Question			Marking details	Marks Available
SECTION A				
1	*(a)*	(i)	$C = \frac{Q}{V}$ understood (1) [or by impl.] i.e Rearranging to give $V = Q/C$ or substitution of capacitance for C and charge for Q V = 12.5(3) V (1)	2
		(ii)	$C = \frac{\varepsilon_0 A}{d}$ understood [simply quoting is not enough] (1) [substitution of all quantities except d] $d = 9.44 \times 10^{-4}$ m [accept 0.9 mm] (1)	2
	(b)		$Q = Q_o \exp\left(\frac{-t}{RC}\right)$ understood (1) [substitution] Taking logs correctly e.g. $\ln Q = \ln Q_o - \frac{t}{RC}$ (1) Algebra e.g. $-1.9 = \frac{-t}{15\times10^{6}\times375\times10^{-12}}$ (1) t = 0.01 [0.007] s (1) [Use of $\log_{10} \rightarrow 0.47$: treat as calculator slip → 3 marks] [Mysterious vanishing of minus sign → slip]	4
	(c)		[Dielectric (or water)] increases C **or** allows more Q to be stored [accept: store more energy **or** time constant increased] (1) so change in C or Q means fog **or** use coulometer to measure Q **or** use multi(meter) to measure C [or voltage] } (1) NB. 0 marks awarded for answers referring to conduction by water.	2
				[10]

Question			Marking details	Marks Available
SECTION A				
2	*(a)*		$B = \frac{\mu_0 I}{2\pi a}$ understood [or $B = 4.8 \times 10^{-7}$ T] (1) [not $\mu_0 nI$] either $5 \times 4.8 \times 10^{-7}$ **or** $B = \frac{4\pi \times 10^{-7} \times 1.5}{2\pi \times 0.125}$ (1)	2
	(b)	(i)	$\sin\theta = 0^\circ$ **or** $\theta = 0^\circ$ **or** $\theta = 180, \pi$ etc (1) Travels along [parallel or opposite to] field lines (1) [NB: 2nd mark implies first] "to the right" → 0 "to the right parallel to field" → 1 bod.	2
		(ii)	$F = Bq\sin\theta$ understood (1) [or by impl.] , i.e. $\theta = 90°$ calculated [by using $q = 1e$] → 1 mark $\theta = 30^\circ$ / 0.52 radian (1)	2
	(c)	(i)	Arrow anti-clockwise ✓	1
		(ii)	$Bqv = \frac{mv^2}{r}$ [or $mr\omega^2$] [accept $r = \frac{mv}{Bq}$] (1) $m = 4 \times 1.66 \times 10^{-27}$ kg and $q = \underline{2e}$ [e.c.f. on q] (1) r = 76.08 km (1) Allow ecf on $q = 1e$ i.e. → r = 157 km [→ 2/3 marks]	3
				[10]

Question			Marking details	Marks Available
SECTION A				
3	*(a)*		**Either** Flux changes (1) hence emf induced (1) [Because of RH rule or Faraday → 2nd mark, but not 1st mark] flux increases and decreases [implies 1st mark] [i.e. $\frac{d\Phi}{dt}$ alternates implied](1) NB. "Change in field" not 1st mark but others available] **Or** B-lines being cut (1) hence emf induced (1) [Because of RH rule or Faraday → 2nd mark, but not 1st mark] direction of cutting changing (1) [Not "magnet oscillating" accept "magnet changing direction [of motion]"]	3
	(b)	(i)	$V_{\text{rms}} = \frac{Vo}{\sqrt{2}} = 0.5\text{ V}$	1
		(ii)	Rate of change of flux (linkage) = 0.707 [V] (1) from Faraday's [or Neuman's] law or $E = N\frac{d\Phi}{dt}$ [allow $E = \frac{\Phi}{t}$](1) [Independent mark – must be stated] For 1 turn = $\frac{0.707}{200}$ = 0.0035(35) Wb s^{-1} (1) NB. 0.0025 Wb s^{-1} [from use of V = 0.5 V]→ 2 if 2nd mark awarded.	3
	(c)		Stating or implying that there is a magnetic field set up in the coil (1) Opposes motion / due to Lenz's law (1) Detail given, e.g. loss (dissipation) of energy due to current or resistance, polarity of coil discussed [can imply 1st mark], work done against resistive force (1)	3
				[10]

<table>
<tr><th colspan="3">Question</th><th>Marking details</th><th>Marks Available</th></tr>
<tr><td colspan="5">SECTION A</td></tr>
<tr><td>4</td><td>(a)</td><td></td><td>γ (1)
Needs high penetration (1)
[or to irradiate shielded side of metal, or because α and β not penetrating enough etc.]
[NB. 2nd mark cannot be given if 1st mark not awarded]</td><td>2</td></tr>
<tr><td></td><td>(b)</td><td>(i)</td><td>$\lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$ understood (1)
λ = 0.1[308] year^{-1} / 4[.14] × 10^{-9} s^{-1} ((unit)) [accept Bq] (1)
[allow ecf on $\log_{10}$ used → 1.8 × 10^{-9} s^{-1} / 0.057 year^{-1}]
[NB per year or per second]</td><td>2</td></tr>
<tr><td></td><td></td><td>(ii)</td><td>Attempt at using $A = \lambda N$ (1) [allow use of number of moles for N]
1 mg = $\frac{1}{60}$ × 10^{-3} mol or $N = 10^{19}$ (1)
A = 4.16 × 10^{10} Bq [or 1.31 × 10^{18} year^{-1}] (1) [NB No unit penalty]</td><td>3</td></tr>
<tr><td></td><td></td><td>(iii)</td><td>$\frac{A}{A_o} = \frac{1}{4}$ (1)
2 half lives (implies above) (1)
t = 10. 6 year (1)

Or
$2^n = \frac{A_0}{A}$
n = 2 (1)
t = 10. 6 year (1)

Or
or $A = A_0 e^{-\lambda t}$ (1) [used]
taking logs (1)
t = 10. 6 year (1)

NB 3.3 × 10^8 → 2 marks, i.e. answer quoted in seconds.</td><td>3
[10]</td></tr>
</table>

Question			Marking details	Marks Available
SECTION A				
5	*(a)*		Conservation of *A* **and** *Z* (1) $^{241}_{95}\text{Am} \rightarrow {}^{237}_{93}\text{Np} + {}^{4}_{2}\alpha$ (1) $^{241}_{95}\text{Am} \rightarrow {}^{241}_{96}\text{Np} + {}^{0}_{1}\alpha$ → 1 mark But **not** $^{241}_{95}\text{Am} \rightarrow {}^{237}_{93}\text{Np} + {}^{0}_{0}\alpha$	2
	(b)		Attempt at LHS – RHS [= 0.00608 but allow slips] (1) Mass in u × 931 (1) or $E = mc^2$ [with mass in kg] (1) = 5.66 MeV (1) ((**unit**)) or 9.06×10^{-12} J ((**unit**))	3
	(c)	(i)	<u>attempt</u> at total mass of p + n (1) [e.g. = 95 m_p + 146m_n] – 241.00471 (1) [1.95125] ×931 and ÷ 241 (1) or $E = mc^2$ and ÷ 241 = 7.5[378] MeV / nucleon (1) or 1.206×10^{-12} J/nucleon [Slips in total mass can get first 3 marks] NB mixing up number of protons and neutrons → 7.27 MeV/nucleon	4
		(ii)	Plot answer on graph e.c.f. ± ½ square [7.4 – 7.6 MeV/nucleon and 238-244 for nucleon number]	1
				10

Question			Marking details	Marks Available
SECTION A				
6.	*(a)*		Insert a voltmeter [V in a circle] on the diagram between front and back faces	1
	(b)		<u>Electrons</u> feel force due to B-field [or *Bqv* or FLHR; accept *Bll]* (1) Force towards rear face [accept electrons move to rear face or into the page] (1) <u>Leaving</u> / <u>hence</u> front positive (or shortage of electrons) (1)	3
	(c)		$E = \frac{V}{d}$ (1) [or by impl.] = $\frac{8.5\times10^{-3}}{0.004} = 2.125\,\text{V m}^{-1}$ (1)	2
	(d)		$Bqv = Eq$ (1) $v = \frac{I}{nAe}$ (rearrange) (1) $E = \frac{BI}{nAe}$ (1) [subst] $n = \frac{BI}{EAe}$ (1)= $5.15 \times 10^{21}\ \text{m}^{-3}$ ((**unit**)) or $V_H = \frac{BI}{ntq}$ (1) → $n = 5.15 \times 10^{21}\ \text{m}^{-3}$ ((**unit**)) (1) Max 2/4 for remembering equation	4
				10

Question			Marking details	Marks Available
SECTION B				
7	*(a)*		Correct substation into speed = $\frac{\text{distance}}{\text{time}}$ (1) $\left[t = \frac{8\times10^8}{3\times10^8}\right]$= 2.67 s (1) [Accept fraction $^8/_3$]	2
	(b)		After travelling both ways extra distance is $\lambda / 2$ (1) Hence destructive **interference** or **antiphase / completely out of phase(1)**	2
	(c)		use of $n\lambda = d\sin\theta$ e.g. $7\times 640 = 815\sin\theta$ (1) $d = 1.23 \times 10^{-5}$ m (1) [accept $^1/_{81\,500}$] any 2 of $\theta_1 = 2.99$, $\theta_2 = 5.99$, $\theta_3 = 9.00$ (1) Sensible comment, e.g. true, nearly true **or** wrong[if qualified, e.g. separation increases slightly etc.] [e.c.f.](1) [1st mark required for 3rd mark to be awarded]	4
	(d)		$N\times\frac{1}{2}mc^2 = \frac{3}{2}nRT$ **or** $\frac{1}{2}mc^2 = \frac{3}{2}kT$ (1) [or by impl.] Algebra $\overline{c^2} = \frac{3kT}{m}$ (1) [or by impl.] $\sqrt{\overline{c^2}} = \sqrt{\frac{3\times1.38\times10^{-23}\times300}{23\times1.66\times10^{-27}}}$ = [570.35 m s^{-1}] (1) NB. Mixing up *m*/*M* and *n* / *N* with correct algebra → 1.	3
	(e)		Any 3 × (1) from • 0.97 GHz corresponds to Doppler shift [due to 570 m s^{-1}] / red shift / blue shift✓ • Sodium atom moving towards laser we get resonant absorption / wavelength [or frequency or energy] is exactly right ✓ • ∴ slowing down is tuned or more probable etc ✓ • If atom moving away there is a shift away from resonance / absorption less probable ✓ [NB "more strongly absorbed", "Doppler-shifted up 0.97 GHz", "Match the resonance frequency" are phrases in the passage.]	3

Question			Marking details	Marks Available
SECTION B				
7	*(f)*		Photon energy = $\frac{hc}{\lambda}$ **or** *hf* and $c = \frac{f}{\lambda}$ (1) [$= 3.825 \times 10^{-19}$ J] No. of photos/sec = power $\div$ photon energy (1.93×10^{10}) (1) Momentum of 1 photon = $h / \lambda = 1.275 \times 10^{-27}$ kg ms^{-1} (1) [indep. mark] Force = $1.93 \times 10^{10} \times 1.275 \times 10^{-27} \times \sin 30 = 1.23 \times 10^{-17}$ N (1) [Slip with nm / m → allow ecf] **Alternative Method**: Force = $\frac{\text{Power}}{c}$ (1) [or by impl.] = 2.467×10^{-17} N (1) Force upwards (on particle) = Force down on light **or** reference to *F* = rate of change of momentum(1) $= 2.467 \times 10^{-17} \times \sin 30^{\circ} = 123 \times 10^{-17}$ N (1)	4
	(g)		<u>**Good**</u> • Lasts long time [accept: sustainable / renewable, lasts 000s years] • No nuclear waste [accept: no harmful waste but **not** "no waste"] • High concentration of energy e.g. per kilogram • No carbon emissions / use less non-renewables • Abundance of fuel / deuterium [and lithium] [**not** tritium → sif] • Could be profitable soon <u>**Bad**</u> • Tritium from where / needs generation • Does not work yet / huge energy in for little out [needs slightly more than "hasn't got to breakeven"] • Induced nuclear waste. • Set-up / research costs • Possible military use Any 2 or 3 advantages and/or disadvantage → 1 4 statements with at least 1 of each (1)	2 **[20]**

Question			Marking details	Marks Available
SECTION C				
8	*(a)*		Laminated (or equivalent) (1) to prevent eddy currents (1) Suitable material for core (1) to avoid magnetising/hysterises losses (1)	4
	(b)	(i)	First mark for diagram with V_L, V_C, V_R perpendicular with V_L, opposite V_C [or impedances] (1) resultant reactive impedance is $\omega L - \frac{1}{\omega C}$ [or $V_{react} = V_L - V_C$], shown on the diagram(1) Resultant [justified] = $\sqrt{\ }$ etc.(1) or $V = \sqrt{(V_L - V_C)^2 + V_R^2}$ **and** $V = \sqrt{\left(I\omega L - \frac{I}{\omega C}\right)^2 + I^2R^2}$	3
		(ii)	$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$ or $\omega = \sqrt{\frac{1}{LC}}$ or $\omega L = \frac{1}{\omega C}$ (1) Convincing substitution and/or algebra (1)	2
		(iii)	$\left[I = \frac{V}{R} = \right]\frac{12}{280}$ (1) Since all voltage across R **<u>or</u>** V_L and V_C cancel (or X_L and X_C) (1)	2
		(iv)	Equation used e.g. $Q = \frac{\omega L}{R}$ or $\frac{1}{\omega CR}$ used (1) Answer = 2.97 or (3) (1)	2
		(v)	Attempt at substitution e.g. accept $\sqrt{\left(10.35\times 64 - \frac{1}{10.35\times 9.2}\right)^2 + 280^2}$ $Z = 1286\ \Omega$ (1) $I = \frac{V}{Z}$ (1) [independent mark]= 9.3 mA (1)	4
		(vi)	ωL doubled and $\frac{I}{\omega C}$ halved(1) X_C and X_L switched (1)(cf(v)) $(416–1671)^2 = (1671–416)^2$ or equivalent –ve number squared. (1) Alternative: X_C =1671 and X_L = 416 and R=280 [used or implied](1) Z = 1286(Ω) – **<u>clearly</u>** shown (1) 3rd mark – noticing X_C and X_L swapped.(1)	3
				[20]

Question			Marking details	Marks Available
9	*(a)*	(i)	I. Studied reflected light (from glass plate) (1) Reflection from 2nd plate depends on orientation (not just angle of inc.) / Light asymmetrical about direction of travel / Reflected light polarised (1) II. Developed wave theory mathematically (1) accounted for polarisation by reflection **or** double refraction **or** diffraction patterns of various obstacles **or** why we cannot see around corners (1)	2 2
		(ii)	• Requires stiff (or solid) medium (where light travels) (1) • which would also support longitudinal waves but not observed **or** would prevent movement of 'ordinary' objects. (1)	2
	(b)	(i)	Magnetic fields – rotating vortices (1) Electric fields – stress (or strain) in vortex material (1)	2
		(ii)	Density and stiffness	1
		(iii)	His ether (or equations) predicted $c = \sqrt{\frac{1}{\varepsilon_0 \mu_0}}$ (1) Experiment confirmed this (within uncertainties).(1)	
		(iv)	Oscillating E and B fields. (1) E and B at right angles to each other and to the propagation direction. (1)	2
	(c)	(i)	*Principle of Relativity* understood (either by statement or implied) (1) Not consistent as laws [of E-M] would have special form in this frame (also implies first mark). (1)	2
		(ii)	I. 6.39 μs	1
			II. $\Delta\tau = \Delta t\sqrt{1-\frac{v^2}{c^2}}$ (1) = 0.625 μs (1) [65.3 μs → 0 marks]	2
			III. 0.706 μs (1) approximately 10% (or 13%) out (1) [or any other correct and relevant remark]	2
				[20]

Question			Marking details	Marks Available
10 A	*(a)*	(i)	LCS – largest plastic deformation	1
		(ii)	QAS – highest breaking stress	1
	(b)		All are same / similar from initial gradients.	1
	(c)		HCS has greater strength and stiffness (1) Carbon in (crystal) lattice (1) Hinders/opposes/stops dislocation movement (1) Hence more opposition to plastic deformation in HCS (1)	4
	(d)	(i)	$\frac{1}{2}mv^2 = \frac{1}{2}Fx$ (1) × ¼ (1) $m=\rho Al$ (1) + convincing algebra (1)	4
		(ii)	$\varepsilon = 0.002$ (1) $v = \frac{1}{2}\sqrt{\frac{700\times10^6\times0.002}{8000}}$ = 6.6 m s^{-1} [answer] (1)	2
		(iii)	Accept either LCS or QAS with sensible reason: e.g. LCS has a higher breaking speed (1) because the area under the graph is greater / ε at breaking is much bigger (1) **or** QAS has a higher speed (1) because the area under the graph in the elastic region is bigger (1)	2
B	*(a)*		2.6→2.7 GPa from the graph (1) 8.3→8.65 kg (1)	2
	(b)		Thin fibres have fewer surface imperfections (1) Very thin fibres have no surface imperfections (1)	2
	(c)		Thin glass fibres encased in resin / epoxy / plastic material	1
				[20]

Question			Marking details	Marks Available
11	*(a)*	(i)	Same shape, below and longer minimum λ_0 (1) peaks in same place (1)	 2
		(ii)	Peaks/spikes/line spectrum **move.**	1
		(iii)	$eV = \frac{hc}{\lambda}$ (1) $\lambda = 1.66 \times 10^{-11}$ m (1)	 2
		(iv)	$P = IV = 9375$ W (1) 99.5% heat = $0.995 \times 9375 = 9328$W (1) **Or** comment that roughly all 9375W dissipated as heat.	 2
	(b)		CT detector(s) rotate (1) about patient / analysis point. Multiple detectors output to computer (1) Series of 2D images obtained or 3D image obtained (1)	 3
	(c)		Radio waves [2-100 MHz] (1) Resonate or Same/match frequency of [hydrogen] nuclear rotation [or precession]. (1) Causes them to flip/change (1) [Not just: change spin]	 3
	(d)	(i)	crystal deforms / vibrates [when alternating p.d. applied]	1
		(ii)	$\frac{\Delta\lambda}{\lambda} = \frac{2v}{c}$ (1) $v = 0.9$ m s^{-1} (1) [e.c.f. on missing factor of 2]	 2
	(e)	(i)	Mention of free radicals (1) [or equivalent, e.g. produces chemicals/ions/atoms which react/are highly reactive]. Damages DNA/cells/molecules (1)	 2
		(ii)	Absorbed dose = energy (absorbed) per unit mass. Dose equivalent = absorbed dose $\times$ Q[uality] factor.	 2
				[20]

Question			Marking details	Marks Available
12	*(a)*	(i)	Power = solar constant $\times$ area [or by impl.] (1) = 1.0686×10^{10} W / 1.0686×10^{7} kW / 10.7 GW or equiv (1).	2
		(ii)	$P=\sigma AT^4$ understood [accept $5.67\times10^{-8}\times A\times5778$] – i.e. 2 terms identified although missing (1) $P = 4\pi r^2$ quoted (1) $P = 3.85 \times 10^{26}$ W (1) Solar constant = $\dfrac{3.85\times10^{26}}{4\pi\times\left(1.496\times10^{11}\right)^2}$ [=1368 W m^{-2}]	4
	(b)		Hours in one year = $24\times365[.25]$ [or by impl.] (1) Total units = $1.0686\times10^{7}\times24\times365\times0.4$ [or by impl.] (1) Money = units $\times0.2$ = £7.5 billion / 7.5×10^{11} p /£7.489×10^{9} (1)	
	(c)		Volume = area$\times$thickness [or by impl.] (1) Mass = density$\times$volume [or by impl.] (1) [manip] Mass = 4.95×10^{6} kg (1)	
	(d)		$4.95\times10^{6}\div2500=198$ missions [or by impl.] (1) [ecf from *(c)*] $\times$ 350 $\times$ 10^6 = £ 69.3 bn [or equiv.] (1)	2
	(e)		Heat engines inefficient [or by impl.] (1) Since $1-\dfrac{T_1}{T_2}\simeq1-\dfrac{300}{400}\simeq0.25$ (1) "which is poor" implies first mark. NB. T_2 in range 373 – 1700 K and T_1 in range 273 – 900 K [< T_2]	2
	(f)		Reasonable since costs recovered in 9/10 years (1) (ignoring time for 200 shuttle missions) + Any 3 × (1) **good** points: • Not weather dependant ✓ • Solar power at night ✓ • Less/no atmospheric absorption by microwaves ✓ • Time for 200 shuttle missions ✓ • Shuttle program ended ✓	4
				[20]