

Page 485 Test yourself on prior knowledge

- Both isotopes have 8 protons in the nucleus and 8 electrons orbiting the nucleus. $^{17}_8\text{O}$ has 9 neutrons in the nucleus; $^{16}_8\text{O}$ has 8 neutrons in the nucleus.
- Nuclear fusion: e.g. of hydrogen and helium in stars.
Nuclear fission: e.g. controlled fission of uranium and plutonium in nuclear power stations, uncontrolled fission in nuclear bombs.
- Radius depends on $A^{1/3}$ so the radius of zinc is approximately 4/5 the radius of iodine because $(64^{1/3}) = 4$ and $(127)^{1/3} \approx 5$.
- $X = 14$
 $Y = 7$
- Number of protons is 92
number of neutrons is $238 - 92 = 146$
- $2.34 \text{ MeV} = 2.34 \times 10^6 \text{ eV} \times 1.6 \times 10^{-19} \text{ C} = 3.74 \times 10^{-13} \text{ J}$

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- The mass of 6 protons + 6 neutrons is greater than the mass of a C-12 nucleus; the mass defect corresponds to the binding energy needed to separate the nucleus into its nucleons, or the energy released when the nucleus forms
 - a) Mass defect, in u, $= (Zm_p + Nm_n) - M_{\text{nucleus}}$

$$= (26 \times 1.00728 \text{ u}) + (30 \times 1.00867 \text{ u}) - 55.935 \text{ u}$$

$$= 56.449 \text{ u} - 55.935 \text{ u}$$

$$= 0.514 \text{ u}$$

b) The binding energy released on formation is

$$0.514 \text{ u} \times 931.5 \text{ MeV u}^{-1} = 478.8 \text{ MeV}$$

c) The binding energy per nucleon is $478.8 \text{ MeV}/56 = 8.55 \text{ MeV}$
 - Using the value for the mass of an alpha particle given in Table 26.1 on page 487,
Mass difference for the nuclei = initial mass – final mass
- $$= 238.0508 \text{ u} - (234.0426 \text{ u} + 4.00151 \text{ u})$$
- $$= 6.69 \times 10^{-3} \text{ u (to 3 sf)}$$
- Difference in binding energy for the nuclei $= 931.5 \times 6.69 \times 10^{-3}$
- $$= 6.23 \text{ MeV}$$
- (The emitted alpha particle has approximately this amount of kinetic energy.)

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- 4 Initial mass = $2 \times 3.343 \times 10^{-27} \text{ kg}$
= $6.686 \times 10^{-27} \text{ kg}$
Final mass = $5.006 \times 10^{-27} \text{ kg} + 1.675 \times 10^{-27} \text{ kg}$
= $6.681 \times 10^{-27} \text{ kg}$
Mass difference = $0.005 \times 10^{-27} \text{ kg}$
Energy released = $0.005 \times 10^{-27} \text{ kg} \times (3 \times 10^8 \text{ ms}^{-1})^2 = 4.5 \times 10^{-13} \text{ J}$
- 5 The attractive strong force is involved in nuclear fusion and is very short range, so nuclei must be close together. The electrostatic force is repulsive and repels nuclei. At high enough temperatures, nuclei have enough kinetic energy to overcome the electrostatic repulsive forces.
- 6 Before: $2 \times 5.006 \times 10^{-27} \text{ kg} = 10.012 \times 10^{-27} \text{ kg}$
After: $6.645 \times 10^{-27} \text{ kg} + 2 \times 1.673 \times 10^{-27} \text{ kg} = 9.991 \times 10^{-27} \text{ kg}$
Mass difference is $2.1 \times 10^{-29} \text{ kg}$
Energy released = $2.1 \times 10^{-29} \text{ kg} \times (3 \times 10^8 \text{ ms}^{-1})^2 = 1.89 \times 10^{-12} \text{ J}$
= $(1.89 \times 10^{-12} \div 1.6 \times 10^{-19}) \text{ eV} = 11.8 \text{ MeV}$
The fusion of helium releases more energy.

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- 7 a) Control rods are inserted into the reactor core to absorb neutrons which reduces the number of fission reactions.
b) Spent fuel rods are highly radioactive and are handled remotely using automated systems such as robotic arms.
c) Fast neutrons passing through the moderator collide elastically with the moderator atoms. The neutrons slow down because they transfer energy to the moderator atoms.
- 8 a) Number of reactions per second: $6 \times 10^9 \text{ Js}^{-1} / 3.2 \times 10^{-11} \text{ J} = 1.875 \times 10^{20}$
Number of reactions per day = $24 \text{ h} \times 3600 \text{ s} \times 1.875 \times 10^{20} \text{ reaction/s} = 1.62 \times 10^{25}$
b) The power station is not 100% efficient – e.g. some energy heats external water used to condense the steam etc.
- 9 a) Power output of the reactor = $840 \text{ MW} / 0.35$
= 2400 MW
b) Mass of U-235 available = $(1700 \text{ rods} \times 14 \text{ kg} \times 3 \%)$
= 714 kg

c) $E = mc^2$

so mass changed to energy per fission reaction = E/c^2

$$= (215 \text{ MeV} \times 1.6 \times 10^{-19} \text{ C}) / (3 \times 10^8 \text{ ms}^{-1})^2$$

$$= 3.8 \times 10^{-28} \text{ kg}$$

d) Each fission reaction produces $215 \times 10^6 \text{ eV} \times 1.6 \times 10^{-19} \text{ C} = 3.44 \times 10^{-11} \text{ J}$

The number of atoms per kg of U-235 is $6 \times 10^{23} \times (1000/238) = 2.52 \times 10^{24}$

So the total number of nuclei available for fission is:

$$N = 714 \times 2.52 \times 10^{24} = 1.8 \times 10^{27}$$

The total energy available is:

$$E = 1.8 \times 10^{27} \times 3.44 \times 10^{-11} \text{ J}$$

$$= 6.2 \times 10^{16} \text{ J}$$

Since $P = E/t$, the time the fuel lasts is:

$$t = E/P = 6.2 \times 10^{16} \text{ J} \div 2.4 \times 10^9 \text{ W}$$

$$= 2.6 \times 10^7 \text{ s}$$

$$= 0.8 \text{ years}$$

Pages 497–499 Practice questions

1 C

2 D

3 C

4 A

5 B

6 A

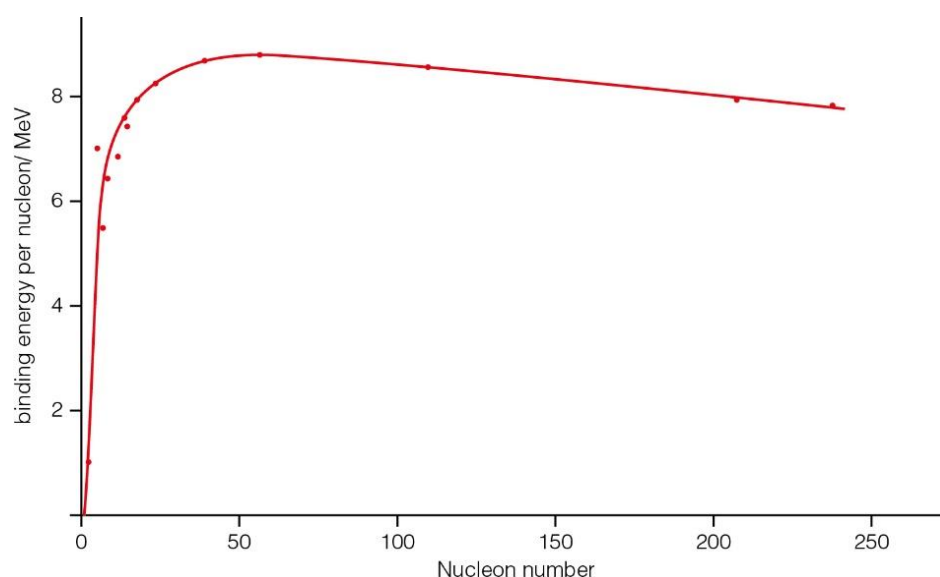
7 D

8 A

9 B

10 D

- 11 a)** [1 mark for correct y-axis scale; 1 mark for correct shape of graph; 1 mark for peak at about $A = 56$]



- b)** Nuclear reactions are more likely if they make the nucleus more stable/release energy. [1]
 The nucleus is more stable if binding energy per nucleon increases. [1]
 Binding energy/nucleon increases as nuclei heavier than $A = 56$ get lighter/undergo fission. [1]
 Binding energy/nucleon increases as nuclei lighter than $A = 56$ get heavier/undergo fusion. [1]

- 12** Any 6 points: [6]

- The fast neutrons released from a fission reaction are slowed down by elastic collisions inside the moderator
- then absorbed by a U-235 nucleus which undergoes fission.
- For constant rate of fission, only 1 neutron should be absorbed per fission reaction.
- Some are absorbed by U-238 in fuel rods
- or by a control rod
- or leave the reactor
- or are not absorbed.

- 13 a)** Mass defect is the difference in mass between the mass of separate nucleons that form an iron-56 nucleus and the mass of the iron-56 nucleus. [1]

- b)** Mass of nucleons is $(28 \times 1.00867 \text{ u}) + (28 \times 1.00728 \text{ u}) = 56.44660 \text{ u}$ [1]

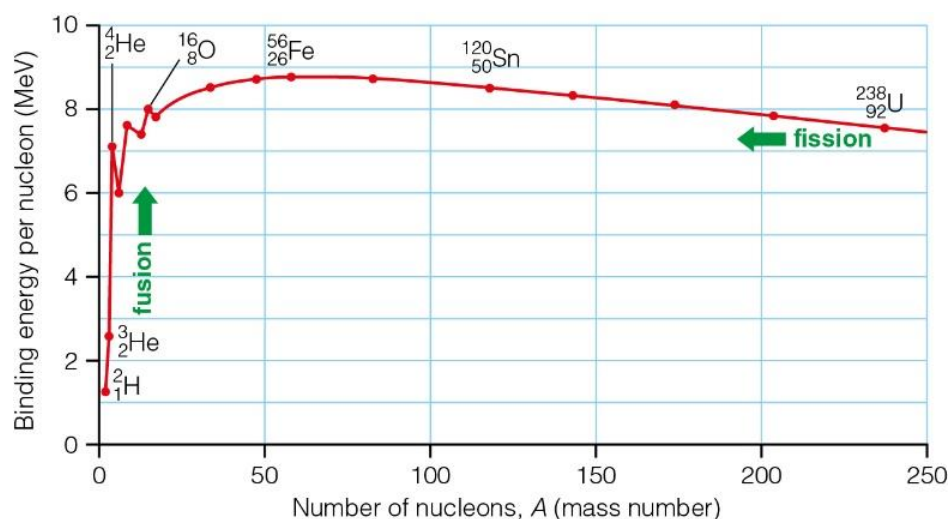
Mass defect is $56.44660 \text{ u} - 55.93493 \text{ u} = 0.51167 \text{ u}$ [1]

Binding energy = $931.5 \text{ MeV/u} \times 0.51167 \text{ u} = 476.62 \text{ MeV}$ [1]

Binding energy per nucleon = $476.62 \text{ MeV} / 56 = 8.51 \text{ MeV}$ [1]

- c)** The most commonly found isotope is the most stable. Stability increases with binding energy per nucleon. [1]
 The binding per nucleon will be lower for other Fe isotopes. [1]

14 a) [one mark for each label = 2]



- b) Very high temperatures [1]
so nuclei have enough kinetic energy to overcome electrostatic repulsion between protons in the nucleus. [1]
High density/pressure [1]
so the strong force can be involved. [1]
- c) The element with the highest binding energy per nucleon is iron. [1]
This sits on the point of the graph between the region where lighter elements undergo fusion and heavier elements undergo fission. [1]

Page 500 Stretch and challenge

15 a) Mass difference = $235.04 \text{ u} + 1.01 \text{ u} - 140.91 \text{ u} - 91.91 \text{ u} - (3 \times 1.01 \text{ u})$
= 0.20 u

b) Energy released per reaction = $0.20 \times 931.5 \text{ MeV} = 186.3 \text{ MeV}$

c) Atomic mass of uranium is $235.04 \times 10^{-3} \text{ kg}$

Number of nuclei in 10 kg of uranium is $(10 \times 6.02 \times 10^{23}) / (235.04 \times 10^{-3}) = 2.56 \times 10^{25}$

Energy released = $2.56 \times 10^{25} \times 186.3 \text{ MeV} = 4.77 \times 10^{27} \text{ MeV}$