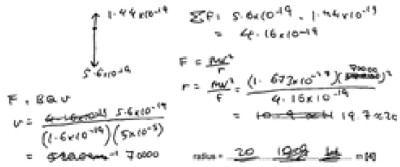
Mark scheme

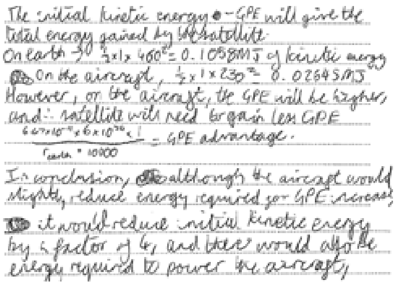
Question			Answer/Indicative content	Marks	Guidance
1	a		*F* (= *EQ*) = 0.90 × 1.60 × 10^{-19} = 1.4(4) × 10^{-19} (N)	B1	Working and answer must both be shown Answer must be given to 2sf or more Unit need not be given but, if given, must be correct **<u>Examiner's Comments</u>** This was an easy introduction to the question, which used the definition of electric field strength; $E = F_E / Q$. Being a 'show that' question, candidates needed to show their working in full, including writing the value for the electronic charge (rather than simply 'e') and giving the answer to at least 2 s.f.
	b	i	(*F* = *BQv* but *B* and *Q* are constant, so) (the magnitude of) the velocity is different /changes	B1	**Allow** speed **Ignore** the direction is different **<u>Examiner's Comments</u>** The force on a charged particle moving at right angles to a magnetic field is given by the formula $F_{mag} = BQv$. Since *B* and *Q* are constants in this case, the reason for the different magnitude of *F* must be that the proton has a different velocity, *v*. **Common problems in 6(b)(i)** • using the formula $F = BIl\sin\theta$ and suggesting that the proton might be travelling at a different angle to the field, not realising that the proton is always travelling at right angles to the magnetic field in this question • suggesting that the proton may be in a weaker (or stronger) field at X than at Y, not realising that the magnetic field is uniform and so its field strength is constant throughout

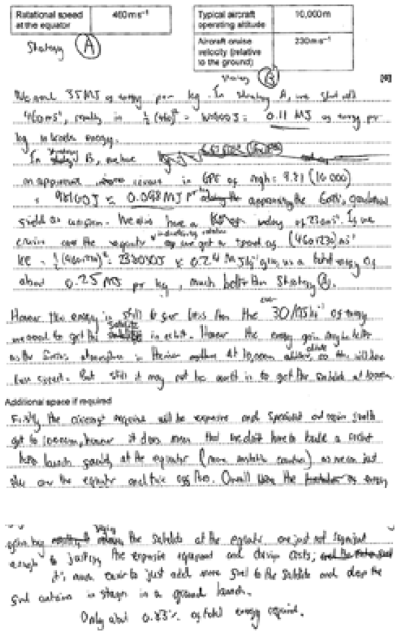
		ii	$v = (\frac{F_{mag}}{BQ} =) \frac{5.6 \times 10^{-19}}{5.0 \times 10^{-5} \times 1.60 \times 10^{-19}}$ resultant force F_R= (5.6 − 1.4) × 10^{-19} $r = \left(\frac{mv^2}{F_R} =\right) \frac{1.673 \times 10^{-27} \times (7.0 \times 10^4)^2}{4.2 \times 10^{-19}}$ r = 20 (m) Alternative all-in-one method: $r = \frac{mF_{mag}{}^2}{F_R B^2 Q^2}$ resultant force F_R= (5.6 − 1.4) × 10^{-19} $r = \frac{1.673 \times 10^{-27} \times (5.6 \times 10^{-19})^2}{4.2 \times 10^{-19} \times (5.0 \times 10^{-5})^2 \times (1.60 \times 10^{-19})^2}$ r = 20 (m)	C1 C1 C1 A1 (C1) (C1) (C1) (A1)	$v = 7.0 \times 10^4$ (m s^{-1}) implies first C1 **Allow** 10^{-19} for 1.4×10^{-19} (giving $\boldsymbol{F_R}$= 4.6×10^{-19}) $F_R = 4.2 \times 10^{-19}$ implies second C1 Do not credit if used as F_{mag} in F_{mag} in $F_{mag} = BQv$ Third C1 is for correct substitution into formula **Allow** $m_p = 1.67 \times 10^{-27}$ kg given to 3 s.f. **Not** $m_p = 1.661 \times 10^{-27}$ kg or $m_p = 1.675 \times 10^{-27}$ kg **Allow ECF** for incorrect v Use of $\boldsymbol{F_R} = 5.6 \times 10^{-19}$ or $= 1.4 \times 10^{-19}$ is **XP** **Allow** r = 19 (m) $\boldsymbol{F_R = 4.2 \times 10^{-19}}$ (4.16×10^{-19} to 3sf) implies second C1 An incorrect value of F_R is **XP** from this point Third C1 is for correct substitution into formula **Allow** r = 19 (m) **<u>Examiner's Comments</u>** This question could not be done in one step, by equating the magnetic force to the centripetal force. This is because, at X, the centripetal force is being provided by a combination of forces from both the electric and the magnetic field. The easiest approach is to find the velocity of the proton using $F_{mag} = BQv$ (the value for F_{mag} is given in the diagram as 5.6×10^{19} N). This velocity v can then be used in the formula $F = mv^2/r$ in order to calculate the radius, r. F here is the *resultant* force towards the centre of the circle, which is found from magnetic force downwards - electric force upwards (the electric force having been calculated in part (a)). Exemplar 3 is an example of a correct

					answer, clearly written to show each stage in the calculation: Exemplar 3 
		iii	$\lvert\text{resultant force}\rvert = (\sqrt{3.9^2 + 1.4^2}) \times 10^{-19}$ $\lvert$resultant force$\rvert$ = 4.1 × 10^{-19} (N)	C1 A1	**Ignore** attempt to calculate weight of proton **Allow** $F_E = 10^{-19}$ **Allow** $\lvert F\rvert = 4.0 \times 10^{-19}$ (N) using $F_E = 1.0 \times 10^{-19}$ **Allow** $\lvert F\rvert = 4.2 \times 10^{-19}$ (N) using $F_E = 1.44 \times 10^{-19}$ **<u>Examiner's Comments</u>** There are two forces acting on the proton at Y: an electric force upwards (given in (a)) and a magnetic force to the left (shown on the diagram). These two forces act at right angles to each other, and so the magnitude of their resultant can be found using Pythagoras's Theorem. Credit was given for using a value for the electric force to 1, 2 or more significant figures.
		iv	<u>resultant / net</u> force is not perpendicular to velocity work is done on proton (therefore kinetic energy changes so speed is not constant)	B1 B1	**Allow** direction of motion / path but **not** speed for velocity **Allow** acceleration / <u>resultant</u> force is not (always) towards centre (of circle) **Allow** electric force is not perpendicular to velocity / is in the same direction as velocity **Ignore** references to centripetal **Ignore** references to centripetal **<u>Examiner's Comments</u>** At Y, the proton is moving downwards, with a resultant force being the combination of an electric force upwards and a magnetic force to the left (calculated in part 1). The resultant force cannot be at right angles to the

					velocity, so we cannot have circular motion. The component of the resultant force acting in the direction of the proton's motion will do work on the proton and change its speed. So, the proton cannot be travelling at a constant speed.
			Total	**10**	
2	a	i	$\frac{GMm}{r^2} = \frac{mv^2}{r}$ $\frac{1}{2}mv^2 = \frac{1}{2}\frac{GMm}{r}$	M1 A1	Allow omission of 'm' on both sides of equation (gravitational field strength = centripetal acceleration) Cancelling/rearrangement/identification of GMm/r as GPE **<u>Examiner's Comments</u>** Many candidates made a good start by equating the formula for gravitational force with the expression for centripetal motion. Others that assumed that g of 9.81 m s^{-2} did not score any marks. The simplest way to arrive at the correct expression was to identify GM/r in the gravitational force formula, to rearrange and then multiply both sides by ½. Approximately ½ of all candidates that responded got as far as this gaining both marks.
		ii	(Increase in) GPE = (−56 − −63 MJ =) 7(MJ) or (Increase in) KE = 0.5 × 56 = 28 (MJ) Sensible reasoning, e.g. 7+28 > 30	M1 A1	Allow **evaluation of total energy** of 35 (MJ) **<u>Examiner's Comments</u>** Many candidates correctly determined how much GPE the satellite needed to gain i.e. 7 MJ in order to reach orbit from -63 MJ to -56 MJ. To find the KE when in orbit, candidates needed to use the result from the previous part of the question. This explains why the in orbit, the KE required is ½ of 56 MJ i.e. 28 MJ. A small fraction of candidates successfully accomplished this step.

					This means the total energy gain is the sum of 28 MJ and 7 MJ i.e. 35 MJ.
	b		**Level 3 (5–6 marks)** Correct calculations, and advantages and limitations discussed. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Correct calculations and an advantages discussed or Correct calculations and a limitation discussed. *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Attempted calculations or a single correct calculation or incomplete explanations of advantages and/or limitations. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 mark** *No response or no response worthy of credit.*	B1 × 6	Use level of response annotations in RM Assessor Ignore general knowledge answers e.g. accidents, cost, politics Allow references to energy, energy per unit mass or potential as interchangeable Allow ecf from candidate's value for total energy per unit mass in orbit from (i.e. 35 MJ) 22bii or use of 30 (MJ) **Indicative scientific points may include:** **Calculations** • (Minimum) additional KE from aircraft=26 kJ • Additional GPE from aircraft = 100 kJ • Additional KE from equatorial launch=110 kJ • GPE calculated by mgh as an acceptable approximation • (Without taking Earth's rotation into account,)KE at equator is about 4x aircraft KE • GPE calculated from vg = (−)GM/r • Total energy = 0.5GM/r **Advantages** • Aircraft launch provides KE and GPE • Aircraft velocity will be higher than 230 depending on where the aircraft takes off. • Less (rocket) fuel required • Aircraft launch has similar/slightly larger energy to equatorial • Equatorial launches can only happen in limited locations/aircraft launches can take place almost anywhere **Limitations**

					• Aircraft launches only suitable for small satellites. • Effects (for either) only significant for near earth orbits/low altitudes • Either launch provides very small fraction (less than 1%) of the energy required **<u>Examiner's Comments</u>** Many candidates found this difficult to access. A solely qualitative evaluation was limited to level 1 (2 marks). Exemplar 2  The initial kinetic energy − GPE will give the total energy gained by the satellite. On earth → $\frac{1}{2}\times1\times460^2 = 0.1058$MJ of kinetic energy On the aircraft, $\frac{1}{2}\times1\times230^2 = 0.02645$MJ However, on the aircraft, the GPE will be higher, and ∴ satellite will need to gain less GPE $\frac{6.67\times10^{-11}\times6\times10^{24}\times1}{r_{earth}+10000}$ = GPE advantage. In conclusion, although the aircraft would slightly reduce energy required for GPE increase, it would reduce initial kinetic energy by a factor of 4, and there would also be energy required to power the aircraft, In Exemplar 2, the candidate has completed a small number of calculations comparing the KE the two methods would raise. There is also a statement that these differ by a factor of 4 along with an attempt at calculating the GPE advantage by launching from the aircraft rather than from the ground. Crucially, there is very little mention of limitation and no supporting calculations. Holistically speaking, therefore, there was not enough evidence to award this candidate Level 3, yet sufficient for a Level 2. Exemplar 3

					 In Exemplar 3, this candidate makes an excellent attempt at every portion of the question. They have taken great effort to make themselves clear with technical language. They have also performed numerous calculations to compare the GPE and KE in the two different scenarios. A further figure appears right at the bottom of the response. The candidate has correctly calculated the percentage of the overall energy required that is supplied by either method. In conclusion, the candidate has used their many correct calculations to weigh up evidence effectively in terms of the advantages and limitations.
			Total	**10**	
3		i	Energy transferred from electrical (energy) to internal (energy) or thermal (energy) of filament Energy transferred from filament to internal energy of gas (because) the (rate of) energy lost to the surroundings = the (rate of) energy transfer gained (by filament)	B1 B1 B1	Allow power supply doing electrical work on filament Allow heating of gas by conduction Allow description of Newton's Law of Cooling Allow heating of gas by radiation Allow reference to thermal equilibrium of any part or whole of lamp structure **<u>Examiner's Comments</u>** Again, the language required to

					suitably communicate the correct Physics was challenging here. Respones which described gas law physics had missed the point. The principal reasons why the temperature of the filament does not increase above any given temperature is that the energy in = energy out in a given time period. Further marks were for describing the energy process for supplying energy to the filament and the transfer of energy away from the filament. **Examination Tip** Quantities in Physics remain unchanged often because an idea of equilibrium or balancing two sides of an equation (see questions 16(a)(iii) or 16(b) for earlier examples). Explaining the physics of either side of that equation is often creditworthy.
		ii	(P/T = constant) $\frac{120}{2400} = \frac{p}{290}$ pressure = 14.5 (kPa)	C1 A1	Allow 15 Allow 14 **Examiner's Comments** Most candidates used the directly proportional relationship of pressure to absolute temperature successfully here.
			Total	**5**	
4	a	i	$P = 7.0 \times 10^{-15} \div 0.11$ $I = 6.36 \times 10^{-14} / 1.0 \times 10^{-4} = 6.4 \times 10^{-10}$ (Wm^{-2})	M1 A1	**Examiner's Comments** Most candidates successfully manipulated the data given to show that the radiant power per unit as required.
		ii	$L/4\pi r^2 = 6.4 \times 10^{-10}$ $r = (L \div (6.4 \times 10^{-10} \times 4\pi))^{0.5}$ $= 5.4 \times 10^{18}$ (m) ($\div 9.5 \times 10^{15}$ =) 560 light years	C1 C1 C1 A1	Allow use of 6×10^{-10} Allow alternative method: Finding intensity at star surface C1 Using ratio of intensities = square of ratio of (star radius / distance to earth) C1 Use of 6×10^{-10} for I gives 580 ly **Examiner's Comments**

					This is a challenging multi-step question. Essentially it tests understanding of the inverse-square relationship. Some candidates simply used the formula given on the formula sheet. Others did not, however successfully manipulated the data to use the inverse-square rule and/or finding the intensity of radiation leaving the surface of the star. Once the candidate arrived at the distance in metres, it was relatively simple to find the distance in light years.
	b		Any three from: There is a range/ ‘band’ in the luminosity values at 6300 K range of luminosity is between L. and about 10 L. The uncertainty in the distance calculated = ½ the uncertainty in the luminosity AW Reference to Nu Persei not necessarily being on the main sequence	B1 B1 B1 B1	Check diagram for rewardable content **<u>Examiner’s Comments</u>** This item also proved very challenging. The key idea here is that there is a range of luminosities (the inherent power of the star) that correspond to a temperature of 6300 K, not least that the star may not be main sequence at all. These ideas are reminiscent of a question in a previous paper. After those initial ideas, the candidates needed to discuss this more quantitatively by noticing that the range of luminosities was about 10, given that the scale is logarithmic. **Assessment for learning** There is a lot of Physics relevant to the H-R diagram other than merely the shape of the main sequence and the positions of other classifications of stars. Teachers might consider explaining how the data for the H-R diagram is collected and processed, along with the accompanying uncertainties in those measurements.
			Total	**9**	

5	a	i	Curve starts at (0,0) with gradient decreasing to a maximum value 30 on vertical axis matching highest point of candidate's line	B1 B1	Accept horizontal asymptote NB ignore candidate's response after their line reaches 30 (m/s) **<u>Examiner's Comments</u>** Most candidates used the grid effectively to put a suitable scale on the speed axis. They also communicated that the maximum speed was 30 m s^{-1}. Many candidates also got the shape of the curve correct, which starts with maximum gradient and then flattens out.
		ii	Resistive force increases (with speed) Zero net or zero resultant force	B1 B1	Allow drag / (air) resistance / friction for 'resistive force' Allow resistive force = component of weight down the slope NOT simply idea of resistive force = weight **<u>Examiner's Comments</u>** While many candidates appreciated that the car reached a maximum speed because the resultant force was zero, some contradicted this by saying that the weight = drag (as it would be in vertical motion) or something else incorrect. Far fewer candidates stated that the drag increases with speed effectively. Quoting the given expression F = kv^2 was deemed insufficient. **Examination Tip** Repeating information given in the question is rarely creditworthy by itself.
		iii	Component of weight down slope = 9300 sin 5° Re-arrange to (k=)$F \div v^2$ (k=)810 ÷ 900 = 0.9…	M1 M1 A1	Allow 810 or 811 seen Allow substitutions for variables Mark is for substitution <u>and</u> candidate's value seen **<u>Examiner's Comments</u>** As this question is a 'show that', all steps were required. Many candidates

					omitted the rearrangement stage, restricting their maximum score for this item to 1 mark. This approach was consistent throughout the paper for this type of question. **Examination Tip** Make sure that all steps of working are presented in 'show that' questions, especially the step that shows the relevant quantity as the subject of the equation. Always show your evaluation to at least 1 more significant figure than that shown in the question.
	b		evidence of substitution of $F=kv^2$ into $P = Fv$ $v = (P \div k)^{1/3}$ $v = 44$ (m s^{-1})	C1 C1 A1	e.g. $P = kv^3$, $P = (kv^2)\ v$, etc Allow use of $k = 1$ which gives 42 Allow answer within range 36 to 53 **<u>Examiner's Comments</u>** The key idea here is that the force from the engine (given by F = P / v) will equal the resistive forces (F = kv^2) when the car is at maximum speed. Candidates could choose which value of k they used here, either k = 1 from the question data or the value of k from the previous item. This gives an acceptable range of speeds as stated in the mark scheme.
	c		Power is proportional to the speed cubed / Max speed is proportional to the cube root of max power / power proportional to speed x kv^2 Valid reference to the cube root of 2 increase in velocity for double power / Valid reference to factor of 8 increase in power for double the velocity	B1 B1	NB cube root of 2 is 1.2599… e.g. 1.26 × 44 = 55 (m s^{-1}) **<u>Examiner's Comments</u>** Even if they couldn't complete the calculation in the previous item, candidates needed to be able to state the idea qualitatively for the first mark. No further calculations were required, except the correct answer that the maximum speed would increase by a factor of cube root (2).
			Total	**12**	
6			**D**	1	**<u>Examiner's Comments</u>** When the initial displacement is doubled, then the amplitude and hence

					maximum speed is also doubled. If the maximum speed is doubles, the maximum KE is quadrupled, since KE = ½ m v^2.
			Total	**1**	
7			energy of one photon of blue light = $6.63 \times 10^{-34} \times 6.38 \times 10^{14}$ (=4.23×10^{-19} J) number emitted in 1s = $\frac{1 \times 10^{-3}}{(6.63 \times 10^{-34} \times 6.38 \times 10^{14})}$ / $1 \times 10^{-3} \div 4.23 \times 10^{-19}$ 2.4×10^{15} photons of blue light which is less than for red light (3.3×10^{15})/the student is incorrect	C1 C1 A1	Calcn using v=fλ and E=hc/λ **<u>Examiner's Comments</u>** Most candidates were given 1 mark for correctly calculating the energy of one photon of blue light by selecting and applying E=hf. Some candidates correctly converted the power of the LED to calculate the number of blue photons emitted in 1 second by using and applying P=E/t. Where candidates did not achieve any further marks, thi was for selecting an incorrect equation and not applying P=E/t.
			Total	**3**	
8			$mgh = \frac{1}{2}mv^2$ **Or** $v^2 = u^2 + 2as$ **Or** $v = \sqrt{2gh}$ **Or** $9.81 \times 2.0 = \frac{1}{2}v^2$ $v = \sqrt{2 \times 9.81 \times 2.0}$ 6.3 (m s^{-1})	C1 C1 C1	**<u>Examiner's Comments</u>** Candidates performed very well on this question by selecting and applying the correct equation of motion to calculate the speed of the ball when it hit the ground. **Selection and application of formulae** Candidates performed well on the selection and application of equations of motion from Module 3: Forces and motion.
			Total	**3**	
9			More energy is dissipated as heat (in a larger *r*) (So) less energy transferred to the bulb **Or** Larger p.d. across *r* /Ir will be larger / More "lost volts"/ Reduces the pd across the bulb/ (ε - Ir) will be smaller **Or**	B1 B1 B1 B1 B1 B1	**Ignore** ref. to less current/dimmer bulbs/more cells/batteries required to power the bulb/batteries need replacing more often **<u>Examiner's Comments</u>** Some candidates achieved 1 mark for this question for suggesting the most common response that the potential difference across the bulb would

			(For larger r) more power is dissipated (as $P=I^2r$) (So) P (power) delivered to the bulb is less		decrease or that there would be more lost volts across the cells but only a few linked these suggestions to achieve 2 marks. Most candidates mixed suggestions by referencing energy transfer and potential difference which meant that they only achieved 1 mark. Some candidates gave suggestions in terms of current and efficiency, which did not link to the undesirability of a large internal resistance and so were not given any marks.
			Total	**2**	
10			Use cos50° **or** sin40° $P = \frac{3.5\text{x } 32 \cos 50}{6}$ **or** $P = \frac{3.5\text{x } 32 \sin 40}{6}$ 12 (W)	C1 C1 A1	**Allow** calcn of v=3.5/6=0.583ms^{-1} **<u>Examiner's Comments</u>** Candidates performed well on this question by correctly applying P=Fv by calculating the horizontal component of the 32N force acting on the box and the velocity as it moved along the floor to calculate the power of the technician as 12W.
			Total	**3**	
11		i	**Either** (thermal/heat) energy required per unit mass to change solid to liquid <u>at constant temperature</u> **or** (thermal/heat) energy released per unit mass when liquid changes to solid <u>at constant temperature</u>	B1 (B1)	**Ignore** *L* = *E* /*m* unless letters are defined **Allow** energy per kg /energy of 1kg for energy per unit mass **Allow** energy required to melt unit mass at constant temperature **Allow** energy released when unit mass solidifies at constant temperature **<u>Examiner's Comments</u>** There were several reasons why responses to this question did not gain credit: • constant temperature was not mentioned • per unit mass (or per kg) was omitted • the phase change was not stated, or was incorrect

					• it was stated that energy was required to turn a liquid into a solid.
		ii	(Energy =) $Pt = mL$ $m = \frac{40 \times 60}{9.4 \times 10^4} =$ **2.6 × 10^{-2}** (kg)	C1 A1	**Allow** $E = Pt$ **and** $E = mL$ seen separately Formulae may be implied from subsequent calculation Correct to at least 2sf 2.553 ×10^{-2} to 4sf so annotate 2.5 ×10^{-2} as AE **Examiner's Comments** This question was well answered by most candidates. However, some tried to use $E = mc\Delta\theta$ with $\Delta\theta$ = 160°C and a few gave their answer to only 1 sf.
		iii	Any two from • not all the heat / energy is used to melt the PLA **or** some heat / energy is 'lost' (to environment / surroundings) • some heat / energy / time is used to raise temperature of PLA up to **or** above its melting point / 160°C • (PLA not all applied to same spot so) PLA needs (time) to move from one place to another • PLA needs (time) to solidify	B1 × 2	For environment, **allow** printer or any named part of printer (e.g. nozzle, print head, print bed, build plate, hot-end, cables) **Allow** energy transfer is not 100% efficient **Not** energy is lost through sound or light **Not** PLA needs time to melt **Examiner's Comments** The most common correct response related to energy dissipated to the surroundings. A smaller number of correct responses mentioned that energy was needed to raise the temperature to melting point. Some candidates incorrectly referred to energy used for other parts of the system (e.g. motors to drive the mechanism) which was not relevant to the question.
		iv	a single line (or curve) starting at **A** which gradually and continuously rises to 160°C followed by an initial flat section at 160°C after a flat section at 160°, the line (or curve) rises and then falls back to 160°C	B1 B1 B1	Note: this flat-topped shape gains the first and third marks  **Examiner's Comments**

			a second flat section at 160°C followed by a single line (or curve) which gradually and continuously falls, ending at **B**		Most responses gained 2 marks for a line from point A followed by a flat section at 160°C and then a line down to point B. A small minority of candidates also gained the 3rd mark for a 'blip' within the flat section, rising above 160°C. Responses that went from A to B without a flat section at 160°C gained no credit.
			Total	**8**	
12		i	number of large squares = 11± 1 no of squares × area of each = 11 x 1 x 10^{-25} = **1.1 × 10^{-24}** (J)	C1 A1	May be inferred from calculation Any valid method allowed (counting squares, trapezium rule, splitting area into regular shapes) **Allow** number of medium squares = 44 ± 4 **Allow** number of small squares = 1100 ± 100 **Allow** answers in the range 1.00 × 10^{-24} to 1.20 × 10^{-24} **Allow** answer to 1s.f. **<u>Examiner's Comments</u>** Candidates who counted squares underneath the curve almost always got areas with in the allowed range. Those who tried to use trapeziums or other regular shapes were usually less successful.
		ii	300 pc ≈ 300 × 3.1 × 10^{16} m (= 9.3 × 10^{18} m) ratio of areas $= \frac{4\pi(300 \times 3.1 \times 10^{16})^2}{3000} = \frac{1.09 \times 10^{39}}{3000}$ $(= 3.6 \times 10^{35})$ energy = ratio of areas × area under curve = **4.0 × 10^{11}** (J)	C1 C1 A1	Mark is for working leading to the correct distance. Distance does not need to be seen explicitly but 9.3 × 10^{18} m implies C1 Mark is for working leading to the correct ratio. Ratio does not need to be calculated but 3.6 × 10^{35} implies C1 **Allow** calculation of inverse ratio (= 2.8 × 10^{-36}) **Ignore** unit if one is given Mark is for correct answer; **allow** answer to 1s.f. Answer = 3.6 × 10^{35} × candidate's answer to 3c(i) **Allow ECF** for incorrect calculation of

					area / energy in 3c(i) Expect an answer in the range 3.6×10^{11} to 4.4×10^{11} Note: candidates could also calculate the answer by using ratio of energies = ratio of powers or intensity of pulsar = intensity at telescope **Examiner's Comments** This question stretched even the highest ability candidates. The key was in realising that the intensity of the pulsar = the intensity at the telescope. So the ratio of powers (or energies) = ratio of surface areas. Most candidates successfully converted 300 pc into metres. However, some did not realise that the surface area of a sphere is $4\pi r^2$, a formula that is in the data, formulae and relationships booklet.
			Total	**5**	
13			power ≈ $400 \times 10^6 / 10^{-3} = 4.0 \times 10^{11}$(W) power required is equivalent to output of ≈ 400 power stations **or** time taken for power station to release stored energy $= 400 \times 10^6 / 10^9 = 0.40$s 0.4s is (much) longer than 1 ms	M1 A1 (M1) (A1)	**Allow** ECF (a)(i) for incorrect POT in 400GW **Allow** this is <u>much</u> more than could be provided by one power station **or** 4.0×10^{11}(W) » 1GW **Ignore** comments about household supply **Allow** ECF (a)(i) for incorrect POT in 400GW **Allow** it would take more time / too long **Examiner's Comments** Candidates were expected to link the power output of a conventional power station (1GW) given at the start of the question to the power requirement of the fusion reactor (400 MJ in less than 1 ms). Alternative approaches which received

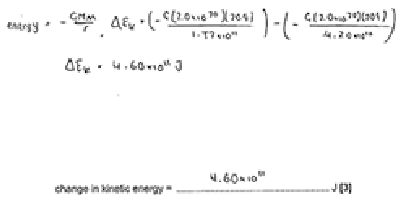
					credit were finding the energy supplied by a conventional power station in 1 ms, or calculating the time required for a conventional power station to release 400 MJ. A common incorrect approach involved attempting to calculate the time constant of a capacitor. Many candidates disregarded the instruction to use a calculation in their response and thus were unable to earn any marks despite a good understanding of the problem.
			Total	**2**	
14	a		22.3 cos 84 (= 2.33) 2.33	M1 A0	**ALLOW** 22.3 sin 6 **<u>Examiner's Comments</u>** Most candidates clearly showed how the initial velocity of the ball could be resolved into its horizontal component. Most candidates used cos 84° although there was a significant minority who correctly used sin 6°.
	b		$v_v^2 = 2.33^2 + 2 \times 9.81 \times 2.4$ $v_v = \sqrt{52.517}$ OR 7.247 7.25	M1 M1 A0	**ALLOW ECF** from (a) **<u>Examiner's Comments</u>** For this part of the question it was necessary for candidates to clearly show the substitution of the data into the equation. This includes the value of g (as 9.81 m s^{-2}) from the data sheet. It was also necessary for candidates to show that having determined v^2, this value needed to have the square root taken. Higher performing candidates wrote the final answer as 7.247 or 7.24685 ≈ 7.25 (m s^{-1}).
	c		u_h =22.3 sin 84 = 22.2 $v = \sqrt{22.2^2 + 7.25^2} = 23.35$ $\left(= \frac{1}{2} \times 0.210 \times 23.35^2\right) = 57.2$ (J) OR Change in potential energy = 0.210 ×9.81 ×2.40 = 4.94 Initial kinetic energy = $\frac{1}{2} \times 0.21 \times 22.3^2$ OR 52.2 (J)	C1 C1 A1 C1 C1 A1	**ALLOW** v^2 = 545 **ALLOW** 57.2 (J) **<u>Examiner's Comments</u>** This question proved challenging to candidates. The common error was to calculate the kinetic energy using a value of 7.25 m s^{-1}. There were two main methods of

			(4.94 + 52.2 =) 57.1 (J)		answering this question: Either: determining the horizontal component of the velocity of the ball, (which remains constant) then working out the resultant velocity of the ball as it hits the ground and then calculate the kinetic energy. Or: Calculate the change in gravitational potential energy Calculate the initial kinetic energy of the ball And then add the two values together. **Misconception** Omitting the kinetic energy in the horizontal direction when calculating the kinetic energy of the ball. Candidates should be able to compare the motion of a projectile in two perpendicular directions and also confirm that similar results are obtained by considering energy transfers.
	d		(change of) Momentum = mass ×(change of) velocity As velocity increases, the momentum increases OR force = rate of change of momentum gravitational force acts on the ball and increases momentum OR Momentum is a vector quantity, change in direction means that the momentum changes.	M1 A1 M1 A1 M1 A1	**ALLOW** changes for increases **<u>Examiner's Comments</u>** There are many possible explanations as to why the momentum of the ball changes. To score full marks candidates needed to state a property of momentum, e.g. momentum = mass × velocity before then explaining why the momentum would change, e.g. as the ball falls, velocity increases so for constant mass the momentum increases.
			Total	**8**	

15			maximum four from: EPE gain (in stretched spring) > EPE lost (in relaxed spring) EPE is dependent on x^2 Total energy increases (and so KE increases since EPE −> KE) Max KE when the system has minimum EPE / at equilibrium position/when x=0 Minimum EPE is unchanged Omega is same, amplitude has increased v_{max} when x=0 so v_{max} has increased (omega^2 = sqrt(A^2-x^2)) v_{max} increased so KE_{max} increased	4 x B1	Allow EPE max is dependent on A^2 NOT EPE dependent on x alone Allow EPE dependent on x and F which is dependent on x (EPE = ½ Fx idea) KE = ½ kx^2 is XP **Examiner's Comments** The language around energy and energy transfers is challenging and this question was pitched as a high demand question. Once more, the technical language needed to be relatively accurate for marks to be given. As soon as the glider is displaced, the total elastic potential energy (EPE) is increased. The spring that is longer than at equilibrium stores more energy than before and the spring that is shorter than at equilibrium stores less. Since the amount of EPE is given by ½ kx^2, the increase in EPE in the longer spring is larger than the decrease in EPE for the shorter spring. A few candidates attempted to prove this algebraically which was not required. Finally, the EPE at equilibrium position is not zero but a minimum. This is why the maximum KE occurs at this point. Some candidates attempted the slightly more accessible route of comparing v_{max} with the amplitude yet did not mention that the angular velocity was the same, although there was still some credit available.
			Total	**4**	
16	a	i	=110x1000÷3600 =31 ms^{-1}	B1 B1	Allow 30.55,30.6 etc Allow answer with consistent unit i.e. 0.031 km/s
		ii	time = distance × speed = 40 ÷ 31 =1.3s	B1	Allow any number of significant figures
		iii	Correct calculation of thinking distance (21 m) or thinking time (0.69 s)	B1 M1 A1	allow "stopping distance greater than 80m" without reference to 120 m but this prevents award of A1

			thinking distance less than 40m (distance between markings) OR thinking time less than 1.3 s (time taken between markings) OR braking distance less than 80 m (distance for two gaps) OR stopping distance is less than 120 m **Correct** conclusion consistent with comparison		ignore references to increased likelihood of collisions
	b	i	F=ma and a=v(-u) × t (F= 1600 × 31 ÷5.6) =8900 N (8.86kN)	C1 A1	Allow F=change in momentum÷time Allow energy approach using the data in the table Allow table distance of 75m or calculation of distance using $v^2 = u^2 + 2as$ and then $\frac{1}{2} mv^2 = Fs$ Allow ECF from (a)(ii) e.g. use of 110 gives 31,400 Allow answers that round to fall in range from 8700 to 8900 Allow 9950 or 10100 for 2 marks (use of 5.6s as stopping time) Allow 10250 for 2 marks (use of 75m braking distance) **<u>Examiner's Comments</u>** In Question 16 (b) (i), most candidates used the data available in the question to calculate an acceleration and hence a resultant force.
		ii	Using forces A component of the weight is acting backwards or there is additional backwards force or greater resultant force down the slope A smaller distance is required to do the <u>same</u> work or transfer the <u>same</u> quantity of KE	B1 B1	Allow energy approach Some of the KE turns to GPE or less KE to be transferred to heat A smaller distance required because the brakes must do less work using the <u>same</u> force Allow equivalent approach e.g. justification using increased deceleration and hence shorter distance for second mark. NB Unqualified smaller distance is insufficient **<u>Examiner's Comments</u>** In part (b) (ii), rather fewer used acceptable technical language to communicate their ideas. Useful

					phrases for explanations on this idea were ‘resultant force’ and ‘component of weight parallel to the slope’ rather than ‘extra force’ or ‘some of the vehicle’s gravity helped’.
			Total	**10**	
17		i	P = work ÷ time = 120 kN x (6.3+1.3) ÷ 90 = 10100 W	C1 A1	Omission of 1.3 m giving 8400 W scores 1 mark
		ii	Any reasonable suggestion e.g. • Motor not 100% efficient / AW • The value found is an average/the power required varies during the lift / AW • decreased time such as needing to raise the bridge in a shorter time / AW • External forces such as drag or extra weight change required work done / AW	B1	**<u>Examiner’s Comments</u>** In part (b) (ii), there were lots of very sensible answers, many of which gained credit.
			Total	**3**	
18			D	1	**<u>Examiner’s Comments</u>** This question was answered well as candidates were able to calculate the correct output power by applying the equation *P* = *Fv* and resolving the 250 N to give its horizontal component.
			Total	**1**	
19		i	$\left(\frac{168}{365}\right)^2 = \left(\frac{r}{1.50 \times 10^{11}}\right)^3$ distance = 8.9×10^{10} (m)	C1 A1	**Ignore** calculation of arithmetic mean of data in question **Allow** substitution into $T^2 = \frac{4\pi^2}{GM}r^3$ **Ignore** units for subs into Kepler’s law **NOT** 8.95 or 9(.0) × 10^{10} (m) (mean calculated) **<u>Examiner’s Comments</u>** Fortunately, most candidates saw the reference to Kepler’s third law in bold

					and used it successfully. Only a small fraction found the mean orbital distance by finding the mean of the maximum and minimum distance. While this is mathematically sound, it does not use Kepler's third law and so was not deemed an acceptable answer to the question.
		ii	(ΔGPE = ΔKE) $GMm\left(\frac{1}{4.20\times10^{10}}\right)$ or $GMm\left(\frac{1}{1.37\times10^{11}}\right)$ (change in KE =) $6.67\times10^{-11}\times2.0\times10^{30}\times m\left(\frac{1}{4.20\times10^{10}}-\frac{1}{1.37\times10^{11}}\right)$ change in kinetic energy = 4.6×10^{11} (J)	C1 C1 A1	**Allow** this mark without the *m* **Allow** this mark without the *m* **Allow** 2 marks for 2.2×10^{9}; ΔV calculated **Ignore** sign **<u>Examiner's Comments</u>** Previous examiner's reports have stated the importance of understanding how gravitational potential energy differences are calculated using the appropriate formula. More candidates got this idea right in this series, which was excellent.  This candidate has understood that the gravitational potential energy at both extremes of the orbit should be calculated and then the difference calculated.
		iii	Description of reasonable effect of Earth has been ignored / work done by fuel (during lift off) / idea that atmosphere has been ignored previously	B1	**<u>Examiner's Comments</u>** This question provides one of the 'stretch and challenge' marks in this paper. The idea is that the satellite needs first to climb out of the Earth's gravitational well before it can be a satellite of the Sun.
			Total	**6**	

20		i	Extension (from graph) is 6.0 (cm) Use of $E = \frac{1}{2} kx^2$ elastic potential energy = 0.90 (J)	M1 M1 A1	**Allow** Use of E = ½ Fx and F = kx **Allow** 1 SF of 0.9 (J)
		ii	($KE = \frac{1}{2} mv^2$) $0.90 = \frac{1}{2} \times 0.030 \times v^2$ v =7.7 (ms^{-1})	M1 A1	**Allow** 1 J instead of 0.90 J **Note** using 1 J gives an answer of 8.2 ms^{-1} **Note** allow possible ECF with energy approx 1 J
		iii	$1.5 = \frac{1}{2} gt^2$ t = 0.55 (s) (R = 7.7 × 0.55) R = 4.2 (m)	C1 C1 A1	**Allow** 8 ms^{-1} or 8.2 ms^{-1} instead of 7.7 ms^{-1} **i.e**. 4.4, 4.5 (m) **Possible** ECF from **(b)(ii)**
		iv	(Actual distance is smaller than calculated R) Valid explanation The velocity /speed (in flight) smaller than expected **or** The initial velocity / speed will be smaller than expected	M1 A1	Examples of valid explanation include: For velocity / speed decreases • drag/air resistance For initial velocity /speed is smaller • not all the energy transfers to the ball • the cord also has KE • hysteresis (so cord heats up) **Ignore** references to efficiency and unqualified energy dissipation. **<u>Examiner's Comments</u>** Questions 16 (a), (b) (i) and (ii) were answered very well indeed. Most candidates recalled the experimental procedure for investigating force-extension relationships well. Question16 (b) (iii) required knowledge of independent motion. Successful candidates used the vertical motion of the object to find the time taken for it to hit the ground. After that, they used that time to find the horizontal range. Question 16 (b) (iv) was answered well by candidates that realised the

					distance in real life would be less and could explain why that was the case.
			Total	**10**	
21	a		Working that leads to $t = \frac{15 \times 10^6}{280 \times 10^3} = 54$ (s)	B1	**Allow** KE = t × P approach **Examiner's Comments** This was completed well. The mark was lost by those, generally, that did not round their answer correctly.
	b		Horizontal arrow to the left same size as F At least one horizontal magnitude given as 6700 (N) At least one vertical magnitude given as 170 000 (N)	B1 B1 B1	by eye **Allow** $280 \times 10^3 \div 42$ or 6670 (N) **Allow** 17000 × 9.81 or 167000 (N) **Examiner's Comments** This question was answered well, in part. Candidates found the weight of the engine with ease, broadly. The force *F*, being the value of the power divided by the velocity was less well calculated. Most candidates realised that this object was in equilibrium and so that there should be a force to the left of equal magnitude to force *F*. This is an example of a frictional force causing an acceleration. The friction force on the rails is to the left. By Newton's 3rd Law, the friction force on the engine from the rails must therefore be to the right. The force to the left is a drag force, causing equilibrium.
	c		(thinking distance =) 0.40 × 42 or 17 m Acceleration = 7 (ms^{-2}) or ½ m v^2 = F d (braking distance =) 125 m Total stopping distance is 142 m (which is less than 167m)	B1 C1 A1 B1	**Allow** ECF in subsequent marks if thinking distance incorrect or omitted **Alternative approach using braking distance** (work done =) 120×10^3 × (167 – thinking distance) (work done =) 18×10^6 (J)

					Work done calculated **and** this is less than the initial KE **Allow** braking distance calculated and 125 m is less than the available braking distance of (167 – thinking distance) **<u>Examiner's Comments</u>** Candidates employed a range of strategies to demonstrate that the engine will stop before the obstruction. Very successful candidates often calculated the deceleration of the engine and then employed an equation of motion to work out first the braking distance and then added the thinking distance. Those candidates also added words to signpost their calculations clearly.
			Total	**8**	
22	a		The gravitational potential energy store of the person has been omitted/(elastic) potential store of the spring has been transferred to gravitational potential energy store (of the person)	B1	**Ignore** references to energy losses **<u>Examiner's Comments</u>** Only about 10% of candidates accessed this question correctly to be given 1 mark for responses describing energy transfers to the gravitational potential energy store of the spring. Most responses described energy transfers as energy losses to increase the thermal store of the surroundings.
	b		KE/kinetic to gravitational PE/potential	B1	**Allow** KE transferred to GPE **Ignore** increase of thermal store of the surroundings **Not** elastic potential energy **<u>Examiner's Comments</u>** Only half of candidates answered this question correctly by recognising that when the spring was at position B the spring had returned to its original length and hence had no store of elastic potential energy. Often, candidates described the energy changes at A, B and C but were not

					explicit in identifying the position of the spring, so it was assumed that responses described positions B and C and hence no marks were given. Candidates must be specific in their responses so there is no ambiguity in their understanding of the question.
			Total	**2**	
23			D	1	**Examiner's Comments** Only half of candidates answered this question correctly, D, with the most common distractor being answer B. This response demonstrated that they had calculated the correct work done in lifting the motor and then calculated the useful power rather than the power supplied to the motor.
			Total	**1**	
24			C	1	**Examiner's Comments** Candidates did not perform as well on this question with just a small majority of candidates calculating the correct answer C. If candidates did show working out it was evident that they understood that power = energy / time but they did not calculate the difference in kinetic energy to calculate the power dissipated in the time given.
			Total	**1**	
25	a	i	E_p(= 0.16 × 9.81 × 2.5)= 3.9 (J)	A1	3.924 **Examiner's Comments** This question was generally answered well.
		ii	$v^2 = \frac{2 \times 3.9}{0.16}$ or 48.75 OR v^2 = 2 × 9.81 × 2.5 or 49.05 v = 7.0 (ms^{-1})	C1 A1	**Allow ECF** from (a)(i) **Allow** 1sf **Examiner's Comments** Most candidates correctly equated the change in gravitational potential energy to kinetic energy and gained the correct answer. Other candidates correctly used $v^2 = 2gh$.

					A number of candidates gave the answer as 7 (ms^{-1}) – since the data in the question was given to two significant figures the answers should also be given to two significant figures. Ideally the substitution of data into appropriate equations should be shown.
	b	i	R(=12 × 0.71) = 8.5(2) (m)	A1	**Examiner's Comments** It was expected that candidates would multiply the horizontal velocity by the time. This was generally answered well. **Assessment for learning** When considering projectile motion, candidates should treat the vertical and horizontal velocities independently.
		ii	$E_k = \frac{1}{2} \times 0.16 \times 12^2$ or 11.5 OR $= \frac{1}{2} \times 0.16 \times 13.9^2$ or $\frac{1}{2} \times 0.16 \times 193$ E_k (= 11.5 + (a)(i) = 11.5 + 3.9) = 15(.4) (J)	C1 A1	**Allow** use of vertical v = 6.97 (calculated using $v = u+at$;) **Allow** 15.5 (J) **Allow ECF** from (a)(i) **Examiner's Comments** Many candidates calculated the kinetic energy of the ball using the velocity of the ball in the horizontal direction but then did not add the change in potential energy of the ball as it fell. Other candidates determined the resultant velocity of the ball and then calculated the kinetic energy.
		iii	$\theta \left(= \tan^{-1}\left(\frac{(a)(ii)}{12}\right) = \tan^{-1}\left(\frac{7}{12}\right)\right) = 30°$	A1	**Allow** ECF from (a)(ii) 30.256 **Examiner's Comments** Candidates achieving on this question correctly determined the angle using the horizontal and vertical velocities. Where the response was incorrect,

					candidates had used either energies or distances.
			Total	**7**	