

7.3 Nuclear Reactions, fission + fusion

Artificial transmutation

- the name given to the process of transmutation when it is conducted artificially, such as in a laboratory.

Example The transmutation of O^{18} into F^{18}

Fluorine-18 is a short-lived radioisotope used as a tracer in medicine (i.e. PET \rightarrow positron emission tomography)



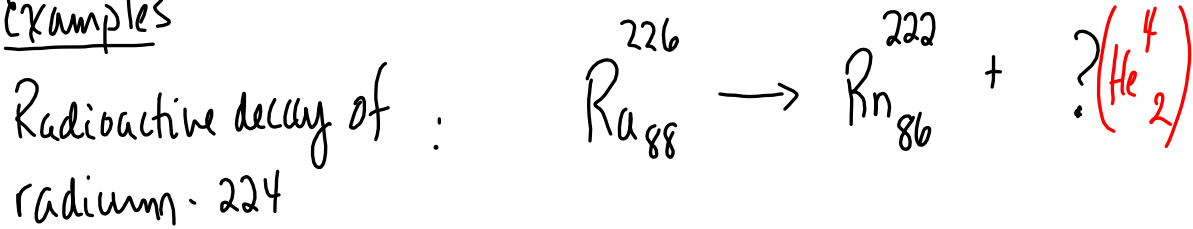
radioisotope \Rightarrow radioactive isotope \rightarrow emits radiation during decay to become more stable

\hookrightarrow used in medical diagnosis, treatment + research.

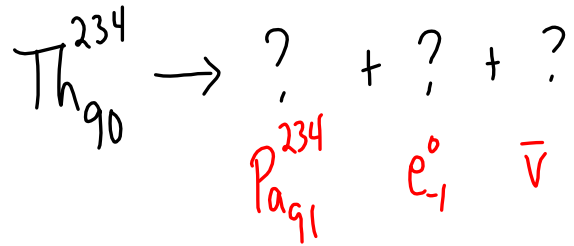
Conservation Laws in nuclear reactions

\rightarrow Charge - the total proton number (or atomic number) Z must be the same on both sides of the reaction.

\rightarrow Number of nucleons - the number of nucleons (or mass number) A must be the same on both sides of the reaction.

Examples

Thorium-234 is a beta emitter and decays into the element protactinium.



You may get questions combining TOPIC2 (Mechanics) and TOPIC7. Recall:

kinetic energy $E_k = \frac{1}{2}mv^2$

momentum $p = mv$

$$p = \sqrt{2mE_k}$$

data booklet. $\rightarrow \left(E_k = \frac{p^2}{2m} \right)$

Unified atomic mass unit:

One unified atomic mass unit (μ) is defined as one-twelfth of the mass of a single neutral atom of the isotope carbon-12 at rest* and in its ground state*.

$$1 \mu = \frac{1}{12} \text{ mass of } \text{C}^{12} \text{ atom}$$

* must be at rest because the mass of a body depends on the speed of the observer.

* mass is related to energy

Carbon-12 has 12 nucleons within its nucleus (6p + 6n)

The mass of C^{12} atom = 12μ (exactly)

mass of O^{16} atom $\approx 16\mu$ (approximately)

Mg^{24} atom $\approx 24\mu$ (approx)

H_2O molecule $\approx 18\mu$ (approx)

Recall from TOPIC 3:

molar mass \rightarrow its molecular mass expressed in grams.

Avogadro's constant (N_A) = $6.02 \times 10^{23} \text{ mol}^{-1}$

So there are N_A atoms in 12g of C^{12}
 16g of O^{16}

and N_A molecules in 18g of H_2O .
 32g of O_2

Unified atomic mass unit and the kilogram:

1 mole of C^{12} has a mass of 12g

1 atom of C^{12} has a mass of $\frac{12\text{g}}{6.02 \times 10^{23}} = 1.99 \times 10^{-26} \text{ kg}$

$$1 \mu = \frac{1}{12} (1.99 \times 10^{-26} \text{ kg})$$

$$1 \mu = 1.66 \times 10^{-27} \text{ kg}$$

(Data booklet $1 \mu = 1.661 \times 10^{-27} \text{ kg}$)

Relation between the unified atomic mass unit and the energy
 { unit MeV

Recall: $E = mc^2$ (mass & energy equivalence)

$$\begin{aligned} 1u &= 1.661 \times 10^{-27} \text{ kg} \\ &= 1.661 \times 10^{-27} \text{ kg} (3.0 \times 10^8 \text{ m/s})^2 \\ &= 1.495 \times 10^{-10} \text{ J} \\ &= 9.31 \times 10^8 \text{ eV} \quad \downarrow \div 1.6 \times 10^{-19} \text{ J eV}^{-1} \\ &= 931 \text{ MeV} \end{aligned}$$

The units MeV c^{-2} and GeV c^{-2} for mass:

$$E = mc^2$$

$$m = \frac{E}{c^2} \leftarrow \frac{\text{MeV}}{c^2} \text{ or } \frac{\text{MeV c}^{-2}}{\text{common units for particle mass}}$$

units: $\rightarrow \frac{\text{J}}{\text{m}^2/\text{s}^2}$

~~$\frac{\text{kg m}^2/\text{s}^2}{\text{m}^2/\text{s}^2}$~~

Example

Determine the energy equivalent to the mass of an alpha particle in units of GeV c^{-2} . ($m_\alpha = 6.67 \times 10^{-27} \text{ kg}$)

$$E = mc^2$$

$$E = (6.67 \times 10^{-27} \text{ kg}) (3.00 \times 10^8 \text{ m/s})^2$$

$$E = 6.003 \times 10^{-10} \text{ J} \left(\frac{1 \text{ eV}}{1.6 \times 10^{-19} \text{ J}} \right)$$

$$E = 3.75 \times 10^9 \text{ eV}$$

$$E = 3.75 \text{ GeV c}^{-2}$$

Example

Determine the energy equivalent to the mass of an electron. Give your answer in MeV c^{-2} . ($m_e = 9.11 \times 10^{-31} \text{ kg}$)

$$(0.511 \text{ MeV c}^{-2})$$