Question	Answer	Marks
Section A		
1 a i	Eight radial lines, equally spaced at surface, direction shown pointing towards Earth.	1 1
1 a ii	Field lines are further apart further away from the Earth.	1
1 b i	Diagram similar to Figure 2, Section 12.3. Equal spacing of equipotentials. Equipotentials crossing field lines at right angles. Field lines at right angles to (equipotential) surface of Earth.	 1 1 1
1 b ii	Uniform spacing of field lines. Uniform spacing of equipotentials.	1 1
1 c	Field strength = $-\frac{k}{r^2}$ where k is a constant. $9.8 \times (6.4 \times 10^6)^2$ = field strength at Earth-Moon distance × $(3.8 \times 10^8)^2$ field strength at Earth-Moon distance = $\frac{9.8 \times (6.4 \times 10^6)^2}{3.8 \times 10^8}$ = 2.8×10^{-3} N kg^{-1}	 1 1 1
2 a	$^{237}_{93}Np$	1
2 b i	No. of particles = $\frac{2.8 \times 10^{-10} \times 6.0 \times 10^{23}}{0.241}$ = $6.97\ldots \times 10^{14}$ Activity = (–)$4.8 \times 10^{-11} \times 6.97\ldots \times 10^{14}$ = (–)33 kBq (2 s.f.)	1 1 1
2 b ii	Calculation of half-life as 451 years. Calculation of activity after five years (assuming initial activity of 33 kBq or using stated other activity) For A_0 = 33 kBq, activity after five years = 32 750 Bq. Comment that this is a small percentage change in acivity. Students also gain full credit for calculating A/A_0 as a ratio.	1 1 1 1
2 c	Alpha radiation is not penetrating so no alpha radiation would leave the casing.	1 1
3 a i	anti-neutrino (or anti-electron-neutrino)	1
3 a ii	Lepton number on LHS = 0. Lepton number on RHS = 0 + 1 + –1 = 0.	1
3 b	The quark composition of a neutron is udd and the quark combination of a proton is uud. When a neutron changes into a proton, the change in quarks is from a down quark to an up quark.	1 1 1
3 c	Mass change = 1.4×10^{-30} kg Energy released = 1.26×10^{-13} J	1 1
3 d i	630 s	1
3 d ii	Most nuclei do not undergo beta decay.	1
3 e	Neutron more massive than a proton. A proton decaying into a neutron requires energy rather than releases energy.	1 1
4 a i	$\frac{E}{kT}$ is very large/tends to infinity as T approaches zero, therefore $e^{-E/kT}$ is close to/tends to zero.	1
4 a ii	$e^{-E/kT} = \frac{1}{e^{E/kT}}$ and $e^{-E/kT}$ must always be greater than 1.	1

4 a iii	When $E = kT$, $e^{-E/kT} = \frac{1}{e}$, which is equal to 0.37	1
4 b i	$f = e^{-E/kT} = e^{-\frac{1.3\times10^{-19}}{310\times1.38\times10^{-23}}}$ $= 6 \times 10^{-14}$ (1 s.f.)	1 1
4 b ii	$f = e^{-E/kT} = e^{-\frac{6\times10^{-20}}{310\times1.38\times10^{-23}}}$ $= 8.1 \times 10^{-7}$ $\frac{8.1\times10^{-7}}{6\times10^{-14}} = 1.35 \times 10^{8}$ (> 1000 000)	1 1 1
4 b iii	More particles have an activation energy greater than the activation energy.	1 1
5 a	Five straight, vertical lines pointing from the positive to the negative plate.	1 1
5 b i	The sphere is negatively charged. For it to be motionless the electric force acting on it must be upwards to balance the gravitational force downwards.	1 1 1
5 b ii	Number of electrons = $\frac{\text{total charge}}{\text{charge on electron}} = \frac{3.2\times10^{-14}}{1.6\times10^{-19}}$ = 200 000	1
5 b iii 1	Force on sphere = mass × gravity = charge × field $E = \frac{m\times g}{Q} = \frac{6.2\times10^{-9}\times9.8}{3.2\times10^{-14}}$ $= 1.9 \times 10^{6}$ V m^{-1}	1 1 1
5 b iii 2	$V = Ed = 2 \times 10^{-6} \times 14 \times 10^{-3}$ $= 2.8 \times 10^{-8}$ m	1 1
Section B		
1 a	$\sin\theta = \frac{x}{L}$ where θ is the angle the string makes to the vertical. $\sin\theta = -\frac{F}{T} = -\frac{F}{mg}$ $= -\frac{a}{g}$ Therefore, $a = -\frac{gx}{L}$	1 1 1
1 b i	$-\frac{gx}{L} = -4\pi^2 f^2 x$ $\therefore f^2 = \frac{g}{4\pi^2 L}$ $\therefore T^2 = \frac{4\pi^2 L}{g}$ $\therefore T = 2\pi\sqrt{\frac{L}{g}}$	1 1
1 b ii	3.2 s	1
1 c i	$a = -\frac{9.8\times0.04}{2.5}$ = 0.157 s = 0.16 s (to 2 s.f.)	1
1 c ii	change of displacement = $\frac{1}{2} \times 0.16 \times 0.2^2 = 0.0032$ m new displacement = 0.040 – 0.0032 = 0.0368 m	1 1

1 d i	Constant gradient implies constant velocity. Pendulum bob has zero velocity at the amplitude, which is not shown in this model.	1 1
1 d ii	time period from graph = 4 × 0.75 s = 3.0 s This is shorter than that calculated in part **b ii**. The acceleration is held constant over the time interval when it is, in reality, constantly changing. The model can be improved by reducing the time interval between calculations.	1 1 1 1
2 a i	Diagram to show flux loops that pass through the primary coil but not the secondary coil. There must be more than one loop and they must not cross each other. Loss of efficiency because the flux is linking the primary coil but not the secondary coil, so it is 'lost' (or similar argument).	1 1 1
2 a ii	There are many possible suggestions here – award marks for any sensible answer. E.g. A metal lead allows the phone to be moved and used during charging but this would not be suitable for a toothbrush where water may come into contact with electrical components.	 1 1
2 b i	p.d. = $\frac{\Delta N\Phi}{\Delta t} = \frac{20\times(3\times10^{-4}-(-3\times10^{-4}))}{0.015-0.005}$ = 1.2 V Taking into account efficiency, peak output p.d. = $\frac{1.2}{0.65}$ = 2 V (1 s.f.)	1 1 1
2 b ii	230 × 0.65 = 149.5 Turns ratio = $\frac{149.5}{2.0}$: 1 = 75 : 1 (2 s.f.)	1 1 1
2 b iii	$I = \frac{Q}{t} = \frac{9.0\times10^{3}}{6\times60\times60}$ = 0.416… = 0.42 A (2 s.f.) $E = IVt$ = 0.416… × 2.0 × (6 × 60 × 60) = 18 kJ (2 s.f.)	1 1 1 1
3 a	The force *F* is equal to the force with which gas is expelled from the chamber (due to equal and opposite forces), which is equal to the pressure *P* multiplied by the area of the nozzle opening *A*.	1 1
3 b	$P = \frac{F}{A}$ $= \frac{1.8\times10^{6}}{\pi\left(\frac{0.33}{2}\right)^{2}}$ = 2.1… × 10^7 Pa = 20 MPa (1 s.f.)	1 1 1
3 c i	$PV = nRT$ $n = \frac{PV}{RT} = \frac{2.1...\times10^{7}\times2.0}{8.31\times3500}$ = 1447.1… number of molecules = 1447.1… × 6.022 × 10^{23} = 8.7 × 10^{26} (2 s.f.)	 1 1 1

3 c ii	$E = kT$ and $E = \frac{1}{2}mv^2$ so $kT = \frac{1}{2}mv^2$ $v = \sqrt{\frac{2kT}{m}}$ $= \sqrt{\frac{2 \times 1.38 \times 10^{-23} \times 3500}{3.0 \times 10^{-26}}}$ = 1794.4… = 2000 m s^{-1} (1 s.f.)	1 1 1
3 c iii	$F = mv = 3.0 \times 10^{-26} \times 2000 = 6 \times 10^{-23}$ Number of molecules = $\frac{1.8 \times 10^6}{6 \times 10^{-23}} = 3 \times 10^{28}$	1 1
3 d	Points can include e.g. • Fuel will be burnt/will run out. • The same acceleration is not needed throughout. • The thruster must be turned off so that the satellite can slow down into orbit.	 1 1 1
4 a i	The spring constants of springs acting in parallel are added. $2.6 \times 10^4 + 2.6 \times 10^4 = 5.2 \times 10^4$	1 1
4 a ii	$e = \frac{F}{k}$ $= \frac{1000 \times 10}{5.2 \times 10^4}$ = 0.19… m = 20 cm (1 s.f)	1 1
4 b	$T = 2\pi\sqrt{\frac{m}{k}}$ $= 2\pi\sqrt{\frac{500}{5.2 \times 10^4}}$ = 0.6 s (1 s.f.)	1 1
4 c	$T = 2\pi\sqrt{\frac{m}{k}}$ therefore $m = \frac{T^2 k}{4\pi^2}$ $= \frac{1.2^2 \times 5.2 \times 10^4}{4 \times \pi^2}$ = 1896.7… kg This is greater than the mass of the truck (500 kg) plus a 1000 kg load, so the truck is above its maximum load.	1 1 1
4 d	When the truck goes over the speed bump, the spring(s) will be displaced in a given direction, causing the truck to oscillate.	1 1
4 e	Oscillating systems have a resonant frequency where the amplitude of oscillations becomes very large.	1 1
4 d	Graph showing: • The same time period as the original curve. • A reducing amplitude throughout. • An amplitude at *x* equal to a quarter of the original.	 1 1 1
5 a i	Ceres: $\frac{8.7 \times 10^{20}}{4.3 \times 10^{17}} = 2.0 \times 10^4$ kg m^{-3} (2 s.f.) Vesta: $\frac{3.0 \times 10^{20}}{7.8 \times 10^{16}}$ = 38 kg m^{-3} (2 s.f.)	1 1
5 a ii	Any sensible suggestion, e.g. Ceres is significantly more dense than Vesta; perhaps Ceres is made of rock and Vesta is made of ice.	1

5 b i	$T = \dfrac{\text{distance}}{\text{speed}} = \dfrac{2\pi r}{\sqrt{\dfrac{GM}{r}}}$ $= \dfrac{\sqrt{\dfrac{4\pi^2 r^2}{1}}}{\sqrt{\dfrac{GM}{r}}}$ $= \sqrt{\dfrac{4\pi^2 r^3}{GM}}$	1 1 1
5 b ii	Vesta It has the smaller orbital period, so r must be smaller as $T \prec \sqrt{r^3}$ and therefore v must be larger (as $v \prec \sqrt{\dfrac{1}{r}}$)	1 1
5 c	$T = \sqrt{\dfrac{4\pi^2 r^3}{GM}} = \sqrt{\dfrac{4\pi^2 \times 35000^3}{6.67\times10^{-11}\times6.69\times10^{15}}}$ = 61589.3… s = 17 hours to 2 s.f. (nearly 24 hours or 1 day)	1 1
5 d i	time = $\dfrac{\text{distance}}{\text{speed}} = \dfrac{3\times10^{11}}{3\times10^{8}}$ = 1000 s (~17 minutes)	1
5 d ii	The same time delay would act on signals travelling from Earth, so the scientists would not be able to respond to anything until ~34 minutes after it had happened (or similar suggestion).	1 1
5 e i	total bytes = 398 × 303 = 120 594 (8 bits per byte) This is much larger than the number of bytes used to store the image, so it must have been compressed.	1
5 e ii	$\dfrac{10576\times8}{10}$ = 8460 s (just over 2 hours)	1 1
6 a	$\lambda = \dfrac{hc}{E}$ $= \dfrac{6.6\times10^{-34}\times3.0\times10^{8}}{3.0\times10^{-19}}$ $= 6.6 \times 10^{-7}$ m	1 1 1
6 b i	$\dfrac{1\times10^{-3}}{600}$ = 1.66… × 10^{-6} = 1.7 × 10^{-6} m (1 s.f.)	1
6 b ii	$\sin\theta = \dfrac{6.6\times10^{-7}}{1.7\times10^{-6}}$ where θ is the angle of first order maximum. $\sin\theta = 0.396$ $\theta = 23°$ (2 s.f.)	 1 1
6 c	with increasing wavelength to the left of the diagram, the zero order would be shifted to the left. The first order maxima would each be further away from the zero order maximum as the wavelength has increased through red shift.	1 1
6 d	$\dfrac{\Delta\lambda}{\lambda} = 0.000\,02$ $v = 0.000\,02\,c$ $= 6000$ m s^{-1}	1 1 1

6 e	intensity of B, I_B = 100 × intensity of A, I_A As both stars have the same actual luminosity: observed intensity of B × (distance of B)^2 = observed intensity of A × (distance of A)^2 100 × (30 parsec)^2 = 1 × (distance of A)^2 distance of star A = 300 parsec	1 1 1
6 f i	$z = \frac{\Delta\lambda}{\lambda} = \frac{1.34\times10^{-6} - 1.22\times10^{-7}}{1.22\times10^{-7}}$ = 9.98 = 10 to 2 s.f.	1 1
6 f ii	If the change in wavelength = 10 wavelengths, the new wavelength will be 1 + 10 = 11. As this increase is due to expanding space, the distance between the galaxy and the Earth must have increased by a factor of 11 during the time it has taken for light to reach Earth from the galaxy.	1 1
Section C		
1 a i	Energy (in one second) = $mc\Delta T$ = 0.17 × 4200 × 4 = 2856 J = 3000 J (1 s.f.)	1 1
1 a ii	Power per square metre = $\frac{2856}{1\times3}$ = 952 W m^{-2}	1
1 a iii	Any sensible suggestion: • The Earth's surface is further from the Sun than the outer surface of its atmosphere, so the incident power will be lower. • Some of the Sun's radiation is absorbed by the atmosphere. • The solar panel is not 100% efficient.	1
1 a iv	Total power emitted = Power per m^2 × area = 1400 × 2.8 × 10^{23} = 4 × 10^{26} W	1 1
1 b i	If $R_Y \geq 100R_X$, $\frac{GM}{R_X}$ is over 100 times larger than $\frac{GM}{R_Y}$ and so $\frac{GM}{R_Y}$ can be discounted (if calculating to 2 or fewer significant figures).	1
1 b ii	$\Delta V_{XY} = \frac{GM}{R_X} = \frac{6.7\times10^{-11}\times2.0\times10^{30}}{7.0\times10^{8}}$ = 1.9… × 10^{11} = 2 × 10^{11} J kg^{-1} (1 s.f.)	1 1
1 b iii	The gravitational potential difference is the energy gained per kg when an object moves through a given distance. As the meteoroid has a mass of 1 kg, it will gain 2 × 10^{11} J of energy.	1
1 b iv	mass per second = $\frac{\text{power}}{\text{gravitational potential difference}} = \frac{4\times10^{26}}{2\times10^{11}}$ = 2 × 10^{15} kg s^{-1}	1 1
2 a	${}^{1}_{1}\text{H} + {}^{1}_{1}\text{H} \rightarrow {}^{1}_{1}\text{H} + {}^{1}\text{n}$	2
2 b i	3.01605 – 2.0140 – 1.00728 = 0.00533 u mass difference = 0.00533 × 1.67 × 10^{-27} = 8.9 × 10^{-30} kg = 9 × 10^{-30} kg (1 s.f.)	1 1
2 b ii	$\Delta E = \Delta mc^2$ = 9 × 10^{-30} × (3 × 10^8)^2 = 8.01 × 10^{-13} J = 8 × 10^{-13} J (1 s.f.)	1 1
2 c i	number of protons in 1 kg = $\frac{1}{1.67\times10^{-27}}$ = 5.98… × 10^{26} Energy produced = $\frac{5.98\ldots\times10^{26}}{4}$ × 4.3 × 10^{-12} = 6.43… × 10^{14} J = 6 × 10^{14} J (1 s.f.)	1 1

2 c ii	Energy available = $2.0 \times 10^{29} \times 6 \times 10^{14} = 1.2 \times 10^{44}$ J $E = Pt$ so $t = \frac{E}{P} = \frac{1.2\times10^{44}}{4\times10^{26}} = 3 \times 10^{17}$ s $\frac{3\times10^{17}}{3.2\times10^{7}} = 1 \times 10^{10}$ years (= 10 billion years)	1 1