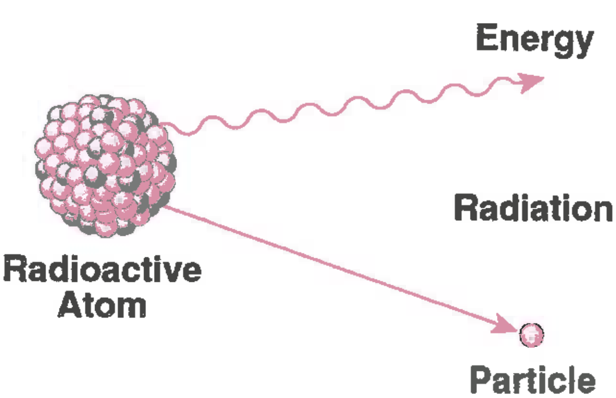
- The electromagnetic force acts to push protons apart (remember: like charges repel).
- Protons and neutrons are pulled together by:
  1. Strong nuclear force
  2. Weak nuclear force




It is the interaction between the repulsive electromagnetic force and the attractive nuclear forces that determines the stability of the atom.

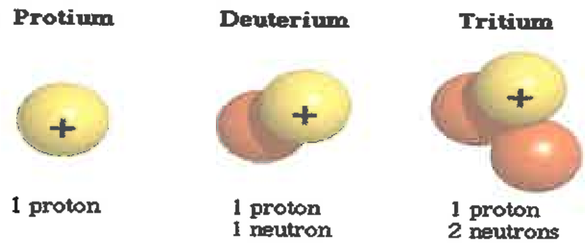
Certain atomic nuclei do not have the optimum ratio of protons to neutrons to maximize their stability.

As such, these unstable atoms will try to reach a more stable nuclear configuration by emitting energy and/or particles in a process known as **radioactive decay**.




All naturally occurring elements with atomic numbers higher than 83 (though Tc and Pm are an exception) experience radioactive decay (and are therefore radioactive).

Certain isotopes, atoms of the same element which have a different number of neutrons, of lighter elements also experience radioactive decay.




E.g. There are three isotopes of hydrogen.

Two of these isotopes are stable, (not radioactive), but tritium (one proton and two neutrons) is unstable and therefore radioactive.

## Half-Life

Radioactive decay results in parent elements turning into daughter elements, which have new chemical and physical properties. For example, U-238, a naturally occurring isotope which is used to fuel nuclear reactors, goes through many radioactive decays until it eventually transforms into stable lead-206.

This process, of going through radioactive decay and changing into a new element, is known as transmutation.

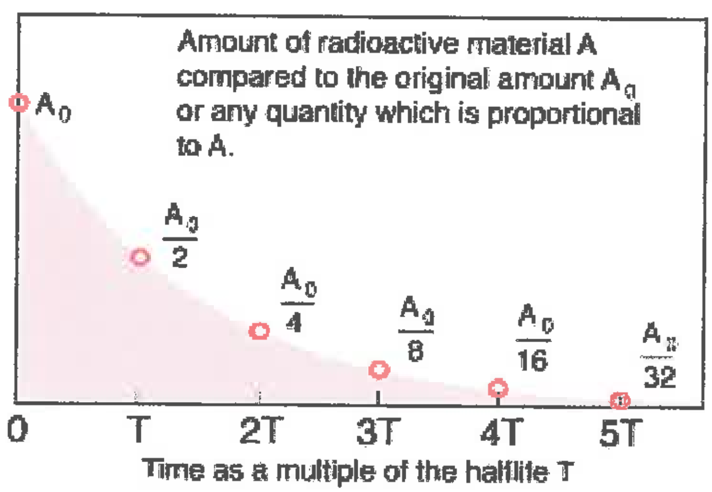
With all these nuclei decaying, you'd think that eventually one would run out of atoms...that's exactly what happens!

The half-life of a nucleus is the time it will take to...

transform 50% of the original atoms into a new element

This amount of time varies from just $10^{-22}$s to $10^{28}$s ... that's $10^{21}$ years!

For example: The half life of C-14 is 5730 years.




- $\frac{1}{2}$ If we start with 100 atoms, after 5730 years there would only be 50 atoms of C-14
- $\frac{1}{4}$ If we wait another 5730 years (or 11, 460 years total), there would be 25 atoms of C-14
- $\frac{1}{8}$ After 17, 980 years there would about 12 or 13 atoms of C-14

Note that half-life refers to the point when ~50% of the atoms will have transformed into a new element.

- only meaningful when applied to a large number of nuclei
- it cannot tell us when any particular nucleus will decay

## Half-Life Calculations

$$A = A_o \cdot \left(\frac{1}{2}\right)^{t/h}$$

- $t$ ← time
- $h$ ← half-life
- $A$ ← final amount
- $A_o$ ← initial amount
- $\left(\frac{1}{2}\right)$ ← This is the split factor... After a half-life, one pound becomes ½ pound.

Example: Marie Curie had a 765g sample of Po-210 (half life = 138d) in a box. After 3.8 years, she goes to the box to get her polonium. Determine how much polonium-210 is left.

Solution:

xample: You have 75g of lead-212. If it has a half life of 10.6h, determine how long it will take until only 9.3g remains.

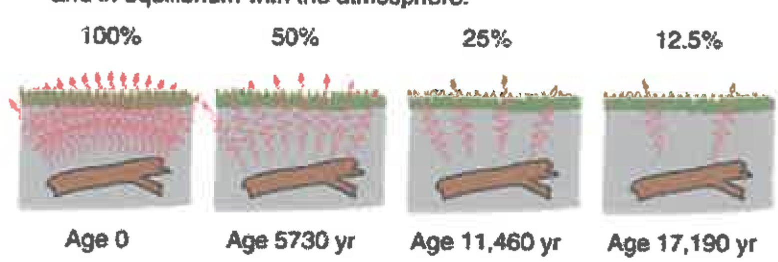
Solution:

## Radio-dating

The age of old materials, such as rocks, can be found by looking at the percentage of radioactive isotopes present.

For example, organic materials can be dated using the amount of C-14 present in the sample and the C-14 half-life. C-14 is found in all living things. When an organism dies it stops taking in any more carbon so as time passes, the amount of C-14 decreases.

Measurement of the beta decay activity of a buried piece of wood provides a measurement of the time elapsed since it was living and in equilibrium with the atmosphere.



**Example**: Marie Curie had a 765g sample of polonium-210 (half life = 138d) in a box. After 3.8 years of refining radium, she goes to the box to get her polonium. Determine how much polonium-210 is in the box.

**Solution:**

Given: $A_0 = 765g$
$t = 3.8y$
$h = 138d$

Need: A

① convert time to days (match half-live units)

$$3.8y \times \frac{365d}{y} = 1387d$$

② find A

$$A = A_0 \cdot \left(\tfrac{1}{2}\right)^{t/h}$$
$$= 765g \cdot \left(\tfrac{1}{2}\right)^{1387d/138d}$$
$$= 0.7213g$$
$$\boxed{A = 0.72g}$$

* all mass still present just as other elements *

**Example**: You have 75g of lead-212. If it has a half life of 10.6h, determine how long it will take until only 9.3g remains.

**Solution:**

Given: $A_0 = 75g$
$h = 10.6h$
$A = 9.3g$

Need: t

① try "guessing" or ÷ by 2 until reaching the approx. A

② $A = A_0 \cdot (1/2)^{t/h}$

$$9.3g = 75g \cdot (1/2)^{t/10.6h}$$
$$\frac{9.3g}{75g} = (1/2)^{t/10.6h}$$

* now take log of each side *

$$\log\left(\frac{9.3g}{75g}\right) = \log(1/2)^{t/10.6h}$$

where $\boxed{\log x^y = y \log x}$

$$\log\left(\frac{9.3g}{75g}\right) = \frac{t}{10.6h}\left(\log(1/2)\right)$$
$$\frac{t}{10.6h} = \frac{\log(9.3/75)}{\log(1/2)}$$
$$t = \frac{\log(9.3/75)}{\log(1/2)} \times 10.6h$$
$$= 31.92h$$
$$t = 32h$$