AP Physics - Modern Physics - Half Life and Nuclear Reactions

Half-Life

In radioactive decay, every atom in a given sample does not decay simultaneously. Rather, individual atoms decay randomly, but the amount of time required for a certain percentage to decay is constant. The amount of time it takes for one half of the atoms to decay is called the "half-life." If you start with 1 kg of an element with a half-life of 3 hours, after 12 hours (4x half life), you will have $\frac{1 kg}{4^2} = \frac{1}{16}$ kg of the element remaining.

Mass Defect/Binding Energy

In a nuclear reaction, unlike a chemical reaction, the mass of the products is less than the mass of the reactants. This mass difference is called "mass defect." The mass defect is due to the fact that, in forming the new nuclei, some mass is converted into energy. This energy is called "binding energy." Mass defect and binding energy are related by relativity as

$$\text{Binding Energy} = (\text{mass defect}) \times (\text{speed of light})^2$$

We can use mass defect to predict whether a given nuclear decay will occur spontaneously:

Decay if: $M_{parent} > M_{daughters}$

$M_p > (M_x + M_y)$

Stable if: $M_{daughters} \geq M_{parent}$

Fission

Large, unstable nuclei will spontaneously split into two or more pieces in a process called "fission". Some elements, such as ^{235}U, take a very long time to spontaneously decay, but if a neutron is added to the nucleus to become ^{236}U, the resulting nucleus will decay very quickly to form two daughter particles (X and Y), several free neutrons, and gamma-ray photons(γ). Note that X and Y could be any element smaller than $^{235}_{92}U$, but they will split according to a probability distribution function.

$$^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{236}_{92}U^{*} \longrightarrow X + Y + \text{neutrons} + \gamma\text{'s}$$

Fusion

Two small nuclei, such as $^{2}_{1}H$, when fused together, will result in a nucleus which is less massive than the two nuclei from which it was formed. This mass defect results in a tremendous amount of energy released.

Fusion Examples

$$^{1}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + \gamma$$

$$^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{4}_{2}He + \gamma$$

$$^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{1}H + {}^{1}_{1}H + \gamma$$