

Solutions

Original-task marking: M1 method, A1 accuracy, B1 reasoning.

2.1 Eight protons, ten neutrons. Binding energy is the total energy to separate the nucleus into free nucleons; per-nucleon binding energy divides that total by A.

2.2 Convert mass deficit before applying rest energy.

$$E_b = \Delta mc_0^2 = (0.098 \text{ u})(1.66 \times 10^{-27} \text{ kg/u})(3.00 \times 10^8 \text{ m s}^{-1})^2 = 1.46 \times 10^{-11} \text{ J}$$

Total energy. Divide by nucleon count and energy conversion.

$$\frac{E_b}{A} = \frac{1.46412 \times 10^{-11} \text{ J}}{12(1.60 \times 10^{-13} \text{ J/MeV})} = 7.63 \text{ MeV per nucleon}$$

Result.

2.3

$$\frac{E_{b,X}}{A_X} = \frac{150 \text{ MeV}}{20} = 7.5 \text{ MeV per nucleon}$$

X.

$$\frac{E_{b,Y}}{A_Y} = \frac{510 \text{ MeV}}{60} = 8.5 \text{ MeV per nucleon}$$

Y. Y has greater binding per nucleon, hence more tightly bound nucleons.

3.1 Compare total binding energies, not just their vertical difference.

$$Q = 2A_p\epsilon_p - A_r\epsilon_r = 2(120)(8.5 \text{ MeV}) - 240(7.6 \text{ MeV}) = 216 \text{ MeV}$$

Energy.

$$Q_J = Q_{MeV}(1.60 \times 10^{-13} \text{ J/MeV}) = (216 \text{ MeV})(1.60 \times 10^{-13} \text{ J/MeV}) = 3.46 \times 10^{-11} \text{ J}$$

Conversion. Products have greater total binding and smaller total rest mass; the decrease becomes kinetic/radiation energy while total energy is conserved.

3.2 The binding-per-nucleon curve peaks near iron/nickel. Appropriate light-nucleus fusion moves towards greater binding per nucleon; heavy-nucleus fission can do the same from the other side. Greater total product binding means lower product rest energy and released energy. High temperature gives nuclei enough kinetic energy for close approach despite electrical repulsion; density/confinement gives sufficient close encounters and retains the reacting material.

3.3 Find total reactant-minus-product mass.

$$\Delta m = m_r - m_p = (5.030 - 5.010) \text{ u} = 0.020 \text{ u}$$

$$Q = \Delta mc_0^2 = (0.020 \text{ u})(1.66 \times 10^{-27} \text{ kg/u})(3.00 \times 10^8 \text{ m s}^{-1})^2 = 2.99 \times 10^{-12} \text{ J}$$

Energy. Power is energy per reaction times reaction rate.

$$\dot{N} = \frac{P}{Q} = \frac{1.0 \times 10^6 \text{ J s}^{-1}}{2.988 \times 10^{-12} \text{ J}} = 3.35 \times 10^{17} \text{ s}^{-1}$$

Rate and unit. Energy per complete reaction is needed; a per-nucleon difference omits the participating nucleon count.