| | | | | |
|---|---|---|---|---|
| **1.** | Force per unit positive charge | | B1 | |
| | | | | **[1]** |

| | | | | |
|---|---|---|---|---|
| **2.** | (i) | Suitable recognisable pattern around (not just between) the charges | B1 | |
| | | Quality mark: symmetry, spacing, lines joined to charges | B1 | |
| | | Consistent arrows toward B on some lines | B1 | |
| | (ii) | Use of $E = (1/4\pi\varepsilon_0)Q/r^2$ | C1 | |
| | | Sum of two equal terms | | |
| | | $E = 2 \times 9 \times 10^9 \times 1.6 \times 10^{-19} / (2.0 \times 10^{-10})^2$ | C1 | |
| | | $E = 7.2 \times 10^{10}$ N C$^{-1}$ or V m$^{-1}$ | A1 | |
| | (iii) | The separation between the ions because this has an effect on the breaking force. (Allow the size of ionic 'charges') | B1 | |
| | | | | **[7]** |

| | | | | | |
|---|---|---|---|---|---|
| **3.** | (a) | (i) | $C_p = 2 + 4 = 6$ μF | A1 | |
| | | (ii) | $1/C = 1/2 + ¼$ | C1 | |
| | | | Cs = 4/3 =1.33 μF | A1 | |
| | (b) | (i) | 6.0 V | A1 | |
| | | (ii) | $Q = C_pV$ | C1 | |
| | | | = 6 × 6 = 36 μC | A1 | |
| | (c) | $E = ½\, C_sV^2$ | | C1 | |
| | | $= 24 \times 10^{-6}$ | | A1 | |
| | (d) | (i) | The capacitors discharge <u>through</u> the voltmeter. | B1 | |
| | | (ii) | $V = V_0e^{-t/CR}$ | | |
| | | | $1/4 = e^{-t/(6\times12)}$ | C1 | |
| | | | $\ln 4 = t / 72$ | C1 | |
| | | | $t = 72 \ln 4 \approx 100$ s | A1 | |
| | | | | | **[12]** |

**4.** Any **seven** from:
α - particle scattering
suitable diagram with source, foil, moveable detector
2 or more trajectories shown
vacuum
most particles have little if any deflection
large deflection of very few
reference to Coulomb's law /elastic scattering
alphas repelled by nucleus (positive charges)
monoenergetic
OR electron scattering
High energy diagram with source sample, moveable detector / film
Vacuum
Electron accelerator or other detail
Most have zero deflection
Characteristic angular distribution with minimum
Minimum not zero
De Broglie wavelength
Wavelength comparable to nuclear size hence high energy — B1 × 7

✎ Clearly shows how evidence for the size of the nucleus follows from what is described. (1)

**[8]**

**5.** (a) He nucleus, a few cm / 3 to 10 cm
About 1 m / 0.3 to 2 m / several m, 1 to 10 mm Al / 1 mm Pb
(high energy) e-m radiation, 1 to 10 cm of Pb / several m of concrete
only 2 correct 1 mark, only 4 correct 2 marks — B3

(b) Source, absorbers placed in front of detector on diagram — B1
Explanation of how results identify the source
(2 marks possible) — B2
Allowance for background (max 2)
(allow for distance expt to a max 2)

**[6]**

**6.** (a) (i) flux = B × A (normal to B) with symbols explained — B1

(ii) linkage = N × flux — B1
A = $x^2$ so linkage = N$Bx^2$ — B1

| | | | |
|---|---|---|---|
| (b) | (i) | Statement of Faraday's law or indication<br>e.g. $V = d(NBx^2) / dt$ from (a)(ii) | |
| | | $V = NB\, x^2 dx/dt$ or $V = NBxv$ / argue area swept out per second as $xv$ | B1 |
| | | $V = 1250 \times 0.032 \times 0.02 \times 0.1$ | B1 |
| | | = 0.08 or 80 mV | B1 |
| | | | A0 |
| | (ii) | equal positive and negative regions | B1 |
| | | equal positive and negative values of 'maxima' labelled on *y*-axis | B1 |
| | | value changes within correct time zones, t = 0.2 to 0.4, 0.6 to 0.8 s | B1 |
| | | 'square pulse' shape | B1 |
| | | *sinusoidal graphs score zero marks* | |

**[10]**

| | | |
|---|---|---|
| **7.** | Universe is isotropic /same in all directions | B1 |
| | Homogeneous / evenly distributed | B1 |

**[2]**

| | | |
|---|---|---|
| **8.** | Any four from: | |
| | Uniform intensity in all directions / everywhere | |
| | Structure in background intensity / ripples | |
| | Produced when matter and radiation decoupled | |
| | Originally gamma radiation | |
| | (gamma) red-shifted to microwave / originally higher energy | |
| | Evidence that universe began with big bang | |
| | Temperature corresponds to 2.7 K / 3K / that predicted by big bang model | B1 × 4 |
| | Link between evidence and explanation. (1) | |

**[5]**

| | | |
|---|---|---|
| **9.** | Any two from: | |
| | No experimental evidence / no physical evidence | |
| | State of matter unknown / laws of physics unknown | |
| | Energies unreproducible / ref. to very high temperature | B1 × 2 |

**[2]**

| | | |
|---|---|---|
| **10.** | Open: Universe expands for all time | |
| | Flat: expands to a limit (but never reaches it) | B1 |
| | Closed: Universe contracts / collapses back | B1 |
| | Reference to role of gravity / critical density | B1 |
| | Marks for (a) can be gained on a labelled diagram | B1 |

**[4]**

**11.** $H_o^2 = (1 \times 10^{-26} \times 8 \times \pi \times 6.67 \times 10^{-11}) / 3$ C1

$H_o = 2.36 \times 10^{-18}\ s^{-1}$ A1

**[2]**

**12.** (a) <u>Density</u> (of medium) B1

<u>Speed of ultrasound</u> (in medium) or any factors that affect the speed of ultrasound in the medium e.g. Young modulus B1

(b) (i) blood:

$f = (1.59 \times 10^{-6} - 1.63 \times 10^{-6})^2 / (1.59 \times 10^{-6} + 1.63 \times 10^{-6})^2$

$f = 1.54 \times 10^{-4}$ B1

muscle:

$f = 1.70 \times 10^{-6} - 1.63 \times 10^{-6})^2 / (1.70 \times 10^{-6} + 1.63 \times 10^{-6})^2$ B1

$f = 4.4 \times 10^{-4}$ B1

so the medium is muscle A1

*(bald muscle scores zero)*

(ii) $(s = u \times t)$

$s = 1.54 \times 10^3 \times 26.5 \times 10^{-6} = 0.0408$ m C1

depth = 0.0408 / 2 = 0.020 m A1

(iii) $\lambda = 1.54 \times 10^3 / 3.5 \times 10^6$ C1

$= 4.4 \times 10^{-4}$ m A1

(do not penalise the same power of ten error in (iii) as in (ii))

**[10]**

**13.** (a) Low energy X-rays are absorbed by the skin / undesirable as can cause damage /greater ionising B1

(b) $I = I_0 e^{-\mu x}$ $\quad \ln I = \ln I_0 - \mu x$ C1

$I_0 = 347 / e^{-250 \times 0.025}$ $\quad \ln I_0 = \ln 347 + 250 \times 0.025$ C1

$I_0 = 1.79 \times 10^5\ Wm^{-2}$ A1

(c) $P = I \times A$

$P = 347 \times \pi \times (0.010 \times 10^{-2})^2$ C1

$P = 1.09 \times 10^{-3}$ W A1

**[6]**

| | | | |
|---|---|---|---|
| **14.** | (i) | P = 18 × 100 / 0.15 | C1 |
| | | P= 12000 W | A1 |
| | (ii) | Energy of one electron = 12000 / 7.5 × $10^{17}$(1.6 × $10^{-14}$) | C1 |
| | | ½ m $v^2$ = 1.6 × $10^{-14}$ | |
| | | v = 1.9 × $10^8$ m $s^{-1}$ | A1 |
| | (iii) | tube current = 7.5 × $10^{17}$ × 1.6 × $10^{-19}$ = 0.12 A | |
| | | P = V × I = 12000 | C1 |
| | | V = 12000 / 0.12 = 100000 V or 100 kV | C1 |
| | | Or: V = W/Q = 1.6 × $10^{-14}$ / 1.6 × $10^{-19}$ = 1.0 × $10^5$ (V) | A1 |

**[7]**

**15.** Any **six** from:

method does not use ionising radiation
hence no radiation hazard to patient or staff
gives better soft tissue contrast than CT scans
generates data from a 3D volume simultaneously
information can be displayed on a screen as a section in any direction
there are no moving mechanisms involved in MRI
There is no sensation, after effects at the field strengths used for routine diagnosis
Strong magnetic field could draw steel objects into the magnet
Metallic objects may become heated
Cardiac pacemakers may be affected by the magnetic fields
CT scanners better for viewing bony structures — B1 × 6

**[6]**

| | | | |
|---|---|---|---|
| **16.** | (a) | Rb 94 | |
| | | Cs 55 | |
| | | U143 | |
| | | –1 for each error | B2 |
| | (b) | Values from graph: U 7.4 MeV *allow 7.3 to 7.4* | |
| | | Rb 8.6 MeV *allow 8.5 to 8.6* | C1 |
| | | Cs 8.4 MeV | |
| | | Total binding energies: U 235 × 7.4 (1739) | |
| | | Rb 94 × 8.6 (808) | B2 |
| | | Cs 142 × 8.4 (1193) | |
| | | Total energy released = 808 + 1193 – 1739 | A1 |
| | | = 262 MeV | |
| | | allow 8.6 + 8.4 – 7.4 = 9.4 MeV for 1 mark only | |

**[6]**

**17.** Any six from: (two advantages and two disadvantages needed)
problems with the reaction getting out of control
maintaining the reaction so that it proceeds continuously
does not produce acid rain or waste gases that could cause pollution
risks from radiation: emissions due to an accident (1);
emissions from radioactive wastes (1)
long half life of some of the waste products (1)
other examples are likely to be added but should be related to Scientific reasons rather than political. B1 × 6

**[6]**

**18.** (a) (i) $\frac{1}{2} mv^2 = 7.6 \times 10^{-13}$ to give $v = \sqrt{(2 \times 7.6 \times 10^{-13} / 6.6 \times 10^{-27}}$ (1)
evidence of calculation $v = \sqrt{2.3 \times 10^{14}}$ *or* $= 1.52 \times 10^{7}$ (m $s^{-1}$) (1) 2

(ii) (electrostatic) repulsion between charged particles (1)
slows alpha and accelerates nucleus/AW (1)
momentum of system is conserved(as no external forces) (1)
sum of momenta of alpha and nucleus must always equal initial momentum of alpha/be a constant (1)
so speed of nucleus can be calculated as momentum = mv (1) 3
*max 3*

(iii) mv = MV or $V = 6.6 \times 10^{-27} \times 1.52 \times 10^{7} / 3.0 \times 10^{-25}$; $= 3.3 \times 10^{5}$ (m $s^{-1}$) 2

(iv) Ft = 2mv or $9.0 \times t = 2 \times 6.6 \times 10^{-27} \times 1.52 \times 10^{7}$; $t = 2.2 \times 10^{-20}$ (s) 2
*give (1) mark for* change in momentum = impulse *or* $\Delta mv = F(\Delta)t$

(b) (i) Coulomb force α distance$^{-2}$ or $F_1/F_2 = r_2^2/r_1^2$ or $Fr^2$ = constant (1)
giving F = 4.0 N at $10 \times 10^{-14}$; = 1.8 N at $15 \times 10^{-14}$ m (2) 3

(ii) plot and draw correct curve *ecf plausible values in b(i)* (1) 1

**[13]**

**19.** (a) (i) $v = 2\pi rf = 2\pi \times 0.015 \times 50$; $= 4.7$ (m $s^{-1}$) 2

(ii) $a = v^2/r = 4.7^2/0.015$; $= 1.5 \times 10^{3}$ (m $s^{-2}$) *ecf(a)(i)* 2

(iii) the belt tension is insufficient to provide the centripetal force; (1) so the belt does not 'grip' the pulley/does not hold the belt against the pulley/there is insufficient friction to pull/push/move the belt. (1) — 2
*alternative argument* the belt does not 'grip' the pulley/there is insufficient friction to pull/push/move the belt; because of its inertia/insufficient to provide force for acceleration of (belt)-drum

(b) resonance occurs; when the natural frequency of vibration of the (1) panel = rotational frequency of the motor (1) — 2

(c) (i) **1** 5, 15, 25 (ms)
**2** 0, 10, 20, 30 (ms) — 1

(ii) Stating/using $\epsilon = d\varphi/dt$ (1)
gradient = $0.67 \pm 0.05$ (Wb turns $ms^{-1}$); emf = gradient $\times 10^3$ (V) (2) — 3

**[12]**

**20.** (a) $Q_o = CV = 1.2 \times 10^{-11} \times 5.0 \times 10^3$; $= 6.0 \times 10^{-8}$; C (3) — 3

(b) (i) $RC = 1.2 \times 10^{15} \times 1.2 \times 10^{-11}$ *or* $= 1.44 \times 10^4$ (s) (1) — 1

(ii) $I = V/R = 5000/1.2 \times 10^{15}$ *or* $= 4.16 \times 10^{-12}$ (A) (1) — 1

(iii) $t = Q_o/I$; $= 6 \times 10^{-8} / 4.16 \times 10^{-12} = 1.44 \times 10^4$ (s) — 2

(iv) $Q = Q_o e^{-1}$; $Q = 0.37Q_o$ so Q lost $= 0.63Q_o$ — 2

(c) (i) capacitors in parallel come to same voltage (1)
so Q stored $\alpha$ C of capacitor (1)
capacitors in ratio $10^3$ so only $10^{-3}$ $Q_o$ left on football (1) — 3

(ii) $V = Q/C = 6.0 \times 10^{-8} /1.2 \times 10^{-8}$ *or* $6.0 \times 10^{-11} /1.2 \times 10^{-11}$ *or* only $10^{-3}$ Q left so $10^{-3}$ V left; = 5.0 (V) — 2

**[14]**

**21.** (a) (i) equally spaced horizontal parallel lines from plate to plate (1)
arrows towards cathode (1) — 2

(ii) $\frac{1}{2} mv^2 = qV$; $v = \sqrt{(2eV/m)} = \sqrt{(2 \times 1.6 \times 10^{-19} \times 7000/9.1 \times 10^{-31})}$ so (1)
$v = 4.96 \times 10^7$ (m s$^{-1}$) (1) 2

(b) (i) arrow perpendicular to path towards centre of arc (1) 1

(ii) out of paper/upwards;using Fleming's LH rule (for conventional current) (2) 2

(iii) $mv^2/r$; $= Bqv$; $r = mv/Bq = \dfrac{9.1\times10^{-31}\times4.96\times10^{7}}{3.0\times10^{-3}\times1.6\times10^{-19}}$ ;$= 9.4 \times 10^{-2}$ (m) 4

(c) change magnitude of current in coils to change field; (1)
change field to change deflection; (1)
reverse field/current to change deflection from up to down (1) *max 2* 2

**[13]**

**22.** (a) (i) 212; β 2

(ii) 208; α 2

(b) range/penetration/absorption experiment:
α place detector very close/ 2cm from source; measure count rate, (1)
use paper screen or move back to 10 cm or more; contrast to (1)
background count level/ other emissions from same source (1)
β place detector eg 10 cm from source; measure count rate, add (1)
thin sheets of Al until count drops to very low or almost constant value (1)
*aliter* deflection experiment:
needs vacuum for α experiment; (1)
source for radiation passes through region of E- or B- field; (1)
deflection of particles detected by detector to distinguish emissions; (1)
detection method (1) *max 4 marks* 4

(c) (i) $A = \lambda N$;$= \lambda m N_A/M$;$= 0.0115 \times 6.02 \times 10^{23} \times 1 \times 10^{-9}/212 = 3.27 \times 10^{10}$ min$^{-1}$ 3

(ii) $T_{1/2} = 0.693/\lambda = 60.3$ (min) (1) 1

(iii) Curve passing through (0,32) (60, 16) (120,8) *ecfs from (i) & (ii)* (1) 1

**[13]**

**23.** *Do not score the same marking point twice; some marking points appear more than once in a different context*
*fission is splitting of nuclei*:
neutron is absorbed by the nucleus; (1)
an (unstable) nucleus splits into two (major) fragments; (1)
and several/two/three neutrons (1)
charges on/Coulomb repulsion pushes fragments apart; (1)
loss of mass/increased binding energy accounts for k.e of fragments/release of energy (1)
*fusion is fusing of nuclei:*
two light nuclei (are moving rapidly enough to overcome the Coulomb repulsion to 'touch' and) fuse; *statement in brackets gets second mark* (1)
has to be very hot for nuclei to have enough kinetic energy/ only (1)
happens naturally inside Sun/star *accept* H-bomb (1)
loss of mass/increased binding energy accounts for release of energy

*similarity*: release of energy/total (rest) mass decrease/'increase' in (1)
binding energy /conservation of charge/mass-energy, etc
*difference*: /cold, hot/heavy, light nuclei/large (200 MeV), small (30 MeV) energy release per reaction (1)
*conditions*: fission rate can be varied/controlled by absorbing and or slowing released neutrons in reactor where chain reaction is occurring/AW (2) *max 2 marks*
fusion needs a very hot and sufficiently dense and plentiful plasma for random fusion collisions to occur, eg inside Sun/star/AW (2) *max 2 marks* 7

Quality of Written Communication 2

**[9]**

**24.** *Appreciation that key is* the difference in numbers of atoms/nuclei *or* equal number of nucleons involved *if nothing else is achieved* (1)
*Full argument*:
235 g of uranium and 4 g of hydrogen/helium contain 1 mole of (1)
atoms (1)
there are 4.26 moles of uranium and 250 moles of helium (1)
so at least 58 times as many energy releases in fusion (1)
ratio of energies is only 7 fold in favour of uranium
therefore more energy release from 1 kg of hydrogen
*any similar alternative argument along same lines scores 4 marks* (1)
eg For U each nucleon 'provides' 0.85 MeV (1)
For H each nucleon 'provides' 7 MeV (1)
(Approximately) same number of nucleons per kg of U or H (1)
so 8.2 times as much energy from H 4

Quality of Written Communication 2

**[6]**

**25.** (a) Sketch to include: Variable frequency A.C source to primary, core, coils; (1)
resistor connected to secondary; (1)
appropriate meters in primary and secondary circuits; (1)
Quantities kept constant: Voltage of source; (1)
Primary current / power; (1)
Resistance of secondary circuit resistor; (1)
Number of turns in both coils; (1)
Procedure: Use several frequencies over a wide range / the range available; (1)
At each frequency read meters; (1)
Table headings to show: meter readings; (1)
primary power, secondary power, efficiency. (1)
Graph of efficiency against drawn; (1)
Details of calculations of power (may use meter readings
and value of resistor); (1)
Expression for efficiency / % efficiency. (1) max 10

(b) Energy / heat is lost in core due to hysteresis; (1)
Energy / heat loss in 1 cycle is proportional to area of hysteresis loop; (1)
Frequency increase reduces efficiency because energy loss
(per second) = frequency × area enclosed by hysteresis loop. (1)
Energy loss takes place due to heat generated in core by induced /
eddy currents; (1)
Induced voltage in core increases with frequency / is proportional
to frequency; (1)
(so) induced current in core increases with frequency / is proportional
to frequency. (1) max 4

**[14]**

**26.** acts only on nearest neighbour / when nuclei are 1 diameter apart; (1)
**either**
so force holding nucleons/ neutrons together independent of size of nucleus (1)
**or**
reference to b so distance apart (of nucleons) must be constant;
so density of nucleus is independent of size; (1) 3

**[3]**

**27.** (a) ${}^{239}_{92}U \rightarrow {}^{239}_{93}Np + {}^{0}_{-1}\beta \,/\, {}^{0}_{-1}e + \bar{\nu}$ (1)
allow ${}^{238}_{92}U + {}^{1}_{0}n$ on LHS

${}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + {}^{0}_{-1}\beta \,/\, {}^{0}_{-1}e + \bar{\nu}$ (1) 2

allow neutrino instead of antineutrino
omits neutrino altogether - gets 1/2

(b) straight line starts from zero and reaches $1.08 \times 10^{13}$ at
$t = 6.0 \times 10^{5}$ s or equivalent (1) 1

(c) (i) rate of decay increases with time; (1)
because rate of decay increases with / is proportional to number of nuclei; (1) 2

(ii) (eventually) rate of decay (of $^{239}_{93}$Np) = rate of formation (1) 1

(iii) d$N$/d$t$ = (–) $\lambda N$ *equation* (1)
$\lambda = 0.693 / T½$
so $N = (dN/dt) / \lambda = 1.8 \times 10^7 / (0.693 / [2.04 \times 10^5])$ *subs*. (1)
$= 5.3 \times 10^{12}$ *ans*. (1) 3
calculation of $\lambda$ gets 1/3

(iv) correctly curved from zero to ($5.3 \times 10^{12}$) or less (1) 1

**[10]**

**28.** (a) (i) to come to rest simultaneously, total mtm. = 0 *or* AW (1) 1
(but initial mtm. not zero)

(ii) initial mtm. = $3\,m\,u - 2\,m\,u = m\,u$ (1)
when closest, mtm. = $(3m + 2m)\,v$ (1) 2
so $5m\,v = m\,u$ (and $v = u / 5$)

(b) (i) initial k.e. = final k.e. + (gain of) p.e. (1) 1

(ii) k.e. = $½\,m\,v^2$ (1)
total k.e. = $½ \times 3\,m\,u^2 + ½ \times 2\,m\,u^2$ (= $2.5\,m\,u^2$) (1)
$= 2.5 \times 1.67 \times 10^{-27}\,u^2$ (= $4.18 \times 10^{-27}\,u^2$) (1) 3
allow $m = 1.66 \times 10^{-27}$ kg for full credit

(iii) gain of p.e. = initial k.e. – final k.e.
$$\frac{(1.6\times10^{-19})^2}{(4\pi\times8.85\times10^{-12}\times1.5\times10^{-15})} = 4.18 \times 10^{-27}\,u^2 - 4.18 \times 10^{-27}\,(u/5)^2 \text{ (2)}$$
$1.53 \times 10^{-13} = 4.01 \times 10^{-27}\,u^2$ (1) *algebra*
$u = 6.18 \times 10^6$ m s$^{-1}$ (1) 4

omits - $4.18 \times 10^{-27}\,(u/5)^2$, gets $u = 6.\,06 \times 10^6$ m s$^{-1}$: 1/2, 1, 1 = 3/4

**[11]**

**29.** (much) greater energy per unit mass of fuel (1*)
detail: greater change of binding energy / nucleon for fusion than fission (1)

no / little radioactive waste (1*)

detail: by-product is (stable) helium (1)

materials in JET structure will not become radioactive over long period (1)

tritium has short half-life (and is used anyway) (1)

fuel / reactants (virtually) limitless (1*)

detail: deuterium available from water (1)
deuterium easily separated from normal hydrogen (1)
lithium is a common material (1)

but <u>not</u> tritium is widely available

no chance of runaway / meltdown (1*)

detail: only minute quantities of reactants (in vessel) (1)

reaction ceases immediately (temperature falls) (1)

any two reasons (*) @ 1mark + corresponding detail @ 1 mark = 2 + 2
accept other valid answers

**[4]**

**30.** (a) $^{236}_{92}U \rightarrow {}^{100}_{40}Zr + {}^{131}_{52}Te + 5\,{}^{1}_{0}n$ (1) 1

(b) (i) nucleon number: no change
proton number: increases by (1) 1

(ii) nucleon number: 100
proton number: 44 (1) 1

(iii) 5 correct points (1)
4 correct arrows (1) 2

(iv) straight line through / close to 56 / 44 of (1) ≤ gradient < 2
if curved, correct sense (1) 1

(c) (i) reactant mass = 99.895 808 u
product mass = 99.891 679 + 0.000 549 (= 99.892 228 u) (1)
mass defect = 0.003 580 u (1) 2

(ii) $\Delta m = 0.003\,580 \times 1.66 \times 10^{-27}$ (= $5.943 \times 10^{-30}$ kg) (1)
$E = (\Delta)m\,c^2$
$= 5.943 \times 10^{-30} \times (3.0 \times 10^8)^2$ (= $5.35 \times 10^{-13}$ J) (1) 2

*or* uses 1 u = 931 MeV so 0.00358 = 931 × 0.00358 (= 3.33 MeV) (1)
$= 3.33 \times 1.6 \times 10^{-13}$ (= $5.33 \times 10^{-12}$ J) (1)

(iii) (anti-)neutrino is also emitted (1)
(anti-)neutrino has (some) energy (1)
recoiling (niobium) nucleus has (kinetic) energy (1) 2
*any 2*

**[12]**

**31.** (a) (i) Q = VC; W = ½ VC.V ( = ½ $CV^2$) (2)

(ii) parabolic shape passing through origin (1)
plotted accurately as $W = 1.1\,V^2$ (1) 4

(b) (i) T = RC; = $6.8 \times 10^3 \times 2.2 = 1.5 \times 10^4$ s = 4.16 h 2

(ii) $\Delta W = ½\,C(V_1^2 - V_2^2) = 1.1(25 - 16)$ ; = 9.9 (J) 2

(iii) $4 = 5\exp(-t/1.5 \times 10^4)$ ; giving $t = 1.5 \times 10^4 \times \ln 1.25 = 3.3 \times 10^3$ (s) 2

(iv) $P = \Delta W/\Delta t = 9.9/3.3 \times 10^3 = 3.0$ mW *ecf b(ii) and (iii)* 1
*allow* $P = V_{av}^2/R = 4.5^2/6.8 \times 10^3 = 2.98$ mW

**[11]**

**32.** (a) (i) suitable pattern; arrows from + ion to – ion 2

(ii) $F = kQ_1Q_2/r^2$; $Q_1 = Q_2 = e$ (2)
$F = 9 \times 10^9 \times 1.6^2 \times 10^{-38}/25 \times 10^{-20} = 9.2 \times 10^{-10}$ (N) (2) 4

(b) (N2 gives) $F_H = m_H a_H$ and $F_I = m_I a_I$ (1)
(N3 gives) $F_H = F_I$ (1) *can be implicit*
SHM gives a $\alpha - x$ (1)
hence $x_H/x_I = a_H/a_I = m_I/m_H = 127$ (1) 4

| | | | | |
|---|---|---|---|---|
| | (c) | (i) | sine or cosine curve; amplitude $8.0 \times 10^{-12}$ m; period = $1.5 \times 10^{-14}$ s | 3 |
| | | (ii) | resonance situation; driving frequency of radiation = natural (1) frequency of oscillation of molecule/AW (1) | 2 |
| | | | | **[15]** |

**33.** A: the number of (undecayed) nuclei which decay per second/rate of decay of nuclei 1
λ: the probability of a given nucleus decaying in the next second or in unit time/the (decay) constant relates the activity to the number of undecayed nuclei 1
N: the number of undecayed nuclei/nuclei of the original nuclide (remaining) 1

**[3]**

**34.** (i) 90 and 234 1

(ii) $2 \times 10^{-6} \times 7.0 \times 10^{6} = 14$ (kg) 1

(iii) $N = (m/M)\, N_A = 14 \times 10^{3} \times 6 \times 10^{23}/238$ $(= 3.5 \times 10^{25})$ 1

(iv) $\lambda = 0.69/T = 0.69/4.5 \times 10^{9} \times 3.2 \times 10^{7} = 4.8 \times 10^{-18}$ $(s^{-1})$ 1
$A = \lambda N = 4.9 \times 10^{-18} \times 3.5 \times 10^{25} = 1.7 \times 10^{8}$; $s^{-1}$ or Bq 2

**[6]**

**35.** force per unit (positive) charge 1
force per unit mass 1
force per unit length of conductor carrying unit current; 1
perpendicular to field and current 1

*examples of similarities*:
all explain action at a distance 1
all forces per unit something…. 1
field lines never cross; density of lines indicates relative strength of field 2
E and g have the same laws/geometry, e.g. for point and/or plane distributions; 1
for E and g force in direction of field; field lines perpendicular to surface 2

*examples of differences:*

| | |
|---|---|
| forces caused by different entities; and act differently i.e. E and g different to B; | 1 |
| force caused by stationary versus moving charge; | 2 |
| direction of force for B given by F.L.H.rule, etc. | 2 |
| g is only attractive, E (and B) can cause attractive and repulsive forces | 1 |
| field lines for B field closed loops others start and finish on m,Q | 1 |
| magnitudes of forces very different for unit ……; detail. | 2 |
| *max 7 marks* | |
| quality of written communication | 2 |

**[9]**

**36.**

| | |
|---|---|
| magnetic flux = BA | 1 |
| meanings of B and A, i.e. flux density or field strength and area $\perp$ to it | 1 |
| magnetic flux linkage refers to the flux linking/passing through a coil; | 1 |
| and equals N × flux where N is the number of turns (of the coil) | 1 |
| Faraday's law: induced e.m.f./voltage is proportional to rate of change of flux linkage through it /correct mathematical formulation/AW | 1 |
| Lenz's law: the direction of the induced e.m.f./voltage is such as to oppose the motion/change that produced it | 1 |
| relationship of Lenz's law to conservation of energy or other valid explanation/discussion/description | 2 |
| *max 5 marks* | |
| quality of written communication | 2 |

**[7]**

**37.** (a) (to a maximum of 7 marks) e.g.

- X-ray source + detectors round patient …
- … rotated around patient …/ the signal / X-ray passes through the same section of the body from different directions.
- … producing a (thin) slice / cross-section.
- Idea of absorption / less gets through / more is absorbed …
- by dense material / bone / material of high Z / High Z related to materials such as bone / Low Z to materials such as soft tissue
- attenuation is by the photo-electric effect
- the possibility of using a contrast medium.
- better than a simple X-ray at differentiating other organs.
- patient is moved a small distance and the process is repeated / process continues in a spiral.
- a computer (analyses the data) / identifies the position of organ/bone …
- … and forms a 3-D image. 7

(b) • Patients are exposed to ionising radiation. (1)

- (Ionising radiation) could cause cancer / damage cells (1)

*Plus a maximum of ONE from:-e.g.* (1)

- It's expensive.
- Time consuming / uses valuable resources, etc.. 3

**[10]**

**38.** *[to a max. of **5**]*

- A p.d. / voltage must be applied …
- … causing the (piezoelectric) crystal to change shape.
- A named crystal (eg quartz, lead zirconate titanate [PZT], lithium sulphate, barium titanate)
- An alternating p.d. causes the crystal to oscillate / vibrate (accept resonate).
- If the frequency applied matches the natural frequency of the crystal, resonance occurs.
- The crystal is damped / stops vibrating when the applied voltage stops …
- … due to the backing material / epoxy resin …
- … which also absorbs backward-travelling sound waves (which might give spurious reflections). 5

**[5]**

**39.** (i)

- 5.4 cm +/– 0.1 cm read from the graph (1)
- $= 5.4 \times 20\ \mu s\ cm^{-1} \times 1.5 \times 10^3\ m\ s^{-1}$ (1)
- = 0.162 m (1)
- 0.162 / 2 = 0.081 m or 8.1 cm (1) 4

(ii)

- High reflection at the air-skin boundary / Little ultrasound enters the body / A very large peak right at the start … (1)
- … due to large difference in acoustic impedance / allow '…due to large difference in density'. (1)
- Very low peaks / no (subsequent) peaks (not just 'nothing') (1) 3

**[7]**

40. (i) (neutrons) having energies comparable with thermal energies / slow moving / low kinetic energy / energy in range 6 - 100 eV / energy similar to (energy of ) atoms of surroundings ; 1

(ii) *either* thermal neutrons will be captured / absorbed (by U-235 nuclei)
*or* higher energy neutrons do not get absorbed; 1

**[2]**

41. (i) 3 points plotted; any point incorrect loses this mark 1

(ii) curve through 3 points and heads down towards zero; (1)
line peaks between Br and origin; (1) 2

(iii) BE per *nucleus* of ${}^{235}_{92}U$ = 7.60 × 235 (= 1786 MeV)
BE of products = 8.20 × 146 + 8.60 × 87 both lines (1)
(= 1197 + 748 MeV)
so energy released = (1197 + 748) – 1786 (1)
= 159 MeV (1)
omits multiplication by nucleon number to get 9.2 MeV gets 0,1,0 = 1 3

**[6]**

42. confines / pulls together plasma / nuclei / ions / nucleons / protons; (1)
so increases density/ concentration / number per unit volume; (1)
and increases frequency / number of collisions among nuclei; (1)
gravitational attraction heats plasma / gravitational p.e. changed to heat; (1)
any 3

**[3]**

43. *either* area is potential / stored energy / work done / energy to overcome coulomb barrier
*or* minimum k.e. at infinity or AW; (1)

it is (minimum) energy needed for fusion; (1)

**[2]**

44. (i) reactant mass = 2 × 1.007 276 = 2.014 552 u
product mass = 2.013 553 + 0.000 549 = 2.014 102 u

so $\Delta m = 4.5 \times 10^{-4}$ u (1)
$E = \Delta m\, c^2$ (1)
$= 4.5 \times 10^{-4} \times (1.66 \times 10^{-27}) \times (3.0 \times 10^{8})^2 = 6.7 \times 10^{-14}$ J (1) 3

allow conversion using 1 u = 931 MeV

(ii) positron and electron annihilate 1

**[4]**

**45.** (a) number of *decayed* U-238 nuclei = ½ × number of *undecayed* U-238 nuclei; (1)
so 1/3 of U-238 has decayed and 2/3 of U-238 has not decayed; (1) 2
(so ratio = 2/3)

(b) *either* $\lambda = 0.693 / T_{½} = 0.693 / (4.47 \times 10^9)$ ($= 1.55 \times 10^{-10}$ $y^{-1}$) subs. (1)
$N = N_0 e^{-\lambda t}$ so $N / N_0 = e^{-\lambda t}$ and $\ln (N / N_0) = -\lambda t$
$\ln (0.667) = -1.55 \times 10^{-10} t$ alg. / arith. (1)
so $t = 2.61 \times 10^9$ y ans. (1) 3

*or* $N / N_0 = (½)^x$ so $0.667 = (½)^x$ and $\ln (0.667) = x \ln(0.5)$
and $x = 0.584$ then $t = x T_{½} = 0.584 \times 4.47 \times 10^9 = 2.61 \times 10^9$ y

(c) *either* $N_0 = (5.00 / 238) \times 6.02 \times 10^{23}$ subs. (1)
$= 1.26 \times 10^{22}$ atoms ans. (1) 2

*or* $N_0 = (5.00 \times 10^{-3}) / (1.67 \times 10^{-27} \times 238)$ (1)
$= 1.26 \times 10^{22}$ atoms (1)

(d) exponential decay graph for U: starts from $N_0$ and approaches $t$ axis; (1)
exponential growth of Pb from zero: approaches a constant value of $N_0$ ; (1)
lines sensibly 'mirror images'; (1) 3

**[10]**

**46.** (i) leptons; 1

(ii) neutrino / muon / tau(on); 1

**[2]**

**47.** (i) up down down / udd; 1

(ii)

| | Q | B | S | | |
|---|---|---|---|---|---|
| u | (+)2/3 | (+)1/3 | 0 | u values (1) | |
| d | –1/3 | (+)1/3 | 0 | d values (1) | 2 |

(iii) so for neutron $Q = 0$
$B = 1$
$S = 0$ 1

**[4]**

**48.** (a) one (or more) electrons removed (or added) to an atom 1

(b) E = hf = hc/λ together with knowledge of symbol meaning (1)

$= \dfrac{6.63\times10^{-34}\times3.00\times10^{8}}{238\times10^{-9}}$ (1)

$= 8.36 \times 10^{-19}$ (J) (1) 3

(c) frequency of UV is greater than frequency of light
OR alternative statement in terms of wavelength.
so photon energy of visible light is less than photon energy of UV (1)
PLUS one of the idea of conservation of energy
it is not possible for a low energy photon to give a high energy photon
this is a one to one process (1) 2

(d) E = V/d and power of 10 correct for d (1)
= 30/0.00020 = 150 000 (1)
V $m^{-1}$ (1) 3

**[9]**

**49.** (a) appropriate shape; lines perpendicular to and touching plate and sphere; (2)
arrows towards negative sphere (1) 3

(b) (i) By moments, e.g F cos 20 = W sin 20 / by triangle of forces /
by resolution of forces / other suitable method; *i.e. justification needed* (1)
$F = 1.0 \times 10^{-5}$ tan 20; $= 1.0 \times 10^{-5} \times 0.364$; ($= 3.64 \times 10^{-6}$ N) (2)
triangle of forces gives W/F = tan 70, etc (1) 3

(ii) E = F/Q; $= 3.64 \times 10^{-6} / 1.2 \times 10^{-9} = 3.0 \times 10^{3}$;N $C^{-1}$ / V $m^{-1}$ 3

(c) $E = (1/4\pi\varepsilon_o)Q/r^2$; $3.0 \times 10^3 = 9 \times 10^9 \times 1.2 \times 10^{-9}/r^2$; (2)
or use $F = (1/4\pi\varepsilon_o)Q^2/r^2$; $r^2 = 3.6 \times 10^{-3}$ giving $r = 6 \times 10^{-2}$ (m) (1) 3

(d) field line sketch *minimum of 5 lines symmetrical about line joining centres with arrows*; (1)
Fig 1 sketch matches RHS of Fig 2/plate analogous to mirror/AW relating to symmetry (1) 2

**[14]**

**50.** (a) 29; 34 2

(b) $\lambda = 0.693/T = 0.693/(120 \times 3.2 \times 10^7) = (1.8 \times 10^{-10}\ s^{-1})$ *accept ln 2* 1

(c) (i) $Q = CV = 1.2 \times 10^{-12} \times 90$; evidence of calculation ($= 1.1 \times 10^{-10}$ C) 2

(ii) $n = Q/e = 1.1 \times 10^{-10}/1.6 \times 10^{-19}$; $= 6.9 \times 10^8$ *allow sig. fig. variations* 2

(iii) $A = \lambda N$; $N = 6.9 \times 10^8/1.8 \times 10^{-10}$; $= 3.8 \times 10^{18}$ *using 7.0 gives 3.9* 3

(iv) 1 y is less than 1% of 120 y so expect to be within 1%/
using $e^{-\lambda t}$ gives exactly 1% fall/ problem of random emission
or other relevant statement 1

**[11]**

**51.** (a) (i) F is towards 'open' end of tube; using Fleming's L.H. rule 2

(ii) F = BIw 1

(iii) $F = 0.15 \times 800 \times 0.0025$; $= 3.0$ (N) 2

(b) (i) A voltage is induced across moving metal as it cuts lines of flux/AW; (1)
voltage is proportional to flux change per second/AW; (1)
the flux change per second is Bwv / is proportional to the area of metal moving through the field per second / is proportional to v (1)
**or** Faraday's law fully stated; with reasonable attempt to; (2)
relate flux linkage per second proportionally to speed (1) 3

(ii) flux (linkage) doubles; so using Faraday's law V doubles/AW 2

**[10]**

**52.** nature and features:
$\alpha$-particle is 2p + 2n/ mass 4 u (1)
charge of +2e (1)
very short range/heavily ionizing/absorbed by paper (1)
spontaneous; and random nature of radioactive decay (2)
energetically more favourable to eject four particles together than a single one/other comment about energy minimisation/mainly occurs from higher A nuclei/AW (1)
small mass decrease/loss provides kinetic energy of $\alpha$-particle (1)
particle energy of a few MeV; particular decay is monoenergetic (2)
$\alpha$-particle scattering:
suitable diagram **and/or** description to illustrate experiment *up to 2 marks* (2)
most particles have little if any deflection (1)
large deflection of very few shows nucleus is small; and very massive (2)
(Coulomb's law enables closest approach to) estimate nuclear size
(in case of $\alpha$-particle back scattering with conservation of energy argument) max 7
Quality of Written Communication 2

**[9]**

**53.** description:
(4) hydrogen or light nuclei/protons are fused together to form a helium/heavier/larger nucleus; (1)
two positrons must also be released; to conserve charge; (2)
the process is more complicated than the summary equation suggests/AW;
mass reduction provides energy release/ $\Delta m = \Delta E/c^2$ (1)
the process requires very high temperatures (to bring the protons together); (1)
normally achieved inside a star; only by man in a bomb so far; (1)
comparison: (2)
Energy release in fusion is much greater than in radioactive decay;
because mass reduction/change in fusion is much greater than in radioactive (1) decay/AW; (1)
as the helium nucleus is so strongly bound; (1)
also energy release from annihilation of positrons; (1) max 5
Quality of Written Communication 2

**[7]**

**54.** $(5.2 \times 1.5 \times 10^{11}) = 7.80 \times 10^{11}$m 1

**[1]**

**55.** Hydrogen atoms/particles (1)
Collapse under gravity/ decrease of gpe (1)
Increase in kinetic energy/ temperature (1)
Fusion of protons (1)
Energy released/ ref. to $E = \Delta mc^2$ (1)

**[5]**

**56.** $v \alpha r$ / $v = H_o \times r$ (1)
labels (including one reference to Earth/Sun/Galaxy) (1) 2

**[2]**

**57.** infinite Universe (1)
all lines of sight end on star (1)
so night sky should be bright/ not dark (1)

either
expanding Universe/light undergoes red shift (1)
more distant galaxies have greater red shift (1)
or
age of Universe is finite (1)
light from distant stars not yet reached Earth (1)

**[5]**

**58.** (i) **accept description of plan view or side view.**
side: central bulge (1)
galactic disc <u>each side (1)</u>
plan: accumulation of stars in centre. (1)
spiral arms (minimum of 2 arms) (1) 2

(ii) correct position of Sun (accept 28000ly from centre) (1) 1

**[3]**

**59.** (i) hydrogen / helium gas (1)
formed after big bang / remnants of supernovas (1)

(ii) critical density is condition for flat Universe. (1)
dark matter increases density of Universe. (1)
density greater than critical density. (1)
Universe will contract / big crunch. (1)

**[6]**

**60.** **Formation of image to a max 3** e.g.

X-rays are detected by a film / scintillation counter etc., (1)
High 'Z' means high attenuation / low transmission
[Allow atomic mass / nucleon number] (1)
shadow on the film / reference to exposure after attenuation (1)
Reference to photoelectric effect / energy range around 1–100keV /
absorption $\infty Z^3$ (1)

**Explanation of the use of a contrast medium to a max.4 e.g.**

X-rays do not differentiate / show up soft tissues well …(1)
… as similar absorption / 'Z' is similar / 'Z' is low for these tissues. (1)
Contrast medium has high 'Z' / absorbs X-rays strongly.(1)
It is usually taken orally / as an enema / can be injected.(1)

**Example of type of structure that can be imaged to a max.1 e.g.**

digestive tract / throat / stomach.(1) to a max. 8

**[8]**

**61.** (a) 6 points plotted correctly (1)
remaining point plotted correctly (1)
sensible continuous smooth graph drawn (1) 3

(b) (i) 0.95 +/– 0.10 mm (1) 1

(ii) $I / I_o = e^{-x}$ (1)
$0.50 = e^{-0.0009}$ (1)
$\mu = 730$ (1)
$m^{-1}$ (1) 4

**[8]**

**62.** (a) forces $F_S$ and $F_G$ acting inwards, force $F_E$ acting outwards - all through centre of proton;
3 forces 2/2, 2 forces 1/2, marked and labelled (2) 2

(b) $F_E = F_S + F_G$;
accept $F_E + F_S + F_G = 0$ *allow ecf from (a)* (1) 1

(c) (i) $F_E = Q^2 / (4\pi\ \varepsilon_0\ r^2)$ (1)
$= (1.6 \times 10^{-19})^2 / [4\pi \times 8.85 \times 10^{-12} (2.8 \times 10^{-15})^2] = 29$ N (1)
use of $r = 1.4 \times 10^{-15}$ m (–1) once only 2

(ii) $F_G = m^2 G / r^2$ (1)
$= (1.67 \times 10^{-27})^2 \times 6.67 \times 10^{-11} / (2.8 \times 10^{-15})^2 = 2.4 \times 10^{-35}$ N (1) 2

(iii) $F_S = 29$ N / same as $F_E$ *allow ecf* (1) 1

(d) $F_E >> F_G$ so $F_G$ negligible / insignificant / can be ignored or AW (1) 1

(e) (i) $F_E = 0$ (1) 1

(ii) $F_G = 2.4 \times 10^{-35}$ N (approx.) allow ecf (1) 1

(iii) $F_S = 2.4 \times 10^{-35}$ N (approx.) (1)

*comment*: $F_S$ now repulsive (not attractive) or AW
*or* indicated by minus sign with $F_S$; (1) *any 3* 1

**[12]**

**63.** (a) (i) $^{238}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{239}_{92}\text{U}$ 1

(ii) $^{239}_{92}\text{U} \rightarrow ^{239}_{93}\text{X} + ^{0}_{-1}\text{e} + ^{0}_{0}\text{v}\,(-\text{bar})$ 2

(iii) $^{239}_{93}\text{X} \rightarrow ^{239}_{94}\text{Pu} + ^{0}_{-1}\text{e} + ^{0}_{0}\text{v}\,(-\text{bar})$ 1
omits any neutrino (–1) once only
electron incorrectly represented (–1) once only

(b) (i) 24 000 year / >24 000 year 1

(ii) $\lambda = \ln 2 / T_{1/2} = \ln 2 / (24000 \times 365 \times 24 \times 3600)$ *subs*. (1)
$= 9.16 \times 10^{-13}$ s$^{-1}$ or $< 9.16 \times 10^{-13}$ s$^{-1}$ *ans*. (1) 2
failure to convert years to s, giving $2.89 \times 10^{-5}$, gets 1/2

(c) (i) 239 g of Pu contain $6.02 \times 10^{23}$ atoms *or* alternative correct use of $N_A$ (1)
$N = (0.05 \times 4.4 / 0.239) \times 6.02 \times 10^{23}$ ie applies % and units correctly (1) 2
($= 5.54 \times 10^{23}$ (atoms))

(ii) activity $= \lambda N$ (1)
$= 9.16 \times 10^{-13} \times 5.54 \times 10^{23}$ *allow ecf*
$= 5.08 \times 10^{11}$ Bq / s$^{-1}$ *ans.* + *unit* (2) 3

**[12]**

**64.** (a) p.e. increases (1)
k.e. decreases (1)
*or* k.e. is converted to p.e. gets 2/2
eventually all k.e. is changed to p.e. (1) 3

(b) $E_P = (1.6 \times 10^{-19})^2 / (4\,\pi \times 8.85 \times 10^{-12} \times 2.1 \times 10^{-15})$ (= $1.1 \times 10^{-13}$ J) (1)
so k.e. of each proton = ½ × $1.1 \times 10^{-13} = 5.5 \times 10^{-14}$ J (1) 2

(c) $5.5 \times 10^{-14} = 2.07 \times 10^{-23}$ T so T = $2.7 \times 10^9$ K *ans*. (1)
accept $2.6 \times 10^9$ K 1

(d) *either*:
$E_K$ is the *mean* k.e. of protons (1)
protons (in plasma) have a range of k.e.s (1) *any 1*
so (at any instant) some protons have much greater k.e. than average
*or:*
protons can fuse for separations > 2.1 fm (1)
because of (quantum) tunnelling (effects) (1) 2

(e) (i) $2 \times (2.3 \times 10^{-13}) + 2 \times (8.8 \times 10^{-13}) + (20.6 \times 10^{-13}) = 42.8 \times 10^{-13}$ J (2) 2
adds energies, without × 2 gives $31.7 \times 10^{-13}$ J for 1/2

(ii) 2 neutrinos escape from the Sun (and carry away energy) (1) 1

(f) *either* $T\ (\infty\ E_K) \infty\ Q_1Q_2$
and $Q_1Q_2$ is greater for reactions in carbon cycle (eg 1 × 12 > 1 × 1);
*or* verbally: repulsion is greater between nuclei in carbon cycle; (1)

greater repulsion / Coulomb barrier means more energy needed
(so higher temp.) (1) 2

**[13]**

**65.** (a) $\beta^+$: ${}^{192}_{79}\text{Au} \rightarrow {}^{0}_{1}\text{e} + {}^{192}_{78}\text{Pt} + {}^{0}_{0}\text{v}$ (1)
$\beta^-$: ${}^{192}_{79}\text{Au} \rightarrow {}^{0}_{-1}\text{e} + {}^{192}_{80}\text{Hg} + {}^{0}_{0}\text{v}$ (–bar) (1) 2
omits both neutrinos gets 1/2 max.

(b) $\beta^+$ decay: reactant mass = 191.921 47 u
product mass = 191.918 24 + 0.000 55 = 191.918 79 u (1)
products mass < reactant mass so reaction can occur (1)

$\beta^-$ decay: (reactant mass = 191.921 47 u)
product mass = 191.921 41 + 0.000 55 = 191.921 96 u
products mass > reactant mass so reaction cannot occur (1) 5

(c) $\beta^+$ mass defect / mass loss= 191.921 47 – 191.918 79 (1)
(= 0.002 68 u)

*then either:* mass loss in kg = $0.002\,68 \times 1.66 \times 10^{-27}$ (1)
(= $4.45 \times 10^{-30}$ kg)

so energy loss = $\Delta m\, c^2$ (1)
$4.45 \times 10^{-30} \times (3.0 \times 10^8)^2$
= $4.00 \times 10^{-13}$ J (1)

*or* : 0.002 68u = $0.002\,68 \times 932$ MeV (2)
= (2.50 MeV)
= $2.50 \times 10^6 \times 1.6 \times 10^{-19}$ (1)
= $4.00 \times 10^{-13}$ J (1)

accept 930 – 934 MeV $u^{-1}$ giving 3.99 – 4.00(5) $\times 10^{-13}$ J 4

**[11]**

**66.** all free hadrons (thought to be) (somewhat) unstable; (1)
protons and neutrons are (both) hadrons; (1) + (1)
protons and neutrons inside a nucleus are stable; (1)
free neutrons have half life of 10 - 15 minutes; (1)
free protons are stable / have half life of about $10^{32}$ year; (1) any 5
allow equivalent marks for other hadrons and / or other relevant points

**[5]**

**67.** (i) weak (force / interaction); (1) 1

(ii) ${}^3_1H \rightarrow {}^3_2He + {}^0_{-1}e + \bar{\nu}$ ; (1) 1

(iii) $d \rightarrow u + e + \bar{\nu}$ ; (2)

$d \rightarrow u$ gets 1/2

u
$d \rightarrow u + e / \beta + \bar{\nu}$ is not in simplest form, so gets ½
d

baryon reaction ${}^1_0n \rightarrow {}^1_1p + {}^0_{-1}e + \bar{\nu}$ gets ½ 2

**[4]**

**68.** fission is when splitting (into two parts releasing energy) takes place and fusion is when joining together takes place (1)
nuclei as the active particles (1) 2

**[2]**

**69.** (a) (i)

| capacitor | capacitance / μF | charge / μC | p.d. / V | energy / μJ |
|---|---|---|---|---|
| X | 5 | 30 | $= Q/C$<br>= 6 (V) (1) | $= \frac{1}{2} CV^2$(1)<br>$= \frac{1}{2} \times 5 \times 6^2$<br>= 90 (1) |
| Y | 25 | $= CV$<br>$= 25 \times 6$<br>=150 (μC) (1) | = 6 (V) (1) | = 450 (1) |
| Z | 10 | 30 + 150 =<br>180 (μC) (1) | $= Q/C$<br>= 180/10<br>= 18 (V) (1) | = 1620 (1) |

Each box correctly calculated scores (1) + (1) for $\frac{1}{2} CV^2$ 9

(ii) **1** 18 V + 6 V = 24 (V) (1)

**2** 180 (μC) (1)

**3** 180 / 24 = 7.5 (1)

**4** 90 + 450 + 1620 = 2160 (μJ) (1) 4

(b) (i) Kirchhoff's second law OR conservation of energy (1) 1

(ii) Kirchhoff's first law OR conservation of charge (1) 1

(c) (i) time constant = $CR$ (1)
$= 7.5 \times 10^{-6} \times 200\,000 = 1.5$ (s) (1) 2

(ii) $Q = Q_o e^{-\frac{4CR}{CR}}$ (1)
$Q/Q_o = e^{-4} = 0.0183$ (1) 2

**[19]**

**70.** (a) zero (do not allow 'small') (1) 1

(b) 300 W for 1 watt therefore 300 W × 20 for 20 W 6000 W (1) 1

(c) e.g. if run at 92 K there is a danger that superconductivity will cease as a result of a slight temperature rise (1)
a 15 K difference provides a safety region (1)
77 K is the boiling point of liquid nitrogen (1)
other sensible suggestion (1) 2
*MAXIMUM (2)*

(d) (i) area of cross-section of wire = $10^{-6}$ m$^2$ (1)
current = $10^{-6}$ m$^2$ × 2.0 × $10^8$ A m$^{-2}$ (1)
= 200 A (0) 2

(ii) $B = \dfrac{1.26 \times 10^{-6} \times 200 \times 3200}{2 \times 0.30}$ (1)
= 1.34 T (1) 2

(e) (i) $F = BQv$ (1) 1

(ii) $BQv = \mathrm{m} \times \dfrac{v^2}{r}$ (1)
$r = mv/BQ$ (1)
$m = 235 \times 1.66 \times 10^{-27}$ kg (1)
$r = \dfrac{235 \times 1.66 \times 10^{-27} \times 8.3 \times 10^5}{1.34 \times 1.6 \times 10^{-19}}$ = 1.51 m (1) 4

(iii) circular paths for both ions (1)
U–235 ion with slightly smaller radius (1)
paths curving upwards (1) 3

**[16]**

**71.** (a) (mv =) 300; kg m s$^{-1}$ **or** N s (2) 2

(b) (i) (The speed of the bar increases so) it is accelerated forwards/AW; (1)
this requires a resultant (forward) force/F = ma idea (1) 2

(ii) Arrow in direction of motion/to right (1) 1

(iii) (t = s/v = 3.0/0.60 =) 5.0 s (1) 1

(iv) F = m (v – u)/t; = 500 × 1.2/5.0; = 120 (N) *ecf b (iii)* (3) 3

(c) γ ray source; (1)
the <u>only</u> radiation with sufficient penetrating power/ability to discriminate between different thicknesses/AW (1) 2

**[11]**

**72.** (a) (i) 5.0 (V) (1) 1

(ii) 10.0 (V) (1) 1

(b) (i) $Q = CV; = 1.0 \times 10^{-3}$ (C) (2) 2

(ii) The total capacitance of each circuit is the same (namely 100 μF); (1)
because capacitors in series add as reciprocals/ in parallel add/
supply voltage is the same and Q = VC, etc. (1) *max 2 marks* 2

(c) (i) A1 will give the same reading as A2; because the two ammeters are (1)
connected in series /AW (1) 2
*answer only in terms of exponential decrease for a maximum of 1 mark*

(ii) A4 will show the same reading as A2 at all times; (1)
A3 will show half the reading of A2 initially;
and at <u>all</u> subsequent times (2) 3

**[11]**

**73.** (a) Positive as E-field is downwards/top plate is positive/like charges repel/AW (1) 1

(b) (i) k.e. = QV; $= 300 \times 1.6 \times 10^{-19} = (4.8 \times 10^{-17}$ J) (2) 2

(ii) $1/2mv^2 = 4.8 \times 10^{-17}; = 0.5 \times 2.3 \times 10^{-26} \times v^2$ so $v^2 = 4.17 \times 10^9$;
(giving $v = 6.46 \times 10^4$ m $s^{-1}$) (2) 2

(c) E = V/d; so $d = V/E = 600/4 \times 10^4 = 0.015$ m (2) 2

(d) (i) semicircle to right of hole (1) *ecf(a); (a) and d(i) to be consistent* 1

(ii) $mv^2/r; = BQv$; (2)
giving $r = mv/BQ = 2.3 \times 10^{-26} \times 6.5 \times 10^4/(0.17 \times 1.6 \times 10^{-19})$; (1)
r = 55 mm;so distance = 2r = 0.11 m (2) 5

**[13]**

**74.** (a) (i) 138 (1) 1

(ii) 86 (1) 1

(b) (i) $\lambda = 0.693/1600 \times 3.16 \times 10^7 = 1.4 \times 10^{-11}\ s^{-1}$ (1) 1

(ii) $A = \lambda N$; $N = 6.02 \times 10^{23}/226$; evidence of calculation to give 3.6 or (2)
$3.7 \times 10^{10}$ Bq (1) 3

(c) $\Delta m = 0.0053$ u ($= 8.8 \times 10^{-30}$ kg); (1)
$E = c^2\Delta m$; $= 9 \times 8.8 \times 10^{-14} = 7.9 \times 10^{-13}$ (J) (2) 3

(d) $Q = mc\theta$; so $0.8 \times 3.7 \times 10^{10} \times 7.9 \times 10^{-13} = 0.001 \times 110\ \theta$: (2)
giving $\theta = 0.213\ K\ s^{-1}$; and $t = 1/\theta = 4.7$ s (2)
or $Q = mc\theta$; $Q/K = 0.001 \times 110 = 0.11\ J\ K^{-1}$; (2)
$Q/s = 0.0234$ J; so $t = 0.11/0.0234 = 4.7$ s (2) 4

**[13]**

**75.** Faraday's law: the emf/voltage induced across a coil/component/circuit is (1)
proportional to the rate of change of flux (linkage) through it /AW (1)
magnetic flux = BA; (1)
meanings of B and A, i.e. flux density or field strength and area ( $\perp$ to it) (1)
magnetic flux linkage refers to the flux linking/passing through a coil; (1)
and equals N × flux where N is the number of turns of the coil (1) max 5
Quality of Written Communication 2

**[7]**

**76.** sine or cosine wave of regular period and amplitude (1)
V doubles when the speed v of rotation of the coil doubles; (1)
when v doubles the rate of change of flux linking the coil doubles; (1)
the frequency of the a.c. signal doubles/period halves/AW (1)
V doubles when the number n of turns on the coil doubles; (1)
when n doubles there is twice as much flux linking the coil/AW; (1)
the frequency/period of the signal is unchanged; (1)
without iron core flux linking coil is much less/flux would spread in all
directions/flux not channelled through low reluctance path/AW (1)
amplitude of output voltage is smaller (1)
*actually is tiny/negligible/mV rather than V* max 7
Quality of Written Communication 2

**[9]**

**77.** **any 4 from:**
end of H burning/red giant/supergiant (1)
onset of He fusion/fusion of heavier nuclei (1)
gravitational collapse of core (1)
supernova explosion/ star explodes (1)
suitable mass limit (chanderasekha limit 1.4M) (1)
supported against gavity by neutron gas pressure/ ref to Fermi pressure (1)
internal structure protons and electrons combined/ very thin atmosphere/ metallic crust (1) — 4

**[4]**

**78.** (i) volume = $4\pi (10{,}000)^3 /3 = 4.2 \times 10^{12}$ (1)
density = $3.5 \times 10^{30} / 4.2 \times 10^{12}$ ecf (1)
density = $8.4 \times 10^{17}$ kg/m$^3$ (1) — 3

(ii) any **two** from
density (very) much greater than material on Earth (1)
quotes typical density on Earth $1 - 10^4$ kg m$^{-3}$ (1)
atomic structure collapsed / density same as atomic nucleus (1) — 2

**[5]**

**79.** (i) energies/temperatures irreproducible on Earth / laws of Physics break down (1) — 1

(ii) temperature decreases (1)
universe expanding/work done against attractive forces/ energy converted to mass (1) — 2

(iii) **any 3** from
protons and electrons separate initially (1)
matter-radiation equilibrium/charge prevents passage of em waves (1)
proton-electron recombination /formation of atoms (1)
gamma/ em waves no longer absorbed (1) — 3

**[6]**

**80.** **any 5** from:
star-light shows red shift (1)
galaxies (stars) receding from Earth (1)
recessional velocity proportional to distance (1)
cosmological microwave background radiation (CMBR) (1)
uniform intensity in all directions (1)
small ripple (1)
(black body temperature) 2.7 K (3K) (1)
High ratio of helium to hydrogen (1)
Indicates very high temperatures existed (1)
ratio too high to originate from stellar fusion (1) 5

**[5]**

**81.** isotropic (1)
homogenous (1) 2

**[2]**

**82.** (i) $H_0 = 75 / 3.1 \times 10^{19}$ (1)
$t_0 = 1 / H_0 = 4.13 \times 10^{17}$ s (1)
$t_0 = 4.13 \times 10^{17}$ s $/ 365 \times 24 \times 3600 = 1.3 \times 10^{10}$y (1) 3

(ii) any two from
universe expands to a limit/ flat universe (1)
but never reaches that limit (1)
density of universe = critical density (1) 2

(iii) curve: passes through P (1)
curves over and back to time axis (1) 2

(iv) Universe not so old (no ecf from (iii)/ Universe will end
in big crunch (no ecf from iii) / universe has finite lifetime (1) 1

**[8]**

**83.** (a) The intensity of sunlight is too small (inverse square law) or
The area of panel required would be too large/massive to launch 1

(b) (i) Energy required = V I t
$= 12 \times 5 \times 120 \times 60$ (1)
$= 4.32 \times 10^5$ J (1) 2

(ii) Steady power required = $(4.32 \times 10^5 \times 100/25) \div 24 \times 3600$ (2)
= 20 W (18.5W if 0.40 MJ used) 2
(or $P = VI = 12 \times 5 = 60$W for 2h so only 5W for 24h if 100% efficient but $= 5 / 0.25 = 20$W)

(iii) Energy carried by alpha $= 5 \times 10^6 \times 1.6 \times 10^{-19} = 8.0 \times 10^{-13}$ J (1)
Activity required $= 20 \div (8 \times 10^{-13})$
$= 2.5 \times 10^{13}$ Bq (1) 2
(or 0.432MJ / $8 \times 10^{-13}$ J alphas per day = 0.432 MJ / $8 \times 10^{-13}$ / $24 \times 3600$ alphas per sec)

(c) Decay constant of Pu 238 = $0.69 / T_{½}$
$= 0.69 / 88 \times 365 \times 24 \times 3600$
$= 2.5 \times 10^{-10}$ sec$^{-1}$ (2)
(allow mark for conversion of 88 years to $2.78 \times 10^9$ seconds)

Number of nuclei required $= A / \lambda = 2.5 \times 10^{13} / 2.5 \times 10^{-10}$ (1)
$= 1.0 \times 10^{23}$ (1)
(allow mark for formula $A = \lambda N$)
Mass required $= 1.0 \times 10^{23} \times 238 / 6.02 \times 10^{23}$ (1)
= 40 gms = 0.040 kg (1) 6

(d) On launch, the rocket gives the spacecraft a huge kinetic energy (in order to escape)
Failure at this point could cause spacecraft and contents to “burn up” in atmosphere
But plutonium would still be radioactive and being vaporised it could be ingested.
Sensible comment on danger periods of launch (or re-entry)
Sensible comment on mechanism of ingesting Plutonium
Allow one sensible comment on no risks in the isolation of deep space 2

**[15]**

**84.** X-ray (photons penetrate patient (1)
attenuation by different media / bones attenuate more than soft tissue (1)
less X-ray reach film under bone / shadow effect (1)
intensity of X-rays is proportional to darkening of film / ref. To fogging or blackening (1)

X-ray photons hit crystals / atoms in intensifying layer (1)
atoms become excited / fluorescence occurs (1)
emitting light (photons) (1)
**detail**: as they return to ground state (1)
so extra fogging of film (1)
**detail**: metal backing stops X-rays passing through / film more sensitive to light than X-rays / most X-rays pass through the film / double sided / photographic film / more contrast but not clearer (1)

Response is quicker / less X-rays needed (1)
so less exposure (1) **to maximum of 8** 8

**[8]**

**85.** alternating voltage or alternating E-field across crystal (1)
at resonant frequency (1) allow reference to resonance of crystal 2

**[2]**

**86.** (i) position of 3 lower oxygen ions closer to positive plate (1) 1

(ii) ref. to change in dimension / shape / distort/ it gets longer (1) 1

**[2]**

**87.** (a) (i) Z for air is 429 (kg $m^{-2}$ $s^{-1}$) and
Z for skin is $1.71 \times 10^6$ (kg $m^{-2}s^{-1}$) (1)

Substitution into equation leading to F = 0.999 (1) 2

(ii) with gel, more ultrasound enters body / without gel, most ultrasound is reflected (1)

most ultrasound is reflected (without gel) when the difference in Z is large
or
most ultrasound enters body when the different in Z is small (1) 2

(b) **1.5** cm × 1 × $10^{-5}$ = 1.5 × $10^{-5}$ s (1)

s = vt or **4080** × 1.5 × $10^{-5}$ (1)

s = 6.12 cm (1) *ecf if speed is wrong*

/2 = 3.06 cm (1) 4

**[8]**

**88.** At least 3 field lines inside solenoid parallel to axis; (1)
Lines equally spaced over some of length of solenoid. (1)
Arrows on lines pointing left to right. (1) 3

**[3]**

**89.** (a) similar mass means large momentum transfer (in collision); (1)
hence fewer collisions are needed; (1) 2

neutron colliding with heavy nucleus bounces off with similar speed / k.e. scores 1/2 max.

neutron colliding with similar mass nucleus transfers large k.e. / speed scores 1/2 max.

(b) ${}^{236}_{92}U \rightarrow {}^{110}_{45}Rh + {}^{121}_{47}Ag + 5{}^{1}_{0}n$ (2)
allow ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{110}_{45}Rh + {}^{121}_{47}Ag + 5{}^{1}_{0}n$

no neutrons 0/2, incorrect number of neutrons ½
$5{}^{1}_{0}N$ gets 1/2 max. ${}^{5}_{0}n$ gets 0/2
if ${}^{1}_{0}$ missing from neutron symbol, 1/2 max.

${}^{236}_{92}U + {}^{1}_{0}n \rightarrow {}^{110}_{45}Rh + {}^{121}_{47}Ag + 6{}^{1}_{0}n$ gets ½ 2

**[4]**

**90.** neutron is udd / proton is uud; (1)
quarks are: up down strange top bottom charm; (1)
*either* up / u has $Q$ = (+)2/3, $B$ = (+)1/3;
*or* down / d has $Q$ = –1/3, $B$ = (+)1/3; (1)

quarks are fundamental particles; (1)
for every quark there is an antiquark; (1)
antiquarks have opposite values of $Q$, $B$ and $S$ (compared to quark) (1)
quarks are held together by strong force / gluons (1)
$Q$, $B$ and $S$ are conserved in (quark) reactions (1) *any 2* 5

**[5]**

**91.** (a) (i) calculates b.e. per nucleus: $1.11 \times 2$ (= 2.22)
$2.57 \times 3$ (= 7.71) *both expressions* (1)
so energy released $= 7.71 - 2 \times 2.22$ (= 3.27 MeV) (1)
$= 3.27 \times 10^6 \times 1.6 \times 10^{-19}$
$= 5.2(3) \times 10^{-13}$ J (1) 3

omits multiplication by 2 and 3, 1/3 max.

(ii) reaction 2 generates more energy (than reaction 1); (1) 1

(b) initial mtm. = final mtm.
so $0 = m_H v_H + m_n v_n$ (1)
$0 = (4\, m_n)v_H + m_n v_n$ so $v_n = 4\, v_H$ (1)
k.e. of ${}^4_2$He $= ½\, m_H\, v_H^2$ k.e. equation applied (to n or He) (1)
$= ½\,(4m_n)\, v_H^2 = 2\, m_n\, v_H^2$
k.e. of ${}^1_0$n $= ½\, m_n\, v_n^2 = ½\, m_n\,(4v_H)^2 = 8\, m_n\, v_H^2$ *alg.* (1)
*either* k.e. of ${}^1_0$n = 4 × (k.e. of He)
*or* ${}^1_0$n has 80% of total energy (1) 5

80% unsupported scores 1/5
k.e. stated to be proportional to 1/(mass) scores 2/5 if correct answer obtained

**[9]**

**92.** (i) In J: $E = m\, c^2$ (1)
$= (2 \times 1.67 \times 10^{-27}) \times (3.0 \times 10^8)^2$ ($= 3.0 \times 10^{-10}$ J) *subs.* (1)
In GeV: $3.0 \times 10^{-10} = 3.0 \times 10^{-10} / (1.6 \times 10^{-19} \times 10^9)$
= 1.88 GeV *ans.* (1) 3

allow 1.9 GeV
uses only one mass, can get 2/3 max.

(ii) particle mass increases with energy / speed; (1)
accelerating voltage gets out of step with passage of particle between electrodes / if voltage out of synch. proton energy cannot increase or AW; (1)
1.88 GeV is high enough to cause (significant) mass increase; (1) 3

**[6]**

**93.** (a) Np graph: graph has exponential shape / there is exponential decay of Np nuclei / number (of Np nuclei) is halved in 2.3 days / constant time / in its half life; (1)

Pu graph: sum of Pu + Np nuclei = $3.0 \times 10^{20}$ at all times; (1)

*either* because <u>one</u> Np nucleus decays to <u>one</u> Pu nucleus
*or* rate of decay of Np and formation of Pu are equal; (1)

and half life of Pu >> / <u>much</u> bigger than half life of Np; (1) 3
*any 2 (2)*

(b) time required = time for Np nucleus to fall to $0.30 \times 10^{20}$; (1)

then *either* $N = N_0\,(½)^{t/T½}$ (1)
so $N/N_0 = (½)^{t/T½}$ $\lg(N/N_0) = t/T_{½}\,(\lg 0.5)$ $\lg(0.1) = t/2.36\,\lg(0.5)$ (1)
$t = 7.8$ days (1)

*or* uses $N = N_0\,e^{-\lambda t}$ where $\lambda = \ln 2 / 2.36$ (= 0.294 day$^{-1}$) (1)
so $0.1 = e^{-0.294\,t}$ (1)
$\ln(0.1) = -0.294\,t$ $t = 7.8$ days (1)

*or* $\lambda = \ln 2 / (2.36 \times 24 \times 3600) = 3.41 \times 10^{-6}\ s^{-1}$ (1)
$0.1 = e^{-3.41 \times 10\exp(-6)\,t}$ $\ln(0.1) = -3.41 \times 10^{-6}\,t$ (1)
$t = 6.76 \times 10^5$ s $= 6.76 \times 10^5 / (24 \times 3600) = 7.8$ days (1) 4

calculates time for Np to fall to $2.7 \times 10^{20}$ / Pu to rise to $0.3 \times 10^{20}$ = 0.36 day gets 0 1 1 1 = 3/4

uses $T_{½}$ for plutonium can get 2/4 max.

attempts to use repeated halving of $N$ can get 2/4 max. if using 0.3 (not 2.7)

**[7]**

**94.** (a) equally spaced horizontal parallel lines from plate to plate; arrows towards B; quality mark 3

(b) E = V/d; = 600/0.04;(= $1.5 \times 10^4$ V m$^{-1}$) 2

(c) F = QE / $1.6 \times 10^{-19} \times 1.5 \times 10^4$;= $2.4 \times 10^{-15}$ (N) 2

(d) $1/2mv^2$ = Fd **or** QV; = $1.6 \times 10^{-19} \times 600$ or = $2.4 \times 10^{-15} \times 0.04$ *ecf (c)* 2
**or** alternative method by constant acceleration formulae;
(either method giving $v^2 = 2.1 \times 10^{14}$ and $v = 1.45 \times 10^7$ m s$^{-1}$)

(e) $\sqrt{2}v = 2.05 \times 10^7$ (m s$^{-1}$) 1

(f) fewer electrons will reach grid B **or** C (as higher initial speed required); so current will fall (to zero if beam is taken to be monoenergetic) 2

**[12]**

**95.** (i) C = Q/V or gradient of graph / = 24 μC/3V; = 8.0 (μF) 2

(ii) $E = ½ CV^2$ / = ½ × 8 × $3^2$; = 36 (μJ) *ecf a(i)* 2
or ½ QV / = ½ × 24 × 3; = 36 (μJ)

(iii) T = RC = (0.04); R = 0.04/8.0μ = 5.0 × $10^3$ (Ω) *ecf a(i)* 2

(iv) idea of exponential/constant ratio in equal times; which is independent of initial value/AW or argued mathematically in terms of $Q/Q_o = e^{-t/RC}$
*give 1 mark for statement that time depends only on time constant/RC* 2

**[8]**

**96.** (i) $C_p$ = C + C = 6 μF; $1/C_s$ = 1/2C + 1/C; = 3/2C giving Cs = 2C/3 = (2 μF) 3

(ii) 2 sets of (3 in series) in parallel/ 3 sets of (2 in parallel) in series 2

**[5]**

**97.** (i) number of decays/atoms/nuclei decaying per second/unit time in the source/AW 1
count (rate) without source present/AW 1

(ii) distance of detector from source/dimensions of source or detector window/efficiency of detector/rate of emission v detection, e.g dead time correction/other sensible suggestion; 1
reason/effect on count rate 1

**[4]**

**98.** (i) (take lns of both sides) appreciate $\ln e^{-\lambda t} = -\lambda t$; and $\ln C/C_o = \ln C - \ln C_o$
**or** when multiplying logs add 2

(ii) gradient = 0.056 $h^{-1}$ *allow ± 0.002 $h^{-}$*; T = ln2/λ = ln2/gradient = ln2/0.056 h;
T = 12.4 h *allow ± 0.4 h* 3

**[5]**

**99.** mass change/charge change/range/speed of emission/monoenergetic v range of speed/alpha emitted from only high mass nuclei/number of particles in the decay/other sensible suggestion **or** further detail

*any three* 3

**[3]**

**100.** (a) (i) BA / = 0.05 × 0.05 × 0.026; = 6.5 × $10^{-5}$; Wb/T $m^2$ 3

(ii) BA sin 45°/BAcos 45° = 4.6 × $10^{-5}$ Wb *ecf (a)i* 1

(iii) 0 1

(b) (i) a point where curve crosses t-axis 1

(ii) voltage is proportional to the rate of change of flux linking the coil; 1
rate of flux change is zero/very small when the flux linking the coil is a maximum 1

(iii) sinusoidal curve; of double the amplitude; and half the period 3

**[11]**

**101.** proves existence of a nucleus to the atom; 1
containing most of the atomic mass; because of bouncing back; 2
of very small size; because of few scattered through any angles at all; 2
containing charged particles; because the scattering is consistent with 1
the pattern predicted by Coulomb/electrostatic repulsion; 1

electrons have opposite/smaller charge; and a much smaller mass; 2
a diffraction pattern is observed (superimposed on the Rutherford scattering curve); 1
as the electrons behave like waves; with a λ of the order of d for 1
significant scattering/having a de Broglie wavelength; 1
pattern/size of ring enables radius of the nucleus to be found *max 7* 1
Quality of Written Communication 2

**[9]**

**102.** (a) uniform intensity detected in all directions/ isotropic 1

(b) Hydrogen and helium in early stars and sun 1
Sun has greater proportion of helium than early stars/
H changed to He by fusion in sun. 1
Virtually no higher elements in first stars/ sun contains
traces of higher elements (accept specific examples up to iron) 1

**[4]**

**103.** Any 5 from
red shift data for galaxies (accept stars) 1
calculate velocity from red shift 1
galaxies/ stars receding from Earth 1
distance data for galaxies/ stars 1
velocity α distance / v/r = constant / v-r graph straight line 1
universe began at a single point 1

**[5]**

**104.** (a) Any two
stars rotate around galactic centre 1
star with velocity component towards Earth 1
reference to motion/shape of galaxy 1
or other valid points eg blue shift

(b) $H_o = 75/ 3 \times 10^{19}\ s^{-1}$ 1
$t \approx 1/ 2.5 \times 10^{-18}$ 1
$t \approx 4 \times 10^{17}$ s 1

**[5]**

**105.** critical density is that for flat universe 1
density > $p_0$ universe closed/contracts/big crunch 1
density < $p_0$ universe open/ expands forever 1
any 2 from
fate unknown because size/mass/density universe uncertain 1
fate unknown because $p_0$ / $H_0$ not known 1

**[5]**

**106.** (i) P = IV (1)
= 3.0 × 12 = 36 W (1) 2

(ii) $P_s = 0.96\ P_p$ (1)
$I_p = Ps / 0.96 \times V_p$ (1)
$= 36 / (0.96 \times 230) = 0.163$ A (1) 3

**[5]**

**107.** (a) repulsion/attraction correctly labelled on axis; 1

(b) (i) correct point N - where strong line crosses distance axis;
at N (resultant) force is zero; (1)
so neutrons must be at equilibrium; (1) any 1 2
not just 'forces equal'

(ii) correct point P; (1)
at P electrostatic and strong forces balance (or AW); (1) 2

(c) crosses axis at P; allow P on either curve if forces equal (1)
crosses e/s force line at point vertically above N; (1)
generally correct shape, entirely above strong line; (1) 3

(d) (i) (F =) $Q^2/[4\pi\varepsilon_0(x)^2]$ *allow* (F =) $Q_1\ Q_2\ /[4\pi\varepsilon_0(x)^2]$ (1) 1

(ii) $25 = (1.6 \times 10^{-19})^2 / (4\pi \times 8.85 \times 10^{-12}\ [d]^2)$ *subs*. (1)
$d = 3.0(3) \times 10^{-15}$ m *allow* $3 \times 10^{-15}$ *m* (1) 2

**[11]**

**108.** (a) *either* produced in a nuclear (fission) reactor
*or* bombard (natural) uranium with neutrons (1)
uranium 238 (nucleus) absorbs / captures a neutron (1)
product (uranium 239) undergoes β-decay (1) *any 2* 2

(b) (i) alpha particle (1) 1

(ii) ${}^{239}_{94}Pu \rightarrow {}^{4}_{2}He + {}^{235}_{92}U$ *each correct product nucleus gets* (1) 2

(c) (i) 24000 years / $7.57 \times 10^{11}$ s (1) 1

(ii) *either* $\lambda = 0.693/24000$ *or* $N = N_0\,(½)^{9000/24000}$ *equation(s)* (1)

$= 2.89 \times 10^{-5}\ \text{y}^{-1}$ $= 5 \times 10^{20}\,(½)^{0.375}$ *subs*. (1)

$N = N_0\,\text{e}^{-\lambda t}$ $(= 3.85 \times 10^{20})$

$= 5 \times 10^{20} \exp(-2.89 \times 10^{-5} \times 9000)$

$(= 3.85 \times 10^{20})$ 2

(d) (i) ratio = 4.0 (1) 1

(ii) original ratio $N_{240} / N_{239} = 40 \times 10^{20} / (5 \times 10^{20}) = 8$ (1)
(ratio after 9000 years = 4)
equal numbers after another 9000 + 9000 = 18000 years (1)
so total time = 9000 + 18000 = 27000 years (1) 3

**[12]**

**109.** *either*
number of atoms of $^{4}_{2}\text{He}$ in 1.0 kg = $(1 / 0.004) \times 6.02 \times 10^{23}$ $(= 1.51 \times 10^{26})$ (1)
so total energy = $1.51 \times 10^{26} \times 28.4 \times 1.6 \times 10^{-19} \times 10^{6}$ (1)
$= 6.9 \times 10^{14}$ J (accept $6.8 \times 10^{14}$ J) (1) 3

*or*
mass of $^{4}_{2}\text{He} = 4 \times 1.67 \times 10^{-27}$ $(= 6.68 \times 10^{-27}\ \text{kg})$
so number of $^{4}_{2}\text{He}$ in 1.0 kg = $1 / (6.68 \times 10^{-27})$ $(= 1.50 \times 10^{26})$ (1)
and energy generated = $1.50 \times 10^{26} \times 28.4$ MeV $(= 4.25 \times 10^{33}\ \text{eV})$ (1)
$= 4.25 \times 10^{33} \times 1.6 \times 10^{-19}$ J
$= 6.8 \times 10^{14}$ J (1) 3

**[3]**

**110.** (a) equation $^{1}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He}$ (+ energy) (1) 1

(b) (i) ke of nuclei converted to (electric) potential energy (1)
<u>all</u> ke is converted (1) 2

(ii) pe = $(1.6 \times 10^{-19}) \times (1.6 \times 10^{-19}) / (4\pi \times 8.85 \times 10^{-12} \times 3.07 \times 10^{-13})$
correct charge subs. (1) correct remaining subs. (1)
$(= 7.5 \times 10^{-16}\ \text{J})$ 2

(iii) initial momentum = final momentum or equivalent (1)
$m\,u - (2m)\,v = 0$ (so $u = 2v$) (1) 2

(iv) ke = ½ m $v^2$ (1)
ke of deuterium = ½ (2 m) $v^2$ (= m $v^2$)
ke of hydrogen = ½ m $(2v)^2$ (= 2m $v^2$)
so deuterium has 1/3 of total ke )
hydrogen has $^2/_3$ ) working (2)
so ke of hydrogen = 2/3 × 7.5 × $10^{-16}$ = 0.50 × $10^{-15}$ J)
ke of deuterium = 1/3 × 7.5 × $10^{-16}$ = 0.25 × $10^{-15}$ J) (1) 4

**[11]**

**111.** (a)

| | hadron | baryon | lepton |
|---|---|---|---|
| neutron | ✓ | ✓ | |
| proton | ✓ | ✓ | |
| electron | | | ✓ |
| neutrino | | | ✓ |

4 lines correct 2/2: 3 lines correct 1/2: 2 or 1 line correct 0/2 (2) 2

(b) (i) 10–15 minutes - any value within range (1) 1

(ii) weak force / interaction (1) 1

(iii) d → u + $e^-$ + ν (-bar) omits $e^-$ or ν loses 1 each (2) 2
(u) (u)
(d) (d)

(iv) charge: $-^1/_3\ (+\ ^2/_3 - ^1/_3) \rightarrow\ ^2/_3\ (+^2/_3 - ^1/_3) -1\ (+0)$ (1)
baryon number: $^1/_3\ (+^1/_3 + ^1/_3) \rightarrow\ ^1/_3\ (+^1/_3 + ^1/_3) + 0\ (+0)$ (1) 2
*nuclear values*:
charge 0 = 1 – 1 (+ 0) *and* baryon no. 1 = 1 + 0 gets 1/2

(c) (i) arrowed line plus 'resultant' / $p_r$ label 1

(ii) anti- (1) neutrino (1) is emitted
carried away some momentum (1)
shows neutrino momentum vector (1) any 3 3

**[12]**

**112.** (a) the splitting of a nucleus into two (or more) smaller nuclei/particles/ fragments (spontaneously/after absorption of a neutron) 1

(b) $^{235}_{92}$U + 10n → $^{141}_{56}$Ba + $^{92}_{36}$Kr + 3$^{1}_{0}$n 2

*–1 mark per error*

(c) $\Delta E = c^2\Delta m$; $\Delta m = 0.186$ u (= $3.09 \times 10^{-28}$ kg); (2)
$\Delta E = 9 \times 10^{16} \times 0.186 \times 1.66 \times 10^{-27} = 2.78 \times 10^{-11}$ (J) (1) 3

(d) $F = kQ_1Q_2/r^2$; $Q_1 = 56e$, $Q_2 = 36e$; (2)
$F = 9 \times 10^9 \times 56 \times 36 \times (1.6 \times 10^{-19})^2/(1.3 \times 10^{-14})^2$; $= 2.7(4) \times 10^3$ (N) (2) 4

**[10]**

**113.** (a) B = F/Il with symbols explained or appropriate statement in words; (1)
explicit reference to I and B at right angles/define from F = BQv etc (1) 2

(b) (i) arrow towards centre of circle 1

(ii) field out of paper; Fleming's L.H. rule/moving protons act as conventional current 2

(iii) F = Bev *allow BQv* 1

(iv) $F = mv^2/r$; $Bev = mv^2/r$; (2)
$B = mv/er = 1.67 \times 10^{-27} \times 1.5 \times 10^7/(1.6 \times 10^{-19} \times 60)$; = 0.0026; T (3) 5

*allow Wb $m^{-2}$*

(v) the field must be doubled; (1)
B ∞ v (as m, e and r are fixed)/an increased force is required to maintain the same radius (1) 2

**[13]**

**114.** α helium nucleus β electron γ photon/e-m radiation/energy (1)
α charge +(2e) mass $4m_p$/4u β charge –(e) mass $m_e$ γ charge 0 mass 0 (2)
α emission energy 3 – 7 MeV β emission energy 1 – 2 MeV γ emission energy about 1 – 2 MeV **or** all of the same order of magnitude/AW (1)
α monoenergetic from given nuclide β range of emission energies from given nuclide from zero to a maximum γ monoenergetic from given nuclide **or** comparison in terms of velocities (1)
α range 3 – 7 cm of air β range 1 – 2 m of air γ range inverse square law in air/ order of kms (1)
α absorbed by paper β absorbed by thin/ 1 mm Al sheet γ up to cm of Pb sheet (1)
α strongly ionising β weakly ionising γ hardly ionising at all (1)
any other sensible comparison (1) 6
*max 6 marks*

Quality of written communication 2

**[8]**

**115.** range/penetration/absorption/deflection experiment suggested (1)
*but no further progress made to answer question otherwise:*
suitable arrangement and choice of apparatus *all can be shown on a diagram* (2)

- range/penetration/absorption experiment:
  α place detector very close/ 2cm from source; measure count rate, use paper screen or move back to 10 cm or more, measure count rate, interpret result; contrast to background count level/ other emissions from same source (3)
  β place detector e.g. 10 cm from source measure count rate, add thin sheets of Al until count drops to very low or almost constant value; interpret result (2)
  γ place detector e.g. 10 cm from source measure count rate, add thin sheets of Pb until count drops to very low/background level; interpret result (2) *max 6 marks*

- *aliter* deflection experiment:
  needs vacuum for α experiment; (1)
  source for radiation passes through region of E- or B- field; (1)
  deflection or not of particles detected by detector to distinguish emissions; (1)
  detail of directions; *all 3 correct – 2 marks can only score max of 1 mark unless vacuum mentioned* (2)
  amount of curvature determines energy of emission; and nature of particle (1) *max 6 marks* 6

Quality of written communication 2

**[8]**

**116.** Planets move in <u>ellipses</u> (Sun at one focus) (1)
Planet sweeps out equal <u>areas</u> in equal times. (1)
Period$^2$ α radius$^3$ / $T^2$/ $r^3$ = constant (1) 3

**[3]**

**117.** (i) $v/c = \Delta\lambda / \lambda$ (1)
$\Delta\lambda = 656.3 \times 10^{-9} \times 6.1 / 3 \times 10^8$ (ignore minus sign) (1)
$\Delta\lambda = 1.33 \times 10^{-14}$ m (1) 3

(ii) Graph: any 4 points plotted correctly (1)
all correct (1) 2

(iii) graph: draw curve, reasonable attempt (1) 1

(iv) Either point where star moves perpendicular to line of sight (1) 1

(v) time = 72 h ± (1)h (ecf read value from their graph ± 1 h) (1) 1

(vi) $r = {}^3\sqrt{(6.7 \times 10^{-11} \times 4 \times 10^{30} \times [72 \times 3600]^2 / 4\pi^2)}$ ecf (1)
$r = 7.70 \times 10^9$ m ecf . (1) 2
(use of t = 72h 1/2)

**[10]**

**118.** correct reference to (1) AU (1)

parallax of (1) arcsecond
(marks can be gained on <u>labelled</u> diagram) (1) 2

**[2]**

**119.** Any 6 from
Nuclear/hydrogen burning ends (1)

Mass > Chandrasekhar limit (1)

Expanding gas/planetary nebular/red giant (1)

Gravitational collapse /ref. to burning He or higher metals (1)

Correct ref. to (Fermi) <u>pressure</u>/ radiation <u>pressure</u> (1)
(must have ref. to pressure or force from radiation.)

Neutron <u>star</u> (neutron by itself, not enough) (1)

Correct reference to Schwarzschild radius/
allow mass> 3M/ allow ref. critical radius (1)

Black Hole (1) 6

**[6]**

**120.** (i) Mass = $3.8 \times 10^{26} / (3 \times 10^8)^2$ (1)

Mass = $4.2(2) \times 10^9$ kg s$^{-1}$ (1) 2

(ii) $3.8 \times 10^{26} = 10^{44}$ / time (1)

time = $8.2(2) \times 10^9$ y (1) 2

**[4]**

**121.** Universe is isotropic/ same in all directions (1)

homogenous/ evenly distributed (1) 2

**[2]**

**122. Any 5 from**
Uniform intensity in all directions/ everywhere (1)

Structure in background intensity/ripples (1)

Produced when matter and radiation decoupled (1)

Originally gamma radiation (1)

(gamma) red-shifted to microwave/originally higher energy (1)

Evidence that universe began with big bang. (1)

Temperature corresponds to 2.7K / 3K / that predicted by big bang model (1) 5

**[5]**

**123.** **Any 2 from**
No experimental evidence/ no physical evidence (1)
State of matter unknown/ laws of physics unknown (1)
Energies unreproducible/ ref. to very high temperature (1) 2

**[2]**

**124.** Open: Universe expands for all time (1)

Flat: expands to a limit (but never reaches it) (1)

Closed: Universe contracts/ collapses back (1)

reference to role of gravity/ critical density (1)

Marks for a. can be gained on <u>labelled</u> diagram. 4

**[4]**

**125.** $H_o^2 = 1 \times 10^{-26} \times 8 \times \pi \times 6.67 \times 10^{-11} / 3$ (1)

$H_o = 2.36 \times 10^{-18}\ s^{-1}$ (1) 2

**[2]**

**126.** **1 each to a maximum of 7:**

- Electrons are emitted from C / (hot) cathode.
- There is a <u>high</u> voltage between C and A …. or stated p.d. >1000 V
- … (so) electrons are <u>accelerated</u> towards A / anode.
- Electrical energy becomes KE (of electron).
- Electrons undergo a sudden deceleration at A / collide with A
- (Some of) the <u>KE</u> is converted to <u>X-rays</u> / (electromagnetic) radiation
- The X-rays are produced by the deceleration / reference to bremsstrahlung
- X-rays characteristic of target produced).
- <u>Most</u> of the (kinetic) energy becomes heat / thermal energy.
- The reason for the vacuum.

Other good point (eg anode rotated / inner shell electron of target atom knocked out / higher pd gives more penetrating X-rays/higher energy photons). 7

**[7]**

**127.** (a) Low energy X-rays are absorbed by the skin / undesirable as can cause damage / greater ionising (1) 1

(b) $I = I_0 e^{-\mu x}$ (1) $\qquad \ln I = \ln I_o - \mu x$

$I_o = \dfrac{347}{e^{-250 \times 0.025}}$ (1) $\qquad \ln I_o = \ln 347 + 250 \times 0.025$

$I_o = 1.79 \times 10^5\ \text{Wm}^{-2}$ (1) 3

(c) $P = I \times A$ (0)

$P = 347 \times \pi \times (0.10 \times 10^{-2})^2$ (1)

$P = 1.09 \times 10^{-3}$ W (1) 2

(d) (i) $P = 18 \times 100 / 0.15$ (1)

$P = 12000$ W (1) 2

(ii) $12000 / 7.5 \times 10^{17}$ ($= 1.6 \times 10^{-14}$ J = energy of each electron) (1)

$0.5\ m\ v^2 = 1.6 \times 10^{-14}$ (0)

$v = 1.9 \times 10^8\ \text{ms}^{-1}$ (1) 2

(iii) tube current $= 7.5 \times 10^{17} \times 1.6 \times 10^{-19} = 0.12$ A (1)

$V \times I = 12000$ (1)

$V = 12000 / 0.12 = 100{,}000$ V or 100 kV (1) 3

**[13]**

**128.** (a) density (of medium) (1)

speed of ultrasound (in the medium) (1) or any factors that affect the speed of ultrasound in the medium e.g. the Young modulus 2

(b) (i) blood:

$f = (1.59 \times 10^6 - 1.63 \times 10^6)^2 / (1.59 \times 10^6 + 1.63 \times 10^6)^2$ (0)

$f = 1.54 \times 10^{-4}$ (1)

muscle:

$f = (1.70 \times 10^6 - 1.63 \times 10^6)^2 / (1.70 \times 10^6 + 1.63 \times 10^6)^2$ (1)

$f = 4.4 \times 10^{-4}$ (1)

so the medium is muscle (1) bald muscle gets 0/4 4

(ii) ($s = u \times t$)

$s = 1.54 \times 10^3 \times 26.5 \times 10^{-6} = 0.0408$ m (1)

$0.0408 / 2 = 0.020$ m (1) 2

(iii) $1.54 \times 10^3 / 3.5 \times 10^6 = \lambda$ (1)
$4.4 \times 10^{-4}$ m (1) *$4.4 \times 10^{-7}$ m gets full credit if $10^3$ penalised in (ii)* 2

**[10]**

**129.** (i) $I = V/R = 12/50$ (1)
$= 0.24$ A (1) 2

(ii) Power in primary = power in secondary / $I_pV_p = I_sV_s$ (1)
$I_p = 0.24 \times 12 / 230 = 0.0125$ A (1) 2

**[4]**

**130.** (a) (i) *either* (mass / mass-energy / energy of separate nucleons) - (mass / mass-energy / energy of whole nucleus) or AW;
*or* energy needed to separate / split / break apart neutrons and protons (completely);
*or* energy released when separate nucleons / protons and neutrons combine to form nucleus;

but NOT energy that binds / holds nucleus together
NOT energy to break bonds between nucleons
'atoms' gets 0 1

(ii) *either* high binding energy (/ nucleon) means greater stability / less likely to fuse or fission
*or* nuclides (tend to) move to / react towards the lowest potential energy/ highest binding energy (/nucleon)
can be won in any of C, U, or Fe explanations or as separate statement; (1)

${}^{12}_{6}C$ can undergo fusion; (1)

${}^{235}_{92}U$ can undergo fission; (1)

${}^{12}_{6}C$ and ${}^{235}_{92}U$ are both unstable gets 1/2

${}^{56}_{26}Fe$ is stable / does not experience fission or fusion; (1) 4

(b) (i) *either* neutron that is at (thermal) equilibrium with medium / substance / material through which it is passing
*or* neutron whose (kinetic) energy is equal / comparable / similar / to energy of atoms / molecules through which it is passing
*or* slow moving neutron
*or* neutron having low (kinetic) energy / energy of 1 – 10 eV; 1

(ii) ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{236}_{92}U$ *'+ neutrino' gets 0* (1) 1

(iii) $^{236}_{92}U \rightarrow ^{135}_{53}I + ^{95}_{39}Y + 6^{1}_{0}n$

accept $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{135}_{53}I + ^{95}_{39}Y + 6^{1}_{0}n$ for 1/1 1

(iv) $^{235}_{92}U$: 7.6 $^{135}_{53}I$: 8.4 $^{95}_{39}Y$: 8.6 MeV
read from graph, nuclides identified with readings (1)

total BE: $^{235}_{92}U$: 7.6 × 235 (= 1786)
$^{135}_{53}I$: 8.4 × 135 (= 1134)
$^{95}_{39}Y$: 8.6 × 95 (= 817) *three expressions* (1)

so energy released = 1134 + 817 – 1786 (1)
= 165 MeV (1)

8.4 + 8.6 – 7.6 = 9.4 MeV gets 1,0,1,0 = 2/4
uses 236 to get 157.4 MeV gets ¾ 4

**[12]**

**131.** (a) energy = $V I t$ (1)
= $V$ × (area under $I$-$t$ graph) (1)
= $1.2 \times 4 \times 10^6 \times (20 + 5)$ (1)
= $1.2 \times 10^8$ J (1) 4

no $V$ gets 0/4 *except* if stated 'area under graph = charge' which gets ¼
area calculation errors eg wrong triangle areas can get ¾
omits $10^6$ can get 3/4

(b) nuclei have (net) charge but atoms don't; (1)
nuclei would be deflected by B field / atoms are not; (1) 2

(c) (momentum conservation: $m_H v_H = m_n v_n$ $m$H = 4 $m_n$ so) $v_n = 4 v_H$ (1)

ke = ½ m $v^2$ (1)

ke of $^{1}_{0}n$ = ½ $m (4 v_H)^2 = 8 m v_H^2$ }
ke of $^{4}_{2}He$ = ½ × 4 $m v_H^2 = 2 m v_H^2$ } subs. (1)

so (ke of $^{1}_{0}n$) = 4 × (ke of He)
(so $^{1}_{0}n$ has 80%, $^{4}_{2}He$ has 20% of total ke) (1) 4

**[10]**

**132.** **baryon**: two examples proton; (1)
neutron; (1)

3 particles quoted, including one wrong gets 1/2 only

quark composition: proton uud; (1)
neutron udd; (1)

(aware consists of 3 quarks, unspecified, gets 1/2)

stability: proton stable inside (stable) nucleus; (1)
proton possible decay / half life = $10^{32}$ years when free; (1)
*allow any half life > $10^{30}$ years*

neutron stable inside (stable) nucleus; (1)

neutron half life = 10/15 minutes when free; (1) any 6

**[6]**

**133.** **lepton**: two examples: electron; (1)
positron; (1)
neutrino; (1) *any 2* (2)
(allow muon, tauon)

3 particles including one wrong gets 1 only

composition: fundamental (- no quark components); (1)

forces: weak force / interaction; (1)
electron / positron - (also) electromagnetic / electrostatic force; (1)

where found: electron - in atom, outside nucleus or in $\beta^-$ decay; (1)

positron (rarely) emerging from (high mass) radioisotopes /
in $\beta^+$ decay / accelerating-colliding machines; (1)

neutrino - travelling in space eg from Sun
*or* emitted (with electron / positron) in beta decay; (1)

allow ONCE 'resulting from high energy particle collisions' any 6

**[6]**

**134.** (a) $v = u + at$ no, but if $u$ is zero then $v$ is proportional to $t$ (1)
provided $a$ is constant (1)

$pV = nRT$ not unless $T$ is in kelvin (1)
and both $n$ and $V$ are constant ($R$ is a constant) (1)

$P = Fv$ yes if $v$ is constant (1)
but all three terms can vary so proportion unlikely (1)
then EITHER if $v$ is constant then $P$ and $F$ will also be constant
OR $P$ is proportional to $F$ when going up hills of different
gradient (at constant $v$) (1)
*MAXIMUM 2*

$A = \pi r^2$ yes ($\pi$ is a constant and $A$ is directly proportional to $r^2$) (1) 7

(b) graph must be a straight line (1)
graph must go through the origin (1) 2

**[9]**

**135.** (a) (i) **radioactive** implies the emission of ionising radiation (1)
OR emits alpha, beta and gamma radiation (1) 1

(ii) **nuclide** refers to a particular nuclear structure (with a stated number of protons and neutrons) (1) 1

(iii) **half-life** is the (average) time taken for the activity to fall to half its original value (1) 1

(b)

| time / hour | activity of material / Bq | activity of nuclide **X** /Bq | activity of nuclide **Y** /Bq |
|---|---|---|---|
| 0 | 4600 | 4200 | 400 |
| 6 | 3713 | 3334 | **379** |
| 12 | 3002 | 2646 | **356** |
| 18 | 2436 | **2100** | **336** |
| 24 | 1984 | **1667** | **317** |
| 30 | 1619 | 1323 | 296 |
| 36 | 1333 | **1050** | **283** |

(i) and (ii) 2100 as first figure to be filled in for nuclide **X** (1)
1667 (1)
1050 (1)
idea of subtraction for nuclide **Y** (1)
correct values for the ones given in nuclide **Y** column (1) 5

(c) sensible graph plotted (1)
extrapolation done (1)
value 70 ± 5 hours (1) 3

OR $A = A_0 \, e^{-\lambda t}$ (1)
$\ln A = \ln A_0 - \lambda t$
e.g. when $A = 296$, $t = 30$ h
$5.6904 = 5.9915 - \lambda \times 30$ (1)
$0.3011/30 = 0.01004 = \lambda$
$\tau = \ln 2/\lambda = 69.0$ h answers will vary slightly dependent on starting and finishing times (1)

(d) separate the two nuclides (before starting the count) (1)
by chemical means (if possible) (1) 2

OR using a centrifuge or diffusion (if isotopes)

OR sensible idea about shielding against one of the emitted particles

(e) decay constants or half lives are different (1)
half-life at the start is approximately that for **X** (1)
**X** decays more rapidly than **Y** so after a long time the half-life is that for **Y** (1)
in between it has a value intermediate between the two (which varies) (1) 3
*MAXIMUM 3*

OR dealt with mathematically, along the lines of

two separate exponential decays (1)

when added together do not give an exponential graph (1)

with back up maths (1)

**[16]**