Radioactivity

• In 1896, Henri Becquerel, while investigating fluorescence in uranium salts, accidentally discovered radioactivity.

• Work by Marie Curie, her husband, and others showed that radioactivity was the result of the decay or disintegration of unstable nuclei.

• Up to that point, atoms were believed to be forever indestructible.
Radiation

Types

• Alpha particles are helium nuclei (2 protons, 2 neutrons):

• Beta particles are speedy electrons:

• Gamma radiation consists of photons (electromagnetic waves with a wavelength shorter than that of visible light):
Example 1: Alpha Decay

\[ \frac{A}{Z} X \rightarrow \frac{A-4}{Z-2} Y + \frac{4}{2} \text{He} \]

- X is called the parent nucleus and Y the daughter nucleus.
- Example is Radium, decaying into Radon and an alpha particle.
- In order for alpha emission to occur, mass of the parent must be greater than combined mass of daughter and alpha particle.
  - excess mass converted into kinetic energy, most of which is carried by the alpha particle.

Before decay:

\[ ^{226}_{88}\text{Ra} \]

\[ KE_{\text{Ra}} = 0 \]

\[ p_{\text{Ra}} = 0 \]

After decay:

\[ ^{222}_{86}\text{Rn} \]

\[ KE_{\text{Rn}} \]

\[ p_{\text{Rn}} \]

\[ KE_{\alpha} \]

\[ p_{\alpha} \]
Example 2: Beta Decay

Example
A neutron turns into a proton emitting an electron

\[ ^{1}_{0}n \rightarrow ^{1}_{1}p + e^{-} \]
Half-life

If a radioactive sample contains N radioactive nuclei at some instant, the number of nuclei that decay in a time $\Delta t$ is proportional to N:

- $\Delta N/\Delta t \sim N$
- $\Delta N = -\lambda N \Delta t$
- where $\lambda$ is a decay constant

$R = |\Delta N/\Delta t| = \lambda N$
- rate of which atoms decay

$N = N_0 e^{-\lambda t}$

$T_{1/2}$ (half-life) is time it takes for half of sample to decay

Decay constants vary greatly for different radioactive decays and thus so do half-lives.
Radioactive Dating

We can often use radioactivity to measure the age of an object. Consider $^{14}\text{C}$ dating.

- cosmic ray interactions in the upper atmosphere cause nuclear interactions that produce $^{14}\text{C}$ from $^{14}\text{N}$
- living organisms breathe in carbon dioxide that has both $^{12}\text{C}$ and the radioactive $^{14}\text{C}$
- so all living creatures have the same ratio of $^{14}\text{C}$ to $^{12}\text{C}$ ($\sim1.3\times10^{-12}$)
- when the organism dies, however, it no longer absorbs carbon dioxide from the air, and so the ratio of $^{14}\text{C}$ to $^{12}\text{C}$ decreases

\[
^{14}\text{C} \rightarrow ^{14}\text{N} + \text{e}^- + \nu
\]

The greater the rate, the more recently the organism died.
Carbon-14 Dating

Works on samples from about 1 to 25,000 years old.

→ Why not longer?
→ The half-life of $^{14}\text{C}$ is 5730 years. After about 5 half-lives too small a fraction of $^{14}\text{C}$ is left ($2^5=32$ so $<1/32$nd left).

Example:
Dead Sea Scrolls date to 1950 years ago
Geiger Counter

- Device used to detect ionizing radiation
- Consists of a tube filled with Argon gas with a central wire at a high voltage
- When a charged particle passes through the gas, it knocks electrons off of the Argon atoms
- The electrons are attracted to the positively charged central wire and are accelerated towards it
- They acquire enough energy to knock more electrons off of Argon atoms
- The result is an avalanche of electrons hitting the central wire which creates an electronic signal