Answers to examination-style questions

Answers	Marks	Examiner's tips
1 (a) (i) Volume of cylinder = $\pi r^2 h$ $= \pi \times 0.30^2 \times 1.50 = 0.424\ \text{m}^3$ Mass of cylinder = volume × density $= 0.424 \times 7800 = 3310$ kg or 3300 kg	1 1	If you can't recall it, the equation for the volume of a cylinder is given in the Data Booklet. Remember that $r = \frac{1}{2} \times$ diameter.
(ii) E_K gained = E_P lost gives $\frac{1}{2}mv^2 = mg\Delta h$ ∴ velocity v of hammer = $\sqrt{2gh}$ $= \sqrt{2 \times 9.81 \times 0.80} = 3.96\ \text{m s}^{-1}$ or $4.0\ \text{m s}^{-1}$	1 1	This calculation can be done equally well using $v^2 = u^2 + 2as$, with $u = 0$, $a = 9.81\ \text{m s}^{-2}$ and $s = 0.80$ m.
(b) (i) Momentum of hammer before impact $= 3310 \times 3.96$ ($= 1.31 \times 10^4$ Ns) Momentum of hammer and girder after impact = $(3310 + 1600)V$ Momentum is conserved ∴ $4910\ V = 1.31 \times 10^4$ ∴ velocity after impact $V = 2.67\ \text{m s}^{-1}$ or $2.7\ \text{m s}^{-1}$	1 1 1 1	Since the hammer does not rebound (or stay in mid-air), the hammer and girder move together as one and the same object after impact. Let their common velocity be V. Conservation of momentum leads to this result.
(ii) Loss of E_K = work done against friction = friction force × distance moved Friction force = $\dfrac{0.5 \times 4910 \times 2.67^2}{25 \times 10^{-3}}$ $= 7.00 \times 10^5$ N	1 1	*Alternatively* the deceleration can be found from $v^2 = u^2 + 2as$, and then the force from $F = ma$. *Or* $F = \dfrac{\Delta(mv)}{\Delta t}$ may be used, with Δt determined by applying $s = \frac{1}{2}(u + v)\ t$.
2 (a) (i) Change of momentum of football $= 0.44 \times 32 = 14.1$ N s (or kg m s^{-1}) or 14 N s	1	The ball was at rest before being kicked, so the initial momentum was zero.
(ii) Using $F = \dfrac{\Delta(mv)}{\Delta t}$ gives $F = \dfrac{14.1}{9.2 \times 10^{-3}}$ ∴ average force of impact = 1.53 kN or 1.5 kN	1 1	The question leads you nicely into this form of solution. *Alternatively* you could use $v = u + at$ and $F = ma$
(b) (i) Use of $v = u + at$ gives $15 = 24 + (9.2 \times 10^{-3})a$ and $a = -978\ \text{m s}^{-2}$ ∴ deceleration of boot = $978\ \text{m s}^{-2}$ or $980\ \text{m s}^{-2}$	1	During the impact the boot is subject to two accelerations at right angles to each other. Part **(i)** considers the linear (negative) acceleration along the line of the impact force. Parts **(ii)** and **(iii)** look at the radial acceleration towards the centre of the arc in which the boot travels.
(ii) Centripetal acceleration of boot at time of impact $= \dfrac{v^2}{r} = \dfrac{24^2}{0.62} = 929\ \text{m s}^{-2}$ or $930\ \text{m s}^{-2}$	1	
(iii) *Before impact*: radial pull on knee joint is caused by centripetal acceleration of boot. *After impact*: radial pull is reduced because speed of boot is reduced.	1 1	The centripetal force on the boot acts inwards, towards the knee joint. The knee joint pulls inwards on the boot but is itself pulled outwards by the boot. When the boot slows down this centripetal force is reduced.

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3 (a) (i) Angular speed $\omega = 2\pi f = 2\pi \times 6.5$ $= 40.8\ \text{rad s}^{-1}$	**1**	The force exerted by the wheel on the mass is the centripetal force on the mass, which acts towards the centre of the wheel. The mass exerts an equal and opposite force on the wheel.
Force exerted by wheel on mass $F = m\omega^2 r = 0.015 \times 40.8^2 \times 0.25$	**1**	
$= 6.25$ N or 6.2 N or 6.3 N	**1**	
(ii) Arrow drawn at a tangent to the circular path, starting on the mass and directed vertically upwards.	**1**	If the mass is no longer fixed to the wheel, it will move in the direction it was travelling at the instant it became detached, **but in a straight line**.
(b) *Graph drawn to show*: • Exactly one cycle of a negative sinusoidal shape. • A period of 0.15 s clearly marked on time axis.	**2**	At $t = 0$ the vertical component of F is zero as F acts towards the centre of the wheel.. It becomes downwards or negative at 90°, and returns to zero at 180°. 0 at 270°, and returns to its original value at 360°. The period of rotation is $\frac{1}{6.5}$ s.
(c) *Relevant points include*: • Forced vibrations occur when a body is subjected to a periodic driving force. • The frequency of vibrations from the wheel increases as it speeds up. • The frequency of the forced vibrations is equal to the frequency of the wheel vibrations. • Resonance occurs at the natural frequency of the mirror. • At resonance the frequency of the forcing or driving oscillator is the same as the natural frequency of the mirror. • The amplitude of vibration reaches a maximum when the wheel rotates at 6.5 rev s^{-1} (or when the frequency of the forcing vibration is 6.5 Hz). • At higher frequencies (or speeds) the amplitude decreases again.	**any 5**	The vibrating wheel provides a periodic driving force that sets the mirror in forced vibration. These vibrations are at the frequency of the driving oscillator (the wheel) and they therefore increase in frequency as speed increases. Eventually the resonant frequency is reached, when there is maximum energy transfer from the driving oscillator to the driven oscillator, the mirror. At resonance the amplitude of vibration is greatest, so the mirror shakes violently. At higher frequencies the mirror still vibrates, but with much smaller amplitudes.
4 (a) (i) Angular speed $\omega = 2\pi f = 2\pi \times 15$ $= 94.2\ \text{rad s}^{-1}$	**1**	The force on each end cap is the centripetal force required to keep it moving in a circular path. This acts inwards, towards the axis about which the rotor is rotating.
Force on an end cap $F = m\omega^2 r = 1.5 \times 94.2^2 \times 0.55$	**1**	
$= 7320$ N or 7330 N (about 7 kN)	**1**	
(ii) Towards the centre of the rotor	**1**	

Answers to examination-style questions

Answers	Marks	Examiner's tips
(iii) Longitudinal stress in blade	1	This question now brings in a topic covered in *AS Physics A* Unit 2: the elastic properties of materials. The centripetal force on the end cap puts the whole rotor blade in tension, creating a tensile (longitudinal) stress throughout the blade. This stress will cause the length of the blade to increase slightly.
$= \frac{force}{c.s.\ area} = \frac{7320}{3.5 \times 10^{-4}}$		
$= 2.09 \times 10^7$ Pa (about 20 MPa)	1	
(iv) Young modulus $E = \frac{\text{tensile stress}}{\text{tensile strain}}$	1	
$\therefore$ tensile strain $= \frac{2.09 \times 10^7}{6.0 \times 10^{10}} = 3.483 \times 10^{-4}$		
tensile strain $= \frac{\Delta L}{L}$	1	
$\therefore$ change in length of blade $\Delta L = 3.483 \times 10^{-4} \times 0.55 = 1.92 \times 10^{-4}$ m (0.192 mm or 0.19 mm)		
(v) Strain energy stored in one blade $= \frac{1}{2}F\,\Delta L = \frac{1}{2} \times 7320 \times 1.92 \times 10^{-4}$	1	Like a stretched spring, a stretched rotor blade stores some potential energy.
$= 0.703$ J or 0.70 J	1	
(b) (i) **In 1 second** volume of air passing over blades = area × length per second $= Av$	1	It is helpful to think about the cylinder of air that is dragged down over the rotor blades. In 1 second this air travels a distance v, so the length of the cylinder is v. The air was at rest (with momentum = 0) before being pulled down by the blades.
Mass of air passing over blades $= Av\rho$		
Momentum gained by air = mass × $v = A\rho v^2$	1	
(ii) **Upward** force on helicopter = weight = 900 N	1	The upwards force on the helicopter is equal to the downwards force on the column of air. When the helicopter has no vertical motion, this force is equal to its weight. Force = rate of change of momentum = momentum gained in 1 second.
Area swept out by blades $A = \pi r^2 = \pi \times 0.55^2 = 0.950$ m^2	1	
$A\rho v^2 = 900$ gives speed of air $v = \sqrt{\frac{900}{0.95 \times 1.3}} = 27.0$ m s^{-1} or 27 m s^{-1}	1	

Answers	Marks	Examiner's tips
5 *Relevant points include*: **(a)** *Why strong vibrations are caused* • The pump creates a periodic driving force which acts on the pipe. • The pipe has a natural frequency of vibration. • The frequency of the periodic driving force increases as the pump speeds up. • At a certain speed, the frequency of the driving force equals the natural frequency of the pipe. • Under this condition resonance occurs.	**any 5**	Part **(a)** illustrates another practical example of resonance, where the periodic driving force is caused by the rotation of the pump in a central heating system. This will set all of the connected pipework into forced vibration at the frequency of the driving force. Every part of the pipework will have a natural frequency of vibration. At particular frequencies, resonance could occur in different parts of the pipework. This will cause large amplitude vibrations if the pipes are free to move.
(b) *Reduction of vibrations* • Fit extra clamps along pipe. • To eliminate (or change) the resonant frequency. **or** • Change pipe dimensions (or material) • To alter the resonant frequency		Damping, perhaps by fitting padding around a pipe, would also be effective in reducing the amplitude of vibrations produced by this effect. Equivalent credit would be available for an answer which referred to damping and explained its effect.
6 **(a)** Centripetal acceleration $a = \frac{v^2}{r}$ $= \frac{(7.68 \times 10^3)^2}{6750 \times 10^3}$ $= 8.74\ \text{m s}^{-2}$	**1** **1** **1**	Notice that this question requires the centripetal acceleration, not the centripetal force. The radius r of the orbit is found by adding the height of the orbit (380 km) to the radius of the Earth (6370 km).
(b) *Relevant points include*: • The scientist is in free fall. • The weight of the scientist provides the centripetal force. • To give the scientist the same orbit radius and acceleration as the ISS. • The scientist experiences no motion (or force) relative to the ISS.	**any 2**	'Apparent weightlessness' in a spacecraft is a similar situation to that of somebody in a lift whose supporting cables have snapped. There is no need for contact with the surrounding capsule, because it has the same acceleration towards the Earth as the person inside it.
(c) **(i)** $T = 2\pi\sqrt{\frac{m}{k}}$ gives $k = \frac{4\pi^2 M}{T^2}$ ∴ stiffness of spring system $k = \frac{4\pi^2 \times 2.0}{1.2^2}$ $= 54.8\ \text{N m}^{-1}$ (about $55\ \text{N m}^{-1}$)	**1** **1**	The quantity represented by k is usually called the 'spring constant', but that is for a single spring. The quantity referred to here as 'stiffness' is the effective spring constant for the two springs.

Answers	Marks	Examiner's tips
(ii) For the atom's vibrations, $T = 2\pi\sqrt{\frac{m}{k}}$ gives period $T = 2\pi\sqrt{\frac{4.7\times10^{-26}}{54.8}}$ $= 1.84\times10^{-13}$ s	**1**	The whole of part **(c)** is a good example of scientific modelling. A system that is much too small to be observed directly can be represented by a laboratory model having similar characteristics. Study of the model will provide information about the behaviour of the system represented by it.
Frequency of vibration $f = \frac{1}{T} = \frac{1}{1.84\times10^{-13}}$ $= 5.43\times10^{12}$ Hz or 5.4×10^{12} Hz	**1**	
7 (a) (i) The period remains unchanged	**1**	For simple harmonic vibrations of small amplitude, the period is independent of the amplitude.
(ii) Since $T = 2\pi\sqrt{\frac{m}{k}}$ and k is quadrupled, the new period T is half the original value	**1**	In greater detail, $\frac{T_{new}}{T_{old}} = \frac{\sqrt{k_{old}}}{\sqrt{k_{new}}} = \frac{\sqrt{k}}{\sqrt{4k}} = \frac{1}{2}$
(iii) $T = 2\pi\sqrt{\frac{m}{k}}$ and m = total mass on spring, M	**1**	Part **(iii)** is a simple exercise in squaring and rearranging the usual equation for a mass–spring system.
$\therefore\ T^2 = \frac{4\pi^2 M}{k}$, giving $M = \frac{kT^2}{4\pi^2}$	**1**	
(iv) Period $T = \frac{1}{f} = \frac{1}{0.91}$ (= 1.099) s	**1**	The total load on the spring is the weight of the lorry together with the weight of the platform on which it stands. The equation from part **(iii)** enables you to find the total mass supported by the spring. The mass of the lorry, given in the question as 5300 kg, must be subtracted from this in order to find the mass of the platform.
using $M = \frac{kT^2}{4\pi^2}$ gives $M = \frac{1.9\times10^5\times1.099^2}{4\pi^2}$	**1**	
$\therefore$ total mass on spring M = 5812 kg and mass of platform = 5820 – 5300 = 512 kg or 510 kg	**1**	
(b) *Relevant points include*: • The system is set into forced vibration by the lorry's engine. • The platform vibrates at the same frequency as the lorry. • Resonance occurs at a particular frequency … • which is around 0.91Hz. • Vibrations are of small amplitude at frequencies that are well away from this. • The amplitude of vibration is a maximum at resonance.	**any 4**	The engine vibrates as it runs, and acts as a source of the driving vibrations. The platform is driven by the vibrations of the lorry. The question states that the frequency of these vibrations is increased from 0.5 Hz to about 4 Hz. The natural frequency of the system is 0.91 Hz, i.e. that of the mass–spring system in part **(a)**. Resonance occurs as the vibrations pass through this frequency.

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8 (a) T/s: 0.35, 0.44, 0.51, 0.57, 0.62 (all shown to 2 decimal places)	1	It is the normal practice in tables of experimental results to maintain a consistent number of decimal places down a column. In this table an example is set by the first entry, given as 0.25 and 0.063.
T^2/s^2: 0.123, 0.194, 0.260, 0.325, 0.384 (all shown to 3 decimal places)	1	
(b) (i) For the mass suspended from the spring, $Mg = k\,\Delta L = k\,(l - l_0)$	1	The extension Δl of the spring is found by subtracting the original length from the new (measured) length. Hooke's law indicates that the tension in the spring is $k\,\Delta L$. When the system is in equilibrium, this tension is equal to the weight of the suspended masses.
Squaring, and substituting in, equation for period gives $T^2 = \frac{4\pi^2 m}{k} = \frac{4\pi^2(l - l_0)}{g}$	1	
(ii) *Graph drawn to have*: • Suitable scales • Both axes labelled: T^2/s^2 and l/mm • At least 5 points plotted correctly • An acceptable straight line	4	The scales you choose should allow your line to occupy more than half of the area of the graph paper. Use a 300 mm ruler when drawing the straight line, which should be the 'best-fit' line for the experimental points.
(iii) Gradient $= \frac{4\pi^2}{g} = \frac{0.400}{0.100}$ $= 4.00\ (\pm 0.05)\ s^2\,m^{-1}$	1	When $T^2 = 0$, $l = l_0$. Hence l_0 is the intercept on the l axis. Expanding the equation of the line gives $T^2 = \frac{4\pi^2 l}{g} - \frac{4\pi^2 l_0}{g}$ Comparison with the straight line equation $y = mx + c$ shows that the gradient (m) is $\frac{4\pi^2}{g}$
$\therefore\ g = \frac{4\pi^2}{4.00} = 9.87\ (\pm 0.15)\ m\,s^{-2}$	1	
Intercept on l axis $= l_0 = 300\ (\pm 5)$ mm	1	
(c) If $T = 1.00$s, $(l - l_0) = \frac{g}{4\pi^2} = \frac{1}{\text{gradient}}$ $= 0.250$ m	1	The largest time period in the experimental results is 0.62 s. The time period increases when a larger mass is placed on the spring. Since $T \propto \sqrt{m}$, a much larger mass would be needed to give $T = 1.00$ s
$\therefore\ l = 0.250 + l_0 = 250 + 300 = 550$ mm	1	
Spring may not obey Hooke's law when large masses are added to it.	1	The extension of the spring would be almost as great as its original length. With such a large extension, the spring would be unlikely to obey Hooke's law.
Beyond limit of proportionality, equal masses produce larger extensions.	1	

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9 (a) (i) Both obey an inverse square law of force or both field strengths are inversely proportional to distance squared or potential is inversely proportional to distance.	**1**	The similarities between electric and gravitational effects are a consequence of the inverse square law. Many of the formulae in these topics are similar, the constant of proportionality being G in one case and $\frac{1}{4\pi\varepsilon_0}$ in the other.
(ii) Gravitational fields always produce attractive forces whereas electric fields can produce attractive or repulsive forces. (**or** gravitational potential is always negative but electric potential can be positive or negative.)	**1**	
(b) Gravitational potential energy of satellite in orbit $= -\frac{GMm}{r}$	**1**	Gravitational potential energy = mass of satellite × gravitational potential of orbit. The change in a quantity is always calculated as (final value) − (initial value). Here the initial radius of orbit is 4.24×10^7 m. The change in potential energy works out to be a negative value, indicating that it is a decrease. You should expect the potential energy of the satellite to decrease as it moves closer to the Earth! For the final mark, don't forget to point out that **it is a decrease**.
Change in potential energy $= -GMm\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$ $= -6.67\times10^{-11}\times5.98\times10^{24}\times165\times\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$ $= -6.58\times10^{16}\times\left(\frac{1}{8.08\times10^6} - \frac{1}{4.24\times10^7}\right)$	**1**	
$= -6.59\times10^9$ J i.e. a decrease of 6.59×10^9 J	**1**	
(c) *Relevant points include*: • Higher orbit is geostationary – useful for maintaining continuous communication since it can act as a fixed reflector above the Earth. • Orbit is geosynchronous because the period of the satellite is the same as the period of the Earth's rotation on its axis. • Lower orbit is useful for monitoring – satellite scans the Earth 12 times a day, enabling many parts of the surface to be observed. • The low height of the shorter orbit allows closer inspection of the Earth's surface.	**any 3**	At the outset you have to realise the significance of the original orbit having a period of 24 hours. Since it is a geostationary satellite, it would have to move in an orbit over the Equator. When its height was reduced, it would still be moving above the Equator, and so it would not scan the whole Earth. A satellite in a low polar orbit scans the whole surface, because the Earth rotates beneath its orbit, about an axis in the plane of the orbit.
10 (a) *Factors affecting g are*: • The radius (or diameter) of the planet • The mass (or density) of the planet	**2**	Since $g = \frac{GM}{R^2}$, R and M are the two factors that count. Careless use of words could cause marks to be lost: 'size' of the planet would not be an acceptable answer.

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(b) (i) Volume of granite $= \frac{4\pi r^3}{3}$	1	The sample of granite rock is spherical. You can find its radius by reading from the second diagram, where its diameter is clearly 0.40 km, or 400 m.
$= \frac{4\pi \times 200^3}{3} = 3.35 \times 10^7\ \text{m}^3$	1	Mass = volume × density, thus $M_1 = V\rho_1$ and $M_2 = V\rho_2$, leading to mass difference $= V(\rho_1 - \rho_2)$. Since you are asked to **show** that the answer is 5.0×10^{10} kg, all working must be written down – including your answer to 3 significant figures.
Mass difference between granite and other material $= 3.35 \times 10^7 \times (3700 - 2200)$	1	
$= 5.03 \times 10^{10}$ kg	1	
(ii) At point **A**, $g_A = 9.81\ \text{N kg}^{-1}$	1	This is a demanding question, but part **(b)(i)** sets you thinking in a helpful direction. The difference in g is caused by the sphere of granite. But the increase it produces has to be corrected for the equivalent volume of matter that it replaces in the Earth. Hence it is the **difference in mass** between the granite and the surrounding material that determines the increase in field strength.
At point **B**, $g_B = 9.81\ \text{N kg}^{-1}$ + (field strength due to mass difference caused by granite sphere) $\therefore g_B - g_A$ = (field strength due to mass difference caused by granite sphere)		
$= \frac{GM}{R^2}$, where $R = 400$ m	1	
$= \frac{6.67 \times 10^{-11} \times 5.03 \times 10^{10}}{400^2}$	1	
$= 2.10 \times 10^{-5}\ \text{N kg}^{-1}$ or $2.1 \times 10^{-5}\ \text{N kg}^{-1}$	1	
(iii) Line drawn on the graph which is the same shape as the original, but with lower values at all points.	1	Since the granite is now at a greater distance from the surface, its presence has a smaller effect.
11 (a) (i) Wavelength of microwaves $\lambda = \frac{c}{f} \times \frac{3.00 \times 10^8}{1200 \times 10^6} = 0.250$ m	1	You should not panic when you read part **(a)(i)**: the angular width of the beam is defined as $\frac{\lambda}{d}$ at the start of the question! You must start by calculating λ, then find the angular width. It would be easy to overlook the fact that your final answer is required to be expressed **in degrees**.
Angular width of beam $= \frac{\lambda}{d} = \frac{0.250}{1.8}$ $= 0.139$ rad or 0.14 rad	1	
$= 0.139 \times \left(\frac{180}{\pi}\right) = 7.96°$ or $8.0°$	1	
(ii) Beam width at 15 000 km $= 1.50 \times 10^7 \times 0.139 = 2.09 \times 10^6$ m (which is 2100 km to 2 significant figures)	1	Angle θ in rad $= \left(\frac{\text{arc length}}{\text{radius}}\right)$ $\therefore$ arc length = radius × θ You can also draw a triangle and work with tangent or sine.
(b) (i) Gravitational force on satellite $F = \frac{GMm}{(R+h)^2}$	1	This is the standard theory for the orbit of a satellite, but expressed in terms of the linear speed v rather than the (more usual) angular speed ω. If it was not already evident, the final result should make it clear that the higher the orbit, the lower the speed of the satellite.
For the circular orbit, $\frac{GMm}{(R+h)^2} = \frac{mv^2}{(R+h)}$	1	
Cancelling m and taking square root gives speed of satellite $v = \sqrt{\frac{GM}{(R+h)}}$	1	

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(ii) Speed of satellite $v = \frac{GM}{(R+h)} = \sqrt{\frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{6.37 \times 10^{6} + 1.5 \times 10^{7})}}$ $= 4320\ \text{m s}^{-1}$ or $4300\ \text{m s}^{-1}$	1 1	This calculation simply makes use of the equation from part **(b)(i)**. At the end of the working, do not forget to take the square root.
Period of satellite $= \frac{2\pi r}{v} = \frac{2\pi \times 2.14 \times 10^{7}}{4320}$ $= 3.11 \times 10^{4}$ s or 3.1×10^{4} s	1 1	The satellite travels at speed v round an orbit whose length is the circumference of a circle. In this equation, r is the previous $(R + h)$.
(iii) Speed of beam over surface $= \left(\frac{\text{circumference of Earth}}{T}\right)$ $= \frac{2\pi \times 6.37 \times 10^{6}}{3.11 \times 10^{4}}$ $= 1290\ \text{m s}^{-1}$ ($1.3\ \text{km s}^{-1}$)	1	The time taken by the beam to move once round the surface of the Earth is the same as the time taken for one orbit by the satellite.
Time $= \left(\frac{\text{beam width}}{\text{speed of beam}}\right) = \frac{2.09 \times 10^{6}}{1290}$ $= 1620\ \text{s} = 27$ min	1	The beam width at the Earth's surface for a satellite at height h (15 000 km) was calculated in part **(a)(ii)**.
12 (a) (i) Force of attraction $F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2} = \frac{e_2}{4\pi\varepsilon_0 r^2}$ $= \frac{(1.6 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times (5.3 \times 10^{11})^2}$ $= 8.19 \times 10^{-8}$ N or 8.2×10^{-8} N	1 1	The charge of the electron is $-e$, whilst the charge of the proton is $+e$. According to this model of the hydrogen atom, this force provides the centripetal force to keep the electron in orbit around the proton.
(ii) $F = \frac{mv^2}{r}$ gives $v^2 = \frac{Fr}{m} = \frac{8.19 \times 10^{-8} \times 5.3 \times 10^{-11}}{9.11 \times 10^{-31}}$ $v = 2.18 \times 10^{6}\ \text{m s}^{-1}$ or $2.2 \times 10^{6}\ \text{m s}^{-1}$	1 1	It is not necessary to go back to first principles, because F has already been determined in part **(a)(i)**. Do not forget to take the square root when working out the final answer.
(ii) $\left(\frac{\text{de Broglie wavelength}}{\text{circumference of orbit}}\right) = \frac{h/mv}{2\pi r}$ $= \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 2.18 \times 10^{6} \times 2\pi \times 5.3 \times 10^{-11}}$ $= 1.00$	1 1	It may be surprising, but the de Broglie wavelength of the electron turns out to be exactly equal to the circumference of the orbit. Because both quantities are lengths, the ratio has no unit.
(b) (i) Energy released by transition $\Delta E = -2.2 \times 10^{-18} \times \left(\frac{1}{2^2} - \frac{1}{1^2}\right)$ $= 1.65 \times 10^{-18}$ J Wavelength emitted $\lambda = \frac{c}{f} = \frac{hc}{\Delta E}$ $= \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{1.65 \times 10^{-18}}$ $= 1.21 \times 10^{-7}$m or 1.2×10^{-7} m	1 1 1	The electron returns to the ground state (n = 1) from the first excited state (n = 2). Substitution of these values for n into the given energy equation allows the energy difference to be calculated. This part then asks you to recall work on emission spectra covered in Unit 1 of *AS Physics A*.

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(ii) The wavelength calculated in **(i)** is in the ultraviolet region of the electromagnetic spectrum. All other transitions to the ground state will produce wavelengths that are shorter than this.	1 1	The shortest visible wavelength is violet light (≈ 400 nm). All the other transitions to the ground state will release more energy than that in **(i)**, and higher energy photons have a shorter wavelength.
13 (a) (i) Mass of α particle $= 4 \times 1.66 \times 10^{-27} = 6.64 \times 10^{-27}$ kg or $2 \times (1.673 + 1.675) \times 10^{-27}$ kg $= 6.70 \times 10^{-27}$ kg Kinetic energy of α particle E_K $= 2.8 \times 10^6 \times 1.6 \times 10^{-19} = 4.48 \times 10^{-13}$ J Use of $E_K = \frac{1}{2}m\,v^2$ gives $v = \sqrt{\frac{2E_K}{m}} = \sqrt{\frac{2 \times 4.48 \times 10^{-13}}{6.64 \times 10^{-27}}}$ $= 1.16 \times 10^7$ m s^{-1} or 1.2×10^7 m s^{-1}	1 1 1	An α particle consists of 4 nucleons (2p + 2n). Its mass is therefore approximately 4u. The kinetic energy is given in MeV in the question; you must change this energy into J. Application of $\frac{1}{2}mv^2$ then leads to the result. α particles from radioactive sources usually have energies ranging from 4 to 9 MeV.
(ii) De Broglie wavelength of α particle $\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{6.64 \times 10^{-27} \times 1.16 \times 10^7}$ $= 8.61 \times 10^{-15}$ m or 8.6×10^{-15} m	1	Since an α particle has a much larger mass than an electron, it has a much smaller de Broglie wavelength when travelling at a similar speed to an electron.
(b) (i) Loss of E_K = gain of $E_P = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$ $Q_1 = 79e$ and $Q_2 = 2e$ $\therefore \frac{79 \times 2 \times (1.6 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times r} = 4.48 \times 10^{-13}$ gives least distance of approach $r = 8.12 \times 10^{-14}$ m or 8.1×10^{-14} m	1 1 1 1	As the α particle approaches the nucleus it gains electric potential energy and continues to lose kinetic energy until it stops. The potential energy gained is (charge × electric potential). The gold nucleus has 79 protons; the α particle has 2 protons. This is a slightly simplified model because the nucleus recoils and the α particle is not stationary at the distance of closest approach.
(ii) Diffraction is negligible because the de Broglie wavelength of the α particle is much smaller than $2r$ (which is the approximate diameter of the nucleus).	1	For significant diffraction, this wavelength has to be comparable with the diameter of the diffracting obstacle. Here it is only 5% of the diameter of the nucleus.
14 (a) Decreases from 40 V to 20 V in 4.7 s Decreases from 20 V to 10 V in (9.0– 4.7) = 4.3 s ∴ average time for pd to halve = 4.5 s	1 1	It is a characteristic of exponential decay that the quantity always decreases to half its original value in the same period of time. Other voltage pairs can be chosen but it is important to measure at least two values and show the values are roughly equal and have an average of about 4.5 s.

Answers	Marks	Examiner's tips
(b) Time constant RC $= \text{time for } V \text{ to fall to } \frac{V_0}{e}$ time for pd to fall from 40 V to 14.7 V = 6.6 s capacitance of **A** $= \frac{6.6}{R} = \frac{6.6}{10.0 \times 10^3}$ $= 6.6 \times 10^{-4}$ F (660 μF)	1 1	This could be calculated by substituting values from the graph into $V = V_0 e^{-t/RC}$, but it would take longer. Note that capacitor **B** discharges more rapidly than **A**, showing that **B** has the smaller capacitance.
(c) Capacitance of **B** = 290 μF (found by method in **(ii)** or a similar method) Energy lost by capacitor **B** when pd falls $= \frac{1}{2}C\,(V_1^2 - V_2^2)$ $= \frac{1}{2} \times 2.9 \times 10^{-4} \times (40^2 - 10^2)$ ∴ energy dissipated in resistor = 0.218 J or 0.22 J	1 1 1 1	The energy dissipated in the resistor must be equal to the energy lost by the capacitor. Any energy calculation involving a capacitor requires the value of its capacitance to be known, so the first step is to find it.
15 (a) (i) Energy lost by capacitor when pd falls $= \frac{1}{2}C(V_1^2 - V_2^2)$ $= \frac{1}{2} \times 2.0 \times 10^{-2} \times (4.5^2 - 2.5^2)$ $= 0.14$ J	1 1 1	The energy delivered to the motor is equal to the energy lost by the capacitor.
(ii) Potential energy gained by mass $= mg\,\Delta h = 0.015 \times 9.81 \times 0.35$ $= 5.15 \times 10^{-2}$ J efficiency of transfer $= \left(\frac{5.15 \times 10^{-2}}{0.14}\right) = 36.8\%$ or 37%	1 1	The 'efficiency of transfer' of energy is $\left(\frac{\text{useful work output}}{\text{energy input}}\right) \times 100\%$. The useful work output is the increase in gravitational potential energy of the mass.
(iii) *Reasons for inefficiency*: • Energy lost due to resistance of wires in the circuit and motor • Work done against friction • Work done against air resistance as the mass rises through the air • Sound energy losses due to vibration of the motor	any 2	All of this wasted energy eventually passes to the surroundings as thermal energy. There will be frictional forces at the bearings of the motor. The amount of energy converted into sound energy is incredibly small.
(b) (i) Average useful power output $= \left(\frac{\text{energy transferred}}{\text{time taken}}\right) = \frac{5.15 \times 10^{-2}}{1.3}$ $= 3.96 \times 10^{-2}$ W (39.6 mW or 40 mW)	1 1	Work, energy and power are covered in Unit 2 of *AS Physics A*.

Answers to examination-style questions

Answers	Marks	Examiner's tips
(ii) Use of $V = V_0\, e^{-t/RC}$ gives $2.5 = 4.5\, e^{-1.3/RC}$	1	The time of discharge from 4.5 V to 2.5 V is stated to be 1.3 s. This calculation involves solution of the equation for exponential voltage decay, using logs. It is assumed that the motor resistance is the total circuit resistance. In practice there will be a small resistance in the wires and terminals of the circuit, so the motor resistance will be slightly less than the calculated value.
$\therefore e^{1.3/RC} = \frac{4.5}{2.5} = 1.80$, $\frac{1.3}{RC} = \ln 1.80 = 0.588$, and $RC = 2.21$ s	1	
Resistance of motor $R = \frac{2.21}{2.0 \times 10^{-2}} = 111\ \Omega$ or $110\ \Omega$	1	
16 (a) (i) Magnetic field exerts a force on the wire when current passes through it.	1	The alternating current produces an alternating force on the wire, making it vibrate up and down between the poles of the magnet.
The current repeatedly reverses, so the force repeatedly reverses.	1	
(ii) At 290 Hz the driving frequency is equal to the fundamental frequency of the wire.	1	In this experiment the wire will resonate at any of its natural frequencies of vibration. The fundamental (lowest) frequency produces vibrations of the largest amplitude.
The wire is set into resonance.	1	
(iii) Wavelength of waves on wire $\lambda = 2L = 2 \times 0.71 = 1.42$ m	1	In the fundamental mode, the length of the wire between the fixed ends is $\frac{\lambda}{2}$. This is the condition for the establishment of a fundamental stationary wave.
Speed of waves on wire $c = f\lambda = 290 \times 1.42 = 412$ m s^{-1} or 410 m s^{-1}	1	
(b) (i) Mass per unit length $\mu = \frac{T}{c^2} = \frac{60}{412^2}$	1	Rearrangement of the equation given in the question gives this result. Note that the quantity you calculate is the mass **per unit length**, with unit **kg m^{-1}**.
$= 3.54 \times 10^{-4}$ kg m^{-1} or 3.5×10^{-4} kg m^{-1} or 3.6×10^{-4} kg m^{-1}	1	
(ii) Cross-sectional area of wire $A = \pi r^2 = \pi \times (0.12 \times 10^{-3})^2 = 4.52 \times 10^{-8}$ m^2	1	This type of calculation is often done most easily when you consider a unit length (1.0 m) of the wire. *Alternatively* you could calculate the density by finding the mass and volume of the 0.71 m length of the wire in the question.
Volume of a 1 metre length of wire $= A \times 1.0 = 4.52 \times 10^{-8}$ m^3	1	
Density of steel in wire $= \frac{\text{mass}}{\text{volume}} = \frac{3.53 \times 10^{-4}}{4.52 \times 10^{-8}} = 7810$ kg m^{-3} or 7800 kg m^{-3}	1	
17 (a) *Path drawn on Figure 1*: Curving downwards towards (or meeting) the negative plate.	1	The path is parabolic in an electric field, but circular in a magnetic field. The direction of the force in the magnetic field, and hence the deflection, is given by Fleming's left-hand rule.
Path drawn on Figure 2: Curving upwards towards the top of the page.	1	

Answers	Marks	Examiner's tips
(b) **(i)** The electric field strength is the force that acts per unit charge on a small positive test charge when placed in the field. The field strength is uniform if the field strength has the same magnitude and direction at all points in the field.	1 1	There are two things to explain here: what is meant by *field strength*, and what is meant by *uniform*. Since electric field strength is a vector, 'uniform' means having the same magnitude **and direction** at all points.
(ii) In a uniform field $E = \frac{V}{d}$ $\therefore V = E\,d$ $= 2.0 \times 10^4 \times 0.045$ $= 900$ V	1 1	The electric field is uniform over most of the region between parallel plates, although it does weaken towards the outer edges.
(c) **(i)** Force on particle in electric field $F = E\,Q = 2.0 \times 10^4 \times 6.4 \times 10^{-19}$ $= 1.28 \times 10^{-14}$ N or 1.3×10^{-14} N	1 1	This force acts vertically upwards, in the same direction as the field, because the charge is positive.
(ii) If the electric force is equal to the magnetic force, $E\,Q = B\,Q\,v$ $\therefore$ initial velocity $v = \frac{E}{B} = \frac{2.0 \times 10^4}{0.17}$ $= 1.18 \times 10^5$ m s^{-1} or 1.2×10^5 m s^{-1}	1 1	This principle is embodied in the velocity selector component of a mass spectrometer: see the earlier examples in Chapter 7.
(d) *Relevant points include*: *In an electric field* • Force always acts in the same direction. • There is an acceleration in the direction of the force. • This acceleration increases the speed in the direction of the force … • but the horizontal speed at right angles to the field remains constant. *In a magnetic field* • The force is always perpendicular to the direction of movement. • This force has no component in the direction of movement. • There is no acceleration in the direction of movement, so speed is constant. • Motion is in a circular path.	**any 6**	The speed remains constant in a *magnetic field* despite the fact that the charged particle is subjected to a force. The force always acts at right angles to the velocity of the particle, causing a centripetal acceleration. The magnetic force has no component in the direction of the particle's movement. There is no acceleration along the path travelled and no change in speed. In an *electric field*, a charged particle moves like a projectile subject to gravity. It continues at constant speed at right angles to the force, whilst being accelerated in the direction of the force.
18 (a) *Relevant points include*: • Gravitational force acts towards the centre of the orbit. • This force is at right angles to the velocity of the satellite. • There is no displacement in the direction of the gravitational force. • No work is done; there is therefore no change in E_K and no change in speed.	**any 3**	The force acting on the satellite is always directed at right angles to the instantaneous velocity. This force therefore has no component in the direction of the velocity. In these circumstances the acceleration produced by the force has the effect of changing the direction of the velocity but not its magnitude.

Answers to examination-style questions

Answers	Marks	Examiner's tips
(b) **(i)** Resultant magnetic flux density $B_{res} = \sqrt{56^2 + 17^2} = 58.5\ \mu T$ or $59\ \mu T$	1	Part **(b)** starts with some of the work involving vectors covered in Unit 2 of *AS Physics A*: vector addition (from the resolved components of a vector) and angles in a vector triangle (or vector parallelogram).
(ii) If the angle is between the rod and B_{res} is θ, then $\tan\theta = \frac{17}{56}$	1	
giving $\theta = 16.9°$ or $17°$	1	
(iii) An emf is induced in the rod because it cuts through the magnetic flux/field of the Earth.	1	The emf induced would vary as the satellite moved round the Earth, because B_{res} (and its components) would be different in different locations.
19 (a) **(i)** E_k gained = E_p lost $\therefore \frac{1}{2}mv^2 = e\,V$	1	A charged particle 'travels' across an electric field in much the same way that a mass falls through a gravitational field. In each case, the force from the field causes kinetic energy to increase.
Speed of electron $v = \sqrt{\frac{2eV}{m}} = \frac{2 \times 1.60 \times 10^{-19} \times 12 \times 10^3}{9.11 \times 10^{-31}}$ $= 6.49 \times 10^7\ m\ s^{-1}$ or $6.5 \times 10^7\ m\ s^{-1}$	1	
(ii) Charge arriving at screen in 1s $= 25 \times 10^{-3}$ C	1	Remember that $Q = It$ (or that 1 A = 1 C s^{-1}), from Unit 1 of *AS Physics A*. Each electron has a charge of e ($= -1.60 \times 10^{-19}$ C), so number of electrons per second $= \frac{I}{e}$.
$\therefore$ in 1s, number of electrons striking screen $= \frac{25 \times 10^{-3}}{1.60 \times 10^{-19}} = 1.56 \times 10^{17}$ or 1.6×10^{17}	1	
(b) **(i)** The changing magnetic field causes changes in the magnetic flux linked with the circuits	1	Faraday's law: the induced emf is equal to the rate of change of flux linkage. Note that strictly it is **emfs** that are induced.
These changes in flux linkage induce **emfs** in the circuits	1	There will be induced **currents** if the circuits are complete.
(ii) *Possible causes of faults*: • When there are induced currents, these could lead to heating effects and/or additional magnetic fields. • Large induced emfs could cause circuit components to fail by breaking down their insulation.	any 1	Changing magnetic fields will always induce emfs. Sometimes metal shielding is fitted around the internal components of electronic equipment in order to protect the components from induced emfs.
(iii) Maximum change in magnetic flux $\Delta B = 7.0 \times 10^{-4}$ T	1	The **maximum** induced emf is given by the maximum rate of change of flux linkage. The flux density changes from 0.35 mT in one direction to 0.35 mT in the other direction (a change of 0.70 mT) in 50 μs.
Maximum change in flux linkage $\Delta(N\phi)$ $= 250 \times 7.0 \times 10^{-4} \times 4.0 \times 10^{-3}$ $= 7.0 \times 10^{-4}$ Wb turns	1	
Maximum induced emf $= \frac{\Delta N\phi}{\Delta t} = \frac{7.0 \times 10^{-4}}{50 \times 10^{-6}} = 14$ V	1	Magnetic flux $\phi = B \times$ area A, and flux linkage $= N\phi$.
(iv) The coil might not be perpendicular to the changing magnetic field.	1	If it was not perpendicular, the induced emf would be smaller.

Answers	Marks	Examiner's tips
Induced currents in other circuits in the television might reduce the magnetic flux through the coil.	1	These induced currents would produce magnetic fields that would oppose the change producing them (Lenz's law).
20 (a) (i) *Relevant points include*: • A current that circulates in a loop within a conductor. • There are alternating currents in the coils of a transformer… • which produce changing magnetic fields in the core. • This effect induces emfs in the core, which cause the eddy currents. • The eddy currents cause energy to be wasted because the currents produce heating of the core.	any 4	The core is a magnetically soft material, which is also a conductor. It can be thought of as 'chains' of atoms. These chains are continuously cut by the changing magnetic fields caused by the alternating currents in the primary and secondary coils. Any conductor subjected to a changing magnetic flux will have an emf induced in it. The emfs in the core cause the eddy currents, which dissipate some of the energy that is supplied to the transformer by heating its core.
(ii) The core of the transformer is **laminated** i.e. made from alternate layers of metal and insulator. Eddy currents are reduced because the metal is no longer continuous (or the resistance of the core is increased).	1 1	A lamina is a plane sheet, such as a sheet of cardboard. The core is made from a stack of metal sheets, separated by insulating material. This means that eddy currents can only flow within each single sheet, instead of in the whole core. Much reduced eddy currents means greatly reduced energy losses.
(b) (i) Current in each lamp $I = \frac{P}{V} = \frac{36}{12} = 3.0$ A Ammeter reading $= 3 \times 3.0 = 9.0$ A	1 1	The secondary of the transformer supplies three identical lamps that are connected in parallel. The total current is the sum of the currents in each lamp.
(ii) Total output power $= I\,V = 9.0 \times 12 = 108$ W Input power $= 108$ W $\therefore$ primary current $I_p = \frac{P}{V} = \frac{108}{48} = 2.25$ A	1 1	Since this transformer is assumed to be perfectly efficient, the input power is equal to the output power. This implies that the current is stepped up by a factor of 4 when the voltage is stepped down by a factor of 4.
(iii) Turns ratio equation $\frac{N_s}{N_p} = \frac{V_s}{Vp}$ gives $N_s = \frac{240 \times 12}{48} = 60$	1	When the voltage is stepped down in the ratio 4:1, the turns ratio must also be 4:1.

Nelson Thornes is responsible for the solution(s) given and they may not constitute the only possible solution(s).