LESSON 5.2.3

Nuclear Fission, Fusion and Energy Release

Both processes can release energy when the products are more tightly bound overall. The total rest mass falls; total energy is conserved.

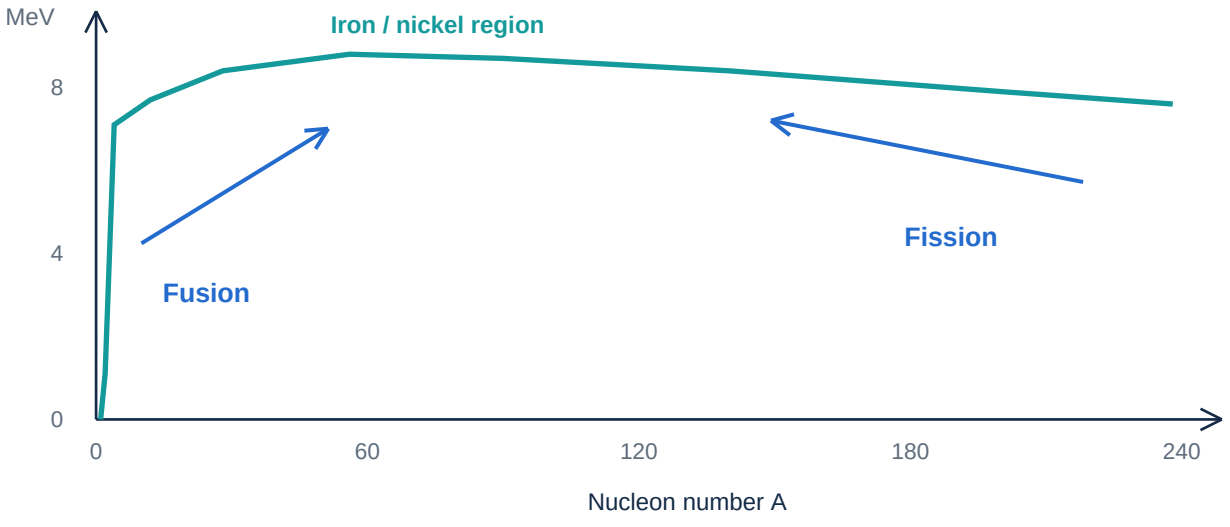
BINDING ENERGY IS ENERGY NEEDED TO SEPARATE A NUCLEUS

It is the energy required to separate a nucleus completely into free protons and neutrons. Its mass is lower than their total free mass: this difference is the mass deficit.

$$E_b = \Delta mc^2 \qquad \Delta m = Zm_p + (A - Z)m_n - m_{nucleus}$$

BINDING ENERGY PER NUCLEON

Binding energy per nucleon = total binding energy / A. Schematic trend.



Light nuclei can release energy by joining; heavy nuclei can release energy by splitting. Both move toward higher binding energy per nucleon, not necessarily all the way to iron.

For a numerical energy balance, compare TOTAL binding energies, including every product. A free neutron has zero nuclear binding energy.

1 Two routes to energy release

Nuclear equations conserve total nucleon number A and total electric charge. Rest mass alone is not conserved: include kinetic energy and radiation.

A. FISSION: A HEAVY NUCLEUS SPLITS

A uranium-235 nucleus can absorb a neutron, forming an excited uranium-236 nucleus that splits into two fragments and emits neutrons. One possible channel is:

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \longrightarrow ^{141}_{56}\mathrm{Ba} + ^{92}_{36}\mathrm{Kr} + 3\,^{1}_{0}\mathrm{n}$$

A: 235 + 1 = 141 + 92 + 3 | Z: 92 = 56 + 36

The fragments gain kinetic energy; neutrons and photons also carry energy. Fragment pairs vary, and many fragments undergo later radioactive decay.

Emitted neutrons may cause further fissions: a chain reaction. A steady reactor balances the neutron population so the average fission rate remains constant.

B. FUSION: LIGHT NUCLEI COMBINE

Deuterium and tritium are hydrogen isotopes. Their reaction produces a helium-4 nucleus and a neutron, with about 17.6 MeV released per reaction.

$$^{2}_{1}\mathrm{H} + ^{3}_{1}\mathrm{H} \longrightarrow ^{4}_{2}\mathrm{He} + ^{1}_{0}\mathrm{n}$$

A: 2 + 3 = 4 + 1 | Z: 1 + 1 = 2 + 0

Positive nuclei repel electrically. Very high temperature raises their kinetic energies, increasing the chance of getting close enough for short-range nuclear attraction; quantum tunnelling also helps.

High particle density increases collision frequency. Sustained fusion also needs confinement long enough for sufficient reactions before energy escapes.

Fusion in stars is powered mainly by hydrogen-to-helium reaction chains, not by a bulk deuterium-tritium fuel mixture. Different fusion settings balance density, temperature and confinement differently.

Energy release depends on the mass difference, not just on splitting or joining.

2 From missing mass to released energy

For a reaction, subtract the total final rest mass from the total initial rest mass. Include emitted particles such as neutrons in the final total.

$$Q = (m_{initial} - m_{final})c^2 = \Delta mc^2$$

Q > 0 means energy is released. The same energy equals total product binding energy minus total reactant binding energy when the proton and neutron totals are unchanged.

WORKED EXAMPLE: A D-T REACTION HAS MASS LOSS 0.0189 u

Use the rounded data below; keep extra digits until the final result.

$$1\ u = 1.661 \times 10^{-27}\ kg \qquad c = 3.00 \times 10^{8}\ m\ s^{-1}$$

1. Convert the mass loss to kilograms.

$$\Delta m = 0.0189 \times 1.661 \times 10^{-27} = 3.13929 \times 10^{-29}\ kg$$

2. Multiply by the square of the speed of light.

$$Q = (3.13929 \times 10^{-29})(3.00 \times 10^{8})^2$$

$$Q = 2.83 \times 10^{-12}\ J \text{ per reaction}$$

3. Convert the unrounded joule value to MeV.

$$1\ MeV = 1.602 \times 10^{-13}\ J;\ \text{therefore } Q = 17.6\ MeV$$

MASS BOOKKEEPING

Do not mix bare nuclear masses with neutral atomic masses. Atomic masses work directly here because the same total number of electrons appears on each side.

ENERGY BOOKKEEPING

Higher product binding energy means lower final rest mass. It does not mean energy must be supplied. Separating a nucleus into free nucleons does require energy.

For many reactions: total energy = number of reactions × Q.

Source alignment: Pearson IAL Physics, p. 34, points 133-136 and 139.

Further reading: DOE Nuclear Fission / Fundamentals Handbook; UKAEA Fusion.

Course lesson numbering. Next: 5.3.1 Simple harmonic motion.