A-Level Physics

Mass and Energy

Mark Scheme

Time available: 75 minutes
Marks available: 55 marks

1. (a) Energy required to separate the nucleus ✓
into its individual nucleons/protons and neutrons ✓
OR
Energy given out when a nucleus is formed ✓
from its individual nucleons/protons and neutrons ✓

2

(b) Statement of binding energy = (mass of nucleons) – (mass of nucleus) ✓$_1$ (which may be seen from a full equation with data)

Standing alone or contained in the binding energy equation show the total mass of $^{56}_{26}Fe$ nucleons to at least 4 sig fig. ✓$_2$

the correct binding energy converted to
MeV = 490 ± 10 (MeV) ✓$_3$

✓$_1$ condone simple numerical errors such as powers of 10 if mark comes from substituted equation.

✓$_2$ for giving data without errors to at least 4 sig figs. The two examples looked for are

$26 \times 1.673 \times 10^{-27} + 30 \times 1.675 \times 10^{-27}$ (= 9.375×10^{-26} kg)

OR

26 × 938.257 + 30 × 939.551 (52580 = MeV)

✓$_3$ answer only and no ecf.

Might see

$(9.375 \times 10^{-26} - 9.288 \times 10^{-26}) \times 931.5 / 1.661 \times 10^{-27}$

= 488 MeV

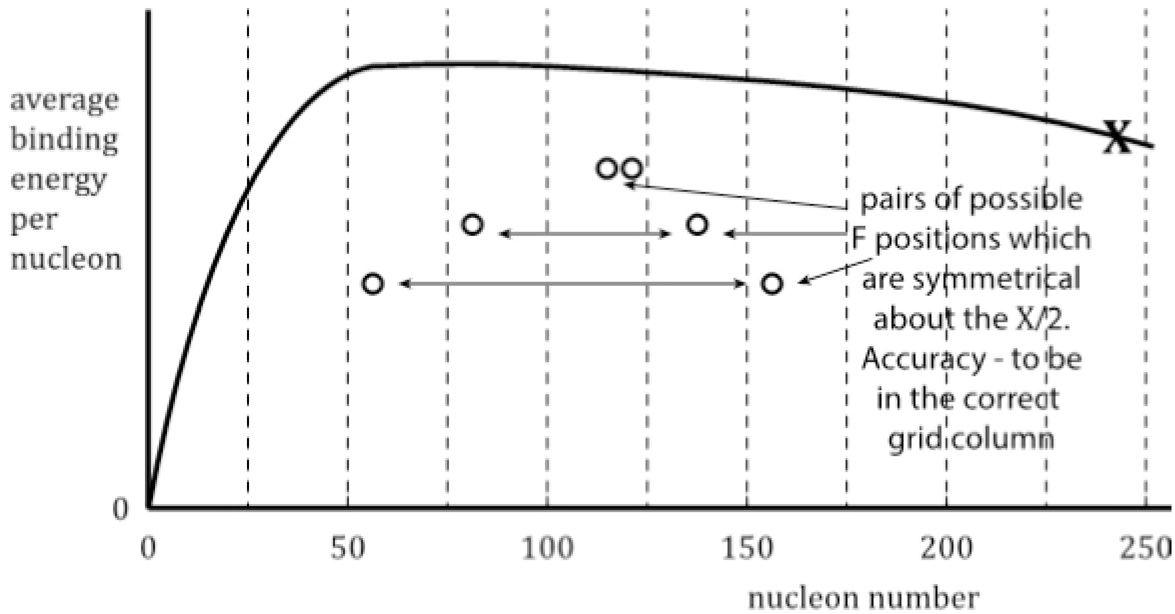
OR

$52580 - (9.288 \times 10^{-26} \times 931.5 / 1.661 \times 10^{-27})$

= 492 MeV

3

(c) Both F_1 and F_2 to be to the right of the peak and marked on the graph or x-axis ✓
F_1 and F_2 to be in the correct grid region that puts them symmetrical about half the nucleon number corresponding to **X**. ✓



*Note that an **F** position cannot have a nucleon lower than the peak. So the 3 examples shown indicate the possible range of an answer.*

2

(d) The starting point of the fission fragments is given the first mark $✓_1$

(normally the initial decay mode is) β^- $✓_2$

which occurs in neutron-rich nuclei
OR changes a neutron to a proton,
OR moves down right on Fig 2 $✓_3$

$✓_1$ fission fragments have a high N/Z ratio

OR

fission fragments are positioned above/left of the line plot in Fig 2

too many neutrons is not given a mark – high N/Z ratio or neutron rich terms must be used

$✓_2$ Mark may be given in isolation

$✓_3$ the mark could be seen on Fig 2

3

[10]

2. (a) Total Mass of nuclei is more than the mass of the fusion product ✓$_1$

✓$_1$ Alternatively the B/A of the fusion product is greater than B/A of both the starting nuclei.

Binding energy or Binding energy per nucleon increases when a nucleus is formed by fusion ✓$_2$

✓$_2$ In order to release energy, the total binding energy of the two nuclei must be less than the binding energy of the nuclide formed

2

(b) $(\Delta m = \left(\text{mass } {}^{3}_{2}\text{He} + \text{mass } {}^{17}_{8}\text{O}\right) - \text{mass } {}^{20}_{10}\text{Ne})$

✓$_1$ Δm = (3.01603 + 16.99913) – 19.99244) = 0.02272 u (must have at least 3 sig fig)

Δm = 0.02272 (u) ✓$_1$

Energy released = 3.38 to 3.40 × 10^{-12} J ✓$_2$ (allow an ecf for the conversion of units)

✓$_2$ Δm = 0.02272 × 1.661 10^{-27} kg = 0.02272 × 1.661 10^{-27} × (3.00 × 10^{8})^2 J = 3.39 × 10^{-12} J

OR

Δm = 0.02272 × 931.5 MeV

= 21.16 × 1.60 × 10^{-13}J = 3.39 × 10^{-12}J

2

(c) Mark for use of potential energy formula and identifying the 2(e) and the 8(e) ✓$_1$

✓$_1$ condone other numerical errors

$$\left(V = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r} = \frac{2 \times 8 \times \left(1.60 \times 10^{-19}\right)^2}{4\pi \times 8.85 \times 10^{-12} \times 5.1 \times 10^{-15}}\right)$$

V = 7.2(2) × 10^{-13} (J) ✓$_2$ (correct answer only)

✓$_2$ correct final answer gains both marks

2

(d) Making reference to the doubling charge which increases the gain in potential energy or force needed (to bring nuclei together) ✓$_1$ (owtte)

✓$_1$ no computation is expected

Condone increase instead of doubling

(So) the larger charge (of $^{34}_{16}S$) requires greater kinetic energy or pressure for fusion and decreases the rate of fusion ✓$_2$ (owtte)

Making reference to the larger radius/size of the sulphur nucleus compared to the oxygen nucleus

(So) the larger radius (of = $^{34}_{16}S$) (requires smaller kinetic energy or pressure for fusion) and the separation can be larger for fusion to take place so increases the rate of fusion ✓$_3$ (owtte)

✓$_3$ A full calculation is not expected, such as

$$\frac{R_S}{R_O} = \sqrt[3]{\frac{A_S}{A_O}} = \sqrt[3]{\frac{34}{17}} = \sqrt[3]{2}$$

If no marks are awarded accept number of protons for charge in mp1.

3

[9]

3. (a) To increase the probability/chance of fission (when neutron collides with fissile material/U-235)
Or
To allow the neutron to be absorbed by the fuel/U-235 ✓

Condone because thermal/slow moving neutrons are needed for fission to take place

'fuel' but not 'fuel rod' to be used in the alternative.

Reject inaccurate descriptions for example ones that imply the neutrons are undergoing fission.

1

(b) $E_{final} = (1 – 0.63)\, E_{incident}$ or $E_{final} = 0.37\, E_{incident}$ ✓$_1$
(continuing this idea, $E_1 = (1 – 0.63)\, E_0$
$E_2 = (1 – 0.63)\, E_1$ so $E_2 = (1 – 0.63)^2\, E_0$
and $E_5 = (1 – 0.63)^5\, E_0$
$E_5 = (1 – 0.63)^5 \times 2.0 \times 10^6$))
$= 1.4 \times 10^4$ eV ✓$_2$ (1.39×10^4 eV)

If no marks are scored a single mark can be given:

if the final answer that has a power of 10 error possibly by not using the M in the eV.

OR

using 0.63 rather than (1 – 0.63) in the calculation giving the answer 2(.0) × 10^5 (eV)

✓$_2$ A correct final answer gains full marks

2

(c) A link made between the change in kinetic energy or momentum to the masses of the (two) particles involved in the collision. ✓$_1$

A consistent argument that results in a statement 'as nucleon number/number of nucleons in the nucleus increases more collisions are required. ✓$_2$

✓$_1$ Ref. to mass is needed.

{Essence of marking point: The mass determines how much KE/momentum is lost}

✓$_2$ Ref to nucleon number or equivalent needed but mass is not.

{Essence of marking point: If N is high then not much KE is lost so more collisions are needed}

An example of an argument could be:

More (kinetic) energy is lost when the mass of the moderator atom/nucleus is closer to the mass of the neutron

So the number of collisions needed increases with nucleon number

2

(d) Mass difference

$= (\text{mass}_U + \text{mass}_n) - (\text{mass}_{Xe} + \text{mass}_{Sr} + 4\ \text{mass}_n)$

$= (235.044 + 1.0087) - (141.930 + 89.908 + 4 \times 1.0087)$ ✓$_1$

$= 0.180$ u ✓$_2$ {if no unit present take u as the default unit}

$(= 0.180 \times 931.5)$

$= 168$ (MeV) ✓$_3$

✓$_1$ Mark for word equation or substitution, one neutron may be cancelled from both parts of the subtraction. Condone any simple slip in transferring the numbers.

Also the mark can be awarded for giving or comparing the mass on the LHS with the RHS.

✓$_2$ Only allow correct answer.

✓$_3$ This mark can stand alone for the conversion of any number of u converted to MeV. 2 sig figs is acceptable.

The conversion mark can come from any part of this question not just the final line.

{1 kg = 6.02×10^{26}}

A correct answer gains all 3 marks.

3

(e) 1. (Small amounts of fossil fuel used) so little greenhouse gas emissions/less global warming/less CO_2/less climate change. {not no greenhouse gas}

2. (Less fossil fuel used) so cleaner air.

3. Small amounts of fuel consumed to get the same/large amount of power/energy.

4. Nuclear power can be produced continuously{condone use of constant} (whereas renewables are dependent on sunlight/wind etc).

5. Some (but not all) nuclear power stations can adjust their output quickly.

6. Benefit of producing medical isotopes.

✓ ✓ ✓ any three points

Just one of the examples may be from the following:

At present nuclear fuel is obtained from stable allied countries (as opposed to oil/gas).

Facilitates nuclear weapon production.

(Less fuel used) so less transportation needed.

Examples of rejected ideas because they are incomplete or wrong:

Produces more energy.

There is more uranium than fossil fuel.

Damages the environment less.

Provides jobs.

More efficient than others.

Reference to cost.

It's a renewable source.

3

[11]

4. (a) (using mass defect = $\Delta m = Z\, m_p + N\, m_n - M_{Co}$)

$\Delta m = 27 \times 1.00728 + 32 \times 1.00867 - 58.93320$ (u) ✓

$\Delta m = 0.5408$ (u) ✓

Binding Energy = 0.5408 × 931.5 = 503.8 (MeV) ✓ (CE this mark stands alone for the correct energy conversion even if more circular routes are followed.

Look at use of first equation and if electrons are used or mass of proton and neutron confused score = 0.

If subtraction is the wrong way round lose 1 mark.

Data may come from rest mass eg m_n =939.551 MeV or 1.675 × 10^{-27} kg or 1.00867 u.

So if kg route used $\Delta m = 8.83 \times 10^{-28}$ kg BE = 7.95×10^{-28} J and 497 Mev.

Conversion mark (2nd) may come from a wrong value worked through. 0.47(5)

3

(b) $(2.52 – 1.76) \times 10^{-13} = 7.6 \times 10^{-14}$ J ✓

$7.6 \times 10^{-14} / 1.60 \times 10^{-13} = 0.47$ or 0.48 MeV ✓(0.475 MeV)

Correct answer scores both marks.

2

(c) 6 (specific wavelengths)

1

(d) (longest wavelength = lowest frequency = smallest energy)
$(2.29 \times 10^{-13} – 2.06 \times 10^{-13}) = 2.3 \times 10^{-14}$ (J) ✓
λ (= $h\,c\,/\,E$) = $6.63 \times 10^{-34} \times 3.00 \times 10^{8} / 2.3 \times 10^{-14}$ ✓
$\lambda = 8.6 - 8.7 \times 10^{-12}$ (m) ✓ (8.6478×10^{-12} m)

Allow a CE in the second mark only if the energy corresponds to an energy gap including those to the ground state.

The allowed energy gaps for CE are:

2.29, 2.06, 1.76, 0.53, 0.30 all $\times 10^{-13}$

Note substitution rather than calculation gains mark.

The final mark must be as shown here and not from a CE above.

3

[9]

5. (a) (i) (Mass change in u=) 1.71×10^{-3} (u)
or (mass Be−7) – (mass He−3) – (mass He−4) seen with numbers

C1

2.84×10^{-30} (kg)
or Converts their mass to kg

Alternative 2nd mark:

Allow conversion of 1.71×10^{-3} *(u) to MeV by multiplying by 931 (=1.59 (MeV))* ***seen***

C1

Substitution in $E = mc^2$ *condone their mass* <u>*difference*</u> *in this sub but must have correct value for* c^2 $(3\times10^{8})^2$ *or* 9×10^{16}

Alternative 3rd mark:

Allow their MeV converted to joules ($\times 1.6 \times 10^{-13}$) ***seen***

C1

2.55×10^{-13} (J) to 2.6×10^{-13} (J)

Alternative 4th mark:

Allow 2.5×10^{-13} *(J) for this method*

A1

4

(ii) Use of $E=hc/\lambda$ ***ecf***

C1

Correct substitution in rearranged equation with λ *subject* ***ecf***

C1

7.65×10^{-13} (m) to 7.8×10^{-13} (m) ecf

A1

3

(b) (i) Use of E_p formula:

C1

Correct charges for the nuclei **<u>and</u>** correct powers of 10

C1

$2.6(3) \times 10^{-13}$ J

A1

3

(ii) Uses K*E* = 3 / 2 *kT*: ***or*** *halves* KE_T, *KE*= 1.3×10^{-13} *(J)* ***seen ecf***

C1

Correct substitution of data **and** makes T subject **ecf**
Or uses KE_T value **and** divides T by 2

C1

6.35×10^9 (K) or 6.4×10^9 (K) or 6.28×10^9(K) or 6.3×10^9 (K) **ecf**

A1

3

(c) (i) Deuteron / deuterium / hydrogen−2

B1

Triton / tritium / hydrogen−3

B1

2

(ii) Electrical heating / electrical discharge / inducing a current in plasma / use of e−m radiation / using radio waves (causing charged particles to resonate)

B1

1

[16]