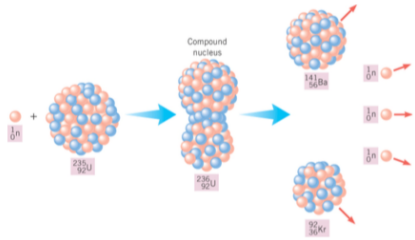
Nuclear Processes

Nuclear Fission: A heavy nucleus splits into two smaller nuclei of roughly equal mass with the release of energy.

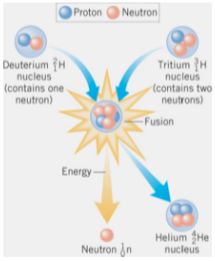


Important occurrences of fission:

Nuclear power plants
Nuclear weapons

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n + \text{energy}$$

Nuclear Fusion: Two light nuclei combine to form a more massive nucleus with the release of energy.



$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + \text{energy}$$

Important occurrence of fusion:

main source of Sun's energy

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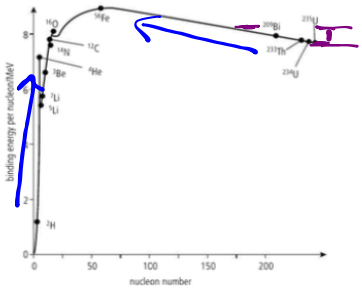
1. Mark and label fission and fusion processes on the accompanying plot of binding energy per nucleon.



2. Fission and fusion reactions . . .

a) release energy

b) put products in a lower energy state

c) increase binding energy per nucleon

d) total rest mass of products is less than total rest mass of reactants

Fission/fusion reactions: $\mathbf{m_{reactants} = m_{products} + \Delta m}$

3. Energy is usually released in the form of . . . kinetic energy of the products and photons

4. Where does this energy come from? Rest mass of nucleons

5. One possible fission reaction for uranium-235 is shown below.

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{236}_{92}U \rightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3^{1}_{0}n + \text{photons}$$

Rest mass of neutron = 1.0087 u
Rest mass of uranium-235 = 235.0439 u
Rest mass of barium-144 = 143.9229 u
Rest mass of krypton-89 = 88.9178 u

a) Determine how much energy is released in this reaction.

$\Delta m = .1858\,u$

$1u = 931.5\,MeV/c^2$

$\Delta E = 173.1\,MeV$ $\quad \frac{BE}{nucleon} = \frac{173.1\,MeV}{236} \sim .7\,MeV$

b) Based on your answer to part (a), how much energy is released from the fissioning of one kilogram of uranium-235?

$n = \frac{N}{N_A}$

$\left(1\,kg \cdot \frac{1\,mol}{.235\,kg} \cdot 6.02\times10^{23}\,mol^{-1}\right) 173.1\,MeV$

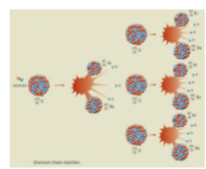
$\approx 4.4\times10^{26}\,MeV$

c) What are the characteristics of the initial neutron that bombards the uranium-235 nucleus for fission to occur?

Must be a "thermal" neutron (low-energy, slow) to have a high probability of inducing fission - If neutron is too fast/too high-energy, fission is not likely

d) What is significant about the reaction producing three neutrons?

These can induce further fissions which may start a chain reaction if there is a sufficient mass (critical mass) of uranium to sustain it



6. One possible fusion reaction is shown below.

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n$$

Rest mass of hydrogen-2 = 2.0141 u
Rest mass of helium-3 = 3.0161 u
Rest mass of neutron = 1.0086 u

a) Determine how much energy is released in this reaction.

$2(2.0141u) - (3.0161u + 1.0086u)$

$= .0035u \times 931.5\,MeV/c^2$

$\Delta m = 3.260\,MeV/c^2$

$\Delta E = 3.260\,MeV$

b) Based on your answer to part (a), how many joules of energy will be released if 5.0 grams of hydrogen-2 fuse in this manner?

$$5g \cdot \frac{1\,mol}{2g} \cdot 6.02\times10^{23}\,mol^{-1} \cdot 3.260\,MeV$$
$$= 4.906\times10^{24}\,MeV$$

c) In order for these two positively charged nuclei to fuse together, they must have …

sufficient kinetic energy to overcome the Coulomb repulsion between them.

This requires very high temperature plasmas

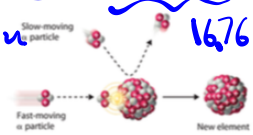
d) The major reason that fusion power plants are not yet in use today is . . .

Magnetic confinement technologies for the high-temperature plasma are not yet feasible

Artificial (Induced) Transmutation: A nucleus is bombarded with a nucleon, an alpha particle or another small nucleus, resulting in a nuclide with a different proton number (a different element).

For example, in 1919, Ernest Rutherford discovered that when nitrogen gas is bombarded with alpha particles, oxygen and protons are produced.

$$\underbrace{{}^{14}_{7}N + {}^{4}_{2}He}_{16{,}767.7u} \rightarrow \underbrace{{}^{17}_{8}O + {}^{1}_{1}H}_{16{,}768.9u}$$



Importance: artificial radioactive isotopes are produced which may be used in medical tests and therapies

Requirement: the bombarding particle must have sufficient kinetic energy to overcome the Coulomb repulsion

Artificial transmutation reactions: $m_{reactants} + \Delta m = m_{products}$

7. Neutron bombardment of lithium can produce the radioactive isotope of hydrogen known as tritium.

Rest mass of lithium-7 nucleus	=7.0160u
Rest mass of tritium nucleus	=3.0161u
Rest mass of He nucleus	=4.0026u

$$\underbrace{{}^{7}_{3}Li + \underbrace{{}^{1}_{0}n}_{\text{tenzsgl}}}_{m} \rightarrow \underbrace{{}^{3}_{1}H + {}^{4}_{2}He + {}^{1}_{0}n}_{m}$$

Determine the minimum initial kinetic energy the bombarding neutron must have to initiate this artificial transmutation.

$m - m = .0027u$ $\Delta E = 2.5\,MeV$