Mark schemes

1 **C** **[1]**

2 D **[1]**

3 C **[1]**

4 B **[1]**

5 B **[1]**

6 B **[1]**

7 D **[1]**

8 A **[1]**

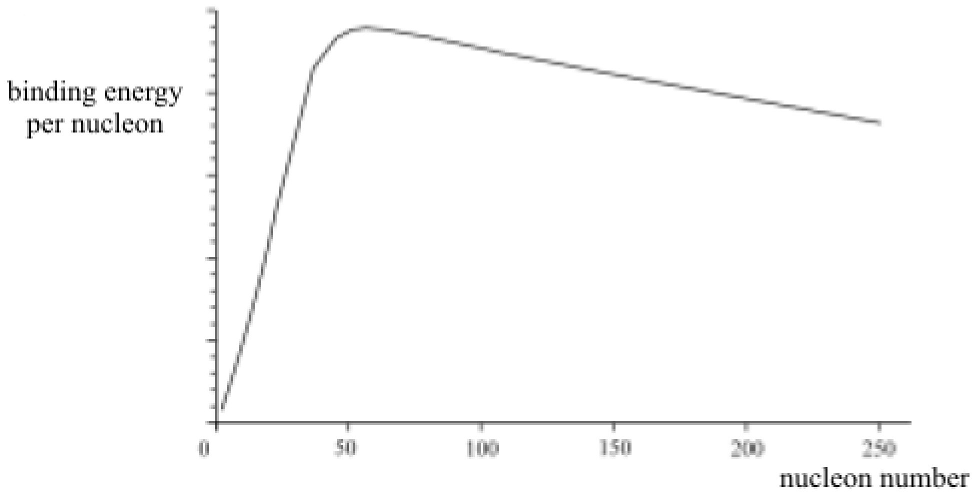
9 D **[1]**

10 C **[1]**

11 C **[1]**

12 D **[1]**

13 (a)



peak 8.7 (accept 8.0 – 9.2)

in MeV ✓

(or peak 1.4×10^{-12} accept $1.3 - 1.5 \times 10^{-12}$ in J ✓)

at nucleon number 50 – 60 ✓ accept 50 – 75

sharp rise from origin and moderate fall not below 2/3 of peak height ✓

4

(b) energy is released/made available when binding energy **per nucleon** is increased ✓

in fission a (large) nucleus splits and in fusion (small) nuclei join ✓

the most stable nuclei are at a peak

fusion occurs to the left of peak and fission to the right ✓

max 3

[7]

14 (a) (i) $\Delta m = Zm_p + (A - Z)m_n - M$ **(1)**

(ii) binding energy per nucleon = $\frac{(\Delta m)c^2}{A}$ **(1)**

2

(b) (i) *A* in range 54 → 64 **(1)**
stability increases as binding energy per nucleon increases **(1)**
[or binding energy per nucleon is a measure of stability]
[or large binding energy per nucleon shows nucleus is difficult to break apart]

(ii) binding energy per nucleon increases from about 7.6 to 8.5 **(1)**
increase of about 0.9 MeV for 235 nucleons **(1)**
hence 210 MeV (≈ 200 MeV) in total **(1)**

5

[7]

15 (a) (i) Fission occurs at *A* values above the peak / above *A* of about 56 and fusion occurs at *A* values below the peak / below *A* of about 56 ✓

Fission is the splitting of a nucleus (into two smaller ones) *and* fusion is the joining of two nuclei ✓

First mark uses the graph so 'fission occurs in very large nuclei' does not gain a mark. (allow other interpretations that use the graph eg gradients)

2nd Mark splitting into 2 is not required for fission but if the answer implies something different like the separating of all the nucleons the mark may not be given.

2

(ii) Energy is released when the binding energy (per nucleon) is increased ✓
fusion energy is greater as the increase in BE(/A) for fusion > increase in BE(/A) for fission (owtte) ✓

The last point can be given for a reference to the larger gradient at small values of A (fusion region) compared to the gradient at large values of A (fission region)

2

(b) (i) $\Delta m = (8m_p + 8m_n) - M_{oxygen}$
mark for substituting data into the above equation in any workable consistent units

= 8(1.00867+1.00728) − 15.991 ✓

(Δm = 0.1366 u

$\Delta m = 0.1366 \times 1.661 \times 10^{-27}$) = 2.3×10^{-28} (kg) ✓

(range of answers 2.2 - 2.3×10^{-28} kg)

Substitution may take the following form

$8(1.673 \times 10^{-27})+8(1.675 \times 10^{-27})-(15.991 \times 1.661 \times 10^{-27})$ ✓

$= 2.23 \times 10^{-28}$ (kg) ✓

Correct answer gains full marks.

Look out for a physics error in which u is not taken as 1.661×10^{-27} kg

2

(ii) $E = m \times c^2 = 2.3 \times 10^{-28} \times (3.00 \times 10^8)^2 = 2.07 \times 10^{-11}$ J
BE = $2.07 \times 10^{-11} / 1.6 \times 10^{-13}$ = 130 (MeV) ✓ (129 MeV)
Or using
using Δm = 0.1366 u (this must appear in b(i) for this approach)
BE = 0.1366 × 931.3 = 130 (MeV) ✓ (127 MeV)

CE is allowed but only if the calculation is shown

Note answer = b(i) × 5.625 × 10^{29}

answer only is acceptable for one mark.

(factor may be 931 or 931.5)

1

(iii) read from the graph the BE/A for $^{16}_{8}O$ and multiply by the number of nucleons (or 16) ✓
Or show the calculation
BE = 8(Mev) × 16(nucleons) = 130 (MeV) ✓ (128 MeV)✓

There must be a reference to $^{16}_{8}O$ position on the graph.

with the calculation allow BE = 8.1(Mev) × 16(nucleons) = 130 (MeV)

A calculation may lead to an answer in joule

1

[8]

16 (a) nucleon number 4

B1

proton number 2

B1

(2)

(b) (i) mass of products is less than mass of reactants / binding energy per nucleon increases / mass defect increases / 'loss' of mass

B1

change in mass converted to energy

B1

(2)

(ii) change in mass = 4.8×10^{-29} kg

C1

$E = mc^2$

C1

4.3×10^{-12} J (4.30×10^{-12} J)

(if truncated sig. figs used only 2nd mark available)

A1

(3)

[7]

17 (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 × 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]

18

(a) the amount of energy required to separate a nucleus ✓
into its separate neutrons and protons / nucleons ✓
(or energy released on formation of a nucleus ✓
from its separate neutrons and protons / constituents ✓)

1st mark is for correct energy flow direction

2nd mark is for binding or separating nucleons (nucleus is in the question but a reference to an atom will lose the mark)

ignore discussion of SNF etc

both marks are independent

2

(b) (i) $2\,{}^{1}_{0}\mathrm{n}$ or ${}^{1}_{0}\mathrm{n} + {}^{1}_{0}\mathrm{n}$ ✓

must see subscript and superscripts

1

(ii) binding energy of U
= 235 × 7.59 ✓ (= 1784 (MeV))
binding energy of Tc and In
= 112 × 8.36 + 122 × 8.51 ✓
(= 1975 (MeV))
energy released (= 1975 – 1784) = 191 (MeV) ✓ (allow 190 MeV)

1st mark is for 235 × 7.59 seen anywhere

2nd mark for 112 × 8.36 + 122 × 8.51 or 1975 is only given if there are no other terms or conversions added to the equation (ignore which way round the subtraction is positioned)
correct final answer can score 3 marks

3

(iii) energy released
= 191 × 1.60 × 10^{-13} ✓
(= 3.06 × 10^{-11} J)
loss of mass (= E / c^2)
= 2.91 × 10^{-11} / (3.00 × 10^8)^2)
= 3.4 × 10^{-28} (kg) ✓
or
= 191 / 931.5 u ✓ (= 0.205 u)
= 0.205 × 1.66 × 10^{-27} (kg)
= 3.4 × 10^{-28} (kg) ✓

allow CE from (ii)
working must be shown for a CE otherwise full marks can be given for correct answer only

note for CE

answer = (ii) × 1.78 × 10^{-30}

(2.01 × 10^{-27} is a common answer)

2

(c) (i) line or band from origin, starting at 45° up to Z approximately = 20 reading
Z = 80, N = 110→130 ✓

initial gradient should be about 1 (ie Z = 20 ; N = 15 → 25) and overall must show some concave curvature. (Ignore slight waviness in the line)
if band is shown take middle as the line
if line stops at N > 70 extrapolate line to N = 80 for marking

1

(ii) fission fragments are (likely) to be above / to the left of the line of stability ✓
fission fragments are (likely) to have a larger N / Z ratio than stable nuclei
or
fission fragments are neutron rich owtte ✓
and become neutron or β^- emitters ✓

ignore any reference to α emission
a candidate must make a choice for the first two marks
stating that there are more neutrons than protons is not enough for a mark
1st mark reference to graph
2nd mark – high N / Z ratio or neutron rich
3rd mark beta minus
note not just beta

3

[12]

19 (a) (i) heat water to 100 °C, energy (= 190 × 4200 × 79) = 63 (MJ) **(1)**
vapourise water, energy
(=190 × 2.3 × 10^6) = 440(MJ) **(1)**
(437MJ)

energy transferred (per sec) = (437 + 63) MJ **(1)**
(= 500 MJ)

(ii) mass of rocks (= 4.0 × 10^6 × 3200)

= 1.3 × 10^{10}(kg) **(1)**

(1.28 × 10^{10})

temperature fall of ΔT in one day, energy removed
(= 1.28 ×10^{10} × 850 × ΔT) = 1.1 × 10^{13} ΔT **(1)**

(1.09 x 10^{13} AT)
(allow C.E. for value of mass of rocks)

energy transfer in one day (= 500 × 10^6 × 3600 × 24)
= 4.3 × 10^{13} (J) **(1)**

in one day $\Delta T \left(= \frac{4.3 \times 10^{13}}{1.1 \times 10^{13}} \right) = 3.9(1)$ K **(1)**

7

(b) number of nuclei in 1 kg of ^{238}U $= \left(\frac{6.02\times10^{23}}{0.238}\right) = 2.5(3)\times10^{24}$ **(1)**

activity of lkg of ^{238}U $= \frac{\ln 2}{T_{1/2}} \times 2.53\times10^{24}$ **(1)**

$\left(= \frac{\ln 2}{4.5\times10^{9}\times3.1\times10^{7}} \times 2.53\times10^{24}\right) = 1.2(6)\times10^{7}\,(s^{-1})$ **(1)**

energy released per sec per kg of ^{238}U

$= 1.2(6) \times 10^{7} \times 4.2 \times 1.6 \times 10^{-13}$(J) **(1)**

$(8.47 \times 10^{-6}$(J))

mass of ^{238}Uneeded $= \frac{500\times10^{6}}{8.47\times10^{-6}} = 5.9(0) \times 10^{13}$kg **(1)**

5

[12]

20 (a) (i) 1/12 the mass of an (atom) of $^{12}_{6}$C / carbon−12 / C12 ✓

a reference to a nucleus loses the mark

1

(ii) separated nucleons have a greater mass ✓ (than when inside a nucleus)

an answer starting with 'its' implies the nucleus

because of the (binding) energy <u>added</u> to <u>separate</u> the nucleons or energy is <u>released</u> when a nucleus is <u>formed</u> (owtte) ✓

marks are independent

direction of energy flow or work done must be explicit

2

(b) nuclei need to be <u>close together</u> (owtte) for the Strong Nuclear Force to be involved or for fusion to take place ✓

e.g. first mark – within the range of the SNF

but the electrostatic / electromagnetic force is repulsive (and tries to prevent this) ✓

(if the temperature is high then) the nuclei have (high) kinetic energy / speed (to overcome the repulsion) ✓

3rd mark is for a simple link between temperature and speed / KE

3

(c) (i) 15 ✓

give the middle mark easily for any e or β with a + in any position

e^{+} ✓ (or β^{+}, $^{0}_{1}\beta$, $^{0}_{1}$e)

12 ✓

3

(ii) Δmass = $4 \times 1.00728 - 4.00150 - (2 \times 9.11 \times 10^{-31} / 1.661 \times 10^{-27})$
or
Δmass = {4 × 1.00728 − 4.00150 − 2 × 0.00055}(u) ✓

(4×1.00728=4.02912)

1st mark – correct subtractions in any consistent unit. use of m_p = 1.67×10^{-27} kg will gain this mark but will not gain the 2nd as it will not produce an accurate enough result

Δmass = 0.02652(u) ✓

2nd mark - for calculated value

0.02652u

4.405×10^{-29} kg

3.364×10^{-12} J

Δbinding energy (= 0.02652 × 931.5) {allow 931.3}

Δbinding energy = 24.7 MeV ✓

3rd mark – conversion to Mev

conversion mark stands alone

award 3 marks for answer provided some working shown - no working gets 2 marks

(2sf expected)

3

[12]

21 (a) Draws appropriate triangle on graph or other mark on graph at ~ 118

B1

Change of approx 1 Me V per nucleon is multiplied by 235

B1

Multiplies by 1.6×10^{-13}

B1

Quotes their answer of approx 3.8×10^{-11} to more than 2 sf

B1

4

(b) (2 × 2.0135) – 4.0026 seen or 0.0244 (u)

C1

Multiplies u by 1.7×10^{-27}

C1

$E = mc^2$ seen or multiplies by $(3 \times 10^8)^2$

C1

3.67×10^{-12}J

A1

4

(c) Multiplies 3.8×10^{-11} or their (b) by 6×10^{23}

M1

attempts to convert to energy per kg by multiplying by 1000 / 4 or 1000 / 235

M1

Compares 5.5×10^{14} (J) (Hydrogen) with 9.6×10^{13} (J) (Uranium) in some way eg by stating that the fusion reaction gives more energy (per kg) than the fission or very similar values – must be consequent on some correct analysis

A1

3

(d) Availability of fuel easier for fusion

B1

Doesn't produce radioactive fission products / no waste management problem

B1

2

[13]

22 (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]

23 (a) (i) Attempt to use KE = 3/2 *kT* expect 0.75 = 3/2 × 1.38 × 10^{-23} *T*

C1

Or correct conversion to J 0.75 × 1.6 × 10^{-19}

Correct equations 0.75 × 1.6 × 10^{-19} = 3/2 1.38 × 10^{-23} *T*

C1

5800 K

A1

3

(ii) Attempt to use energy = $qQ/4\pi\varepsilon_o r$

C1

arrives at 1.9(2) $\times 10^{-9}$ or uses (2 × 0.75) or twice candidate's energy from (i)

C1

9.6×10^{-10} m

A1

3

(iii) For fusion nuclei have to touch or separation has to be nuclear diameter

energy has to be sufficient to overcome the nuclear repulsion (between protons)

B1

Close enough for nuclear strong force to act

B1

answer to 4 a (ii) is much greater that 10^{-15} m

B1

or is greater that atomic radius

or is greater than the range of the strong force

3

(b) (i) Use of $pV=NkT$

C1

(Allow incorrect powers of 10 or rearrangement to make *N* subject)

$1\times10^{16}\times1=N\times1.38\times10^{-23}\times1.5\times10^{6}$

C1

4.8 (3)$\times 10^{32}$

A1

3

(ii) 1.67×10^{-27} or 1.7×10^{-27} used

C1

$8.0 – 8.2 \times 10^5$ (kg m^{-3}) Allow ecf for *N* from (b)(i)

A1

2

(c) (i) Number of protons = moles of proton/mass of protons / Mass per second × Avogadro constant used

B1

Or

No of protons = mass per second/proton mass

(allow if numerical equation seen with a subject)

4.18 or 4.19 or 4.21×10^{38} correct to at least 2 sf from correct working

B1

2

(ii) Attempt to use $E = mc^2$ with any mass and substitution for *c*

C1

Energy radiated = $5 \times 10^9 \times c^2$ energy radiated 4.5×10^{26} J

A1

Number of helium nuclei formed = 1.05×10^{38} (allow 1×10^{39})

B1

Approximate BE per nucleon from article = $4.28(4.5) \times 10^{-12}$ J

B1

(Which is consistent)

4

[20]