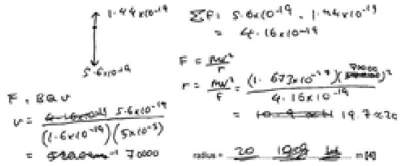
Mark scheme

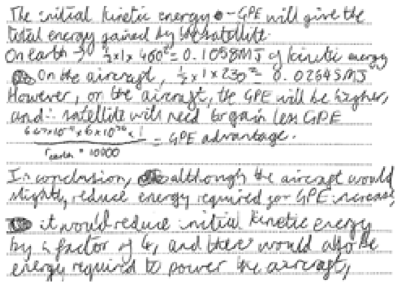
Question			Answer/Indicative content	Marks	Guidance
1	a		F (= EQ) = 0.90 × 1.60 × 10^{-19} = 1.4(4) × 10^{-19} (N)	B1	Working and answer must both be shown Answer must be given to 2sf or more Unit need not be given but, if given, must be correct **Examiner's Comments** This was an easy introduction to 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 **Examiner's Comments** 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

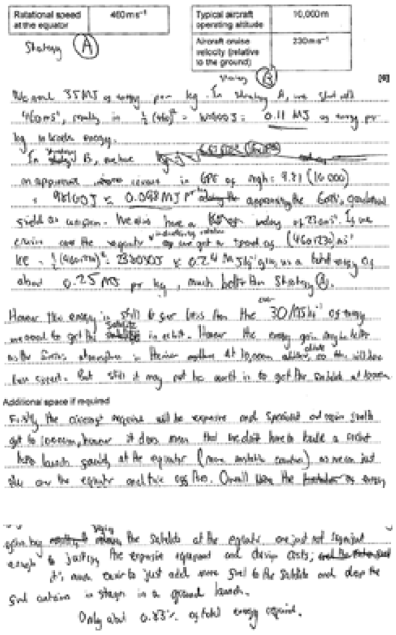
		ii	$v = (\frac{F_{mag}}{BQ} =) \frac{5.6 \times 10^{-19}}{5.0 \times 10^{-5} \times 1.60 \times 10^{-19}}$ resultant force F_R= (5.6 − 1.4) × 10^{-19} $r = \left(\frac{mv^2}{F_R} =\right) \frac{1.673 \times 10^{-27} \times (7.0 \times 10^4)^2}{4.2 \times 10^{-19}}$ *r* = 20 (m) Alternative all-in-one method: $r = \frac{m{F_{mag}}^2}{F_R B^2 Q^2}$ 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 × 10^4 (m s^{-1}) implies first C1 **Allow** 10^{-19} for 1.4×10^{-19} (giving F_R= 4.6 × 10^{-19}) F_R = 4.2 × 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 × 10^{-27} kg given to 3 s.f. **Not** m_p = 1.661 × 10^{-27} kg or m_p = 1.675 × 10^{-27} kg **Allow ECF** for incorrect *v* Use of F_R = 5.6 × 10^{-19} or = 1.4 × 10^{-19} is **XP** **Allow** *r* = 19 (m) **F_R = 4.2 × 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) **Examiner's Comments** 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	$\lvert\text{resultant force}\rvert = (\sqrt{3.9^2 + 1.4^2}) \times 10^{-19}$ |resultant force| = 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 → ½×1×460² = 0.1058MJ of kinetic energy On the aircraft, ½×1×230² = 0.02645MJ However, on the aircraft, the GPE will be higher, and ∴ satellite will need to gain less GPE 6.67×10⁻¹¹×6×10²⁴×1 / 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			**C**	1	The condition for circular motion is that the centripetal force is equal to the resultant force. In this case, the resultant force is the weight - normal contact force so W - R = m v^2 / r. The person leaves the seat when R ≤ 0. When rearranged with W = mg gives the correct answer C.
			Total	**1**	
4			**B or D**	1	**<u>Examiner's Comments</u>** Many candidates used their knowledge

					of circular motion to select either option B or option D, both of which were acceptable, being mathematically equivalent.
			Total	**1**	
5	a	i	Arrow **along** the line of the support rod labelled tension or T.	B1	Allow unlabelled single arrow along either rod Allow unlabelled arrows along both rods Allow arrow(s) up, down or both NOT any contradictory arrows **<u>Examiner's Comments</u>** In Question 17 (a) (i) of this question, the phrase 'tension in the rod' can mean several different things, all of which were given in the mark scheme.
		ii	11.1 sin 35 or 11.1 cos 55 seen addition of 3.9 (half the diameter of the support disc) to candidate's horizontal component of rod length Total= 10.3m	M1 M1 A0	NOT use of tan 35 or tan 55 allow 7.8/2 for 3.9 10.27 to 2 dp NB use of 11.1 cos 35 or 11.1 sin 55 arriving at 12.99 scores 1 (wrong trig) NB reject use of radians (scores 0) **<u>Examiner's Comments</u>** Many candidates approached part (ii) with some confidence, spotting that the horizontal portion of the rod was 11.1 sin(35) and that it should be added to the radius of the disc.
		iii	mg=T cos 35 T= mg ÷ cos 35 = 140 N	C1 C1 A1	Allow use of sin 55 NOT use of tan 35 or tan 55 Answer is 143.7 N to 4 sf **<u>Examiner's Comments</u>** Parts (a) (iii) and (iv) were more challenging, requiring good knowledge of both circular motion and how to calculate components of forces. Again there were several legitimate routes to the right answer, all of which were

					mentioned in the mark scheme. Very logical approaches were in part (a) (iii), to equate the vertical component of the tension with the weight of the sandbag.
		iv	T sin 35 = mrω^2 $\omega=\sqrt{\frac{T\sin 35}{mr}}$ =0.8(17) radian s^{-1}	M1 A1 A0	Allow use of W tan 35 or W tan 55 Allow use of cos 55 and/or mv^2/r Allow use of Pythogoras to find centripetal force (82.4...) NOT use of T tan 35 or T tan 55 Allow ω^2 subject. Allow any combination of rearrangement and substitution ECF allowed for T and r. Use of 2 s.f. values for T and r gives 0.84 m **Examiner's Comments** In part (a) (iv), the quickest approach was to equate the horizontal component of the tension with the centripetal force. The data booklet provides a convenient expression for the centripetal force in terms of the angular velocity, without the need for finding the tangential velocity.
	b	i	Use of 17=1/2 gt^2 =1.9 (1.86) s	C1 A1	i.e. substitution of 17 and g or 9.81 or 9.8 e.g. s=(ut)+ ½ at^2 $t=\sqrt{\frac{2s}{a}}$ $=\sqrt{\frac{2 x 17}{9.81}}$ Allow any subject
		ii	Horizontal speed = rω or Horizontal distance = speed × time = 0.82 radians s^{-1} × 10.26 m × 1.86 s = 16 m (15.6 m)	C1 C1 A1	Use of data in the question stem (0.8 and 10) allowed, which gives 15.2 m. Ecf for use of candidate's value of r and ω, giving values rounding to between 14.9 and 16.0 m

		iii	Relevant variable identified Effect on speed of shoe or time of flight of shoe correctly identified Conclusion consistent with relevant physics e.g. • Shoe is lower mass yet no change in angular velocity or radius since independent of mass so no change in horizontal displacement. • Shoe is below seat so would be travelling with larger radius/speed so larger distance travelled horizontally • Shoe might have be kicked off backwards so have lower speed so lower distance • Shoe would come from below the seat/lower than the sandbag i.e. vertical distance to fall less, thus time of flight and horizontal distance less. • Effect of air resistance hadn't been included so shoe suffers drag, decelerating horizontally so distance would be smaller	M1 M1 A1	e.g mass/weight, drag/air resistance, radius, height, starting condition (e.g. kicking shoe off) Assume "it" in response refers to the shoe. ignore velocity for first M1 allow correct explanation of "no effect" on speed or time by change of mass **Examiner's Comments** Question 17 (b) explored ideas about parabolic flight due to gravitation. The only force acting on the sandbag and the shoe after they have been released is the weight force, which acts vertically downwards. Many candidates realised that the vertical velocity of the sandbag when it left the swing was zero, enabling them to calculate the time for the bag to fall 17m vertically downwards (using $s = \frac{1}{2}gt^2$) To calculate the horizontal distance travelled required both the horizontal velocity (from $v = r\omega$) and the time of flight from part (b) (iii). There was lots of scope for applying error carried forward rules as mentioned in the mark scheme. ? **Misconception** In lots of questions, candidates make assumptions when trying to use formulae to justify their ideas. In this case, it was that for the same radius, the shoe must leave the seat faster than the sandbag, purely because the shoe had less mass. Often, what is constant is as important to consider as what is changing. Here, if the radius for the sandbag and the shoe are the same, then the horizontal velocity at release must be the same, since the radius and angular speed for both are the same, using $v = r\omega$.
			Total	**16**	
6			D	1	**Examiner's Comments**

					The question is asking for the candidate to calculate the speed of an object in a circular orbit with radius 42 400 km, i.e. 42.4×10^6 m. To do this, the candidate equates the gravitational force, *F*G = GMm/r^2. with the centripetal force required for that orbit, *F*C = mv^2/r, where *M* is the mass of the Earth and *m* is the mass of the satellite. Rearranging gives $v = \sqrt{GM/r}$. Substituting the correct values for *G, M* and *r* will give answer D.
			Total	**1**	
7		i	$a = \omega^2 r$ **and** $\omega = 2\pi / T$ **or** $a = v^2/r$ **and** $v = 2\pi r / T$ **Either** $\omega = \frac{2\pi}{5830 \times 3600}$ **or** $v = \frac{2\pi \times 6050 \times 10^3}{5830 \times 3600}$ **or** $a = \frac{4\pi^2}{(5830 \times 3600)^2} \times 6050 \times 10^3$ $a = 5.42 \times 10^{-7}$ (ms^{-2})	C1 C1 A1	**Allow** use of $T^2 = 4\pi^2 r^3/(GM)$ **and** $v = 2\pi r/T$ $\omega = 2.99 \times 10^{-7}$ (rad s^{-1}) $v = 1.81$ (ms^{-1}) $a = \omega^2 r = (2.99 \times 10^{-7})^2 \times 6050 \times 10^3$ $a = v^2/r = 1.81^2 / (6050 \times 10^3)$ **Do not allow** incorrect or omitted conversion of *T* **Allow** answer given to 2sf **Allow** any answer which rounds to 5.4×10^{-7} Do **not** penalise incorrect km conversion (giving $a = 5.42 \times 10^{-10}$) if already penalised in **(a)** **<u>Examiner's Comments</u>** A slightly harder question, requiring the use of two formulas (either $a = \omega^2 r$ and $\omega = 2\pi / T$, or $a = v^2/r$ and $v = 2\pi r / T$). Some marks were available for calculating either ω or *v* correctly. **Common problems in 1(b)(i)** • omitting to convert *T* from hours to seconds, or converting *T* incorrectly

					• omitting to convert r from km to m and so incurring a POT error
•		ii	(Mass of fluid displaced = $\rho \times V$ =) 65 × 1.7 (Weight of fluid displaced = $\rho \times V \times g$ =) 65 × 1.7 × 8.87 U (= weight of fluid displaced) = 980 (N)	C1 C1 A1	Possible **ECF** from **(a)** but **do not allow** g = 9.81 N kg^{-1} **Examiner's Comments** Unfortunately, many candidates did not know how to calculate upthrust, often confusing it with the normal contact force. This may be because upthrust forms a small part of the syllabus and is therefore easily overlooked. Upthrust = weight of fluid (atmosphere) displaced by the probe. The volume of the atmosphere displaced by the probe is identical to the volume of the probe itself. **Common problems in 1(b)(ii)** • using the value g = 9.81 rather than the value of g on Venus calculated in (a) • using the mass of the *probe* instead of calculating the mass of the *atmosphere* using the formula mass = density of atmosphere × volume of probe
•		iii	Any 2 from: • Forces are balanced at **A** /there is no centripetal force at **A** / forces are unbalanced at **B** / there is a resultant **or** centripetal force at **B** • correct balanced forces equation at **A** • correct expression of Newton's second law at **B** • calculation of centripetal force at **B** • calculation of normal contact force at **A** • calculation of normal contact force at **B** <u>therefore</u> reaction force (must be) greater on **A**	B1 × 2 B1	**Allow** the pole for **A** and the equator for **B** throughout **Allow** weight provides the centripetal force but **do not allow** normal contact force/upthrust provides the centripetal force **Allow** acceleration in place of force **Ignore** any statement that suggests that centripetal force is a separate or additional force e.g. $R_A = W - U$ e.g. ($mr\omega^2$ **or** ma **or**) $F = W - U - R_B$ Centripetal force (= ma = 760 × 5.4 × 10^{-7}) = 4.1 × 10^{-4} (N) Possible **ECF** from **(b)(i)** R_A (= $W - U$ = (680 × 8.87) − 980) =

					5760 (N) Possible **ECF** from **(a)** and **(b)(ii)** R_B (= $W - U - ma$ = 5760 − 4.1 × 10^{-4}) Possible **ECF** from **(a), (b)(i)** and **(b)(ii)** Conclusion must follow some valid and relevant reasoning in which upthrust is mentioned **Allow** reverse argument **Allow** CF is negligible therefore reaction force is same at **A** and **B** **Examiner's Comments** Candidates often struggle to demonstrate a clear understanding of circular motion, and this year was no exception. Most candidates understood that probe **B** on the equator was acted on by centripetal force whereas probe **A** at the pole was not. However, some thought that the centripetal force acted outwards, away from the surface. Many thought that the centripetal force was a separate force acting on probe **B** in addition to its weight. These candidates wrongly concluded that this would increase the force towards the centre, resulting in an increased normal contact force. Whereas the opposite is actually the case; part of the probe's weight must be used to provide the centripetal force, and so the normal contact force would be smaller. A very common mistake was to ignore the effect of upthrust acting on the probe. Although the upthrust would be the same both at the equator and at the pole, it was worth a mention. Upthrust = 980N (from b(ii)) whereas the centripetal force was only 760 × 5.42 × 10^{-7}N (from b(i)). **Assessment for learning** The author of the examination paper

					structures questions to support candidates in writing their responses. 1(b)(i) is a calculation of the centripetal acceleration and 1(b)(ii) is a calculation of the upthrust. These provide a logical progression to 1(b)(iii) which involves both centripetal acceleration and upthrust (and not, say, the shape of Venus or its magnetic field).
			Total	**9**	
8			$G\frac{Mm}{r^2} = \frac{mv^2}{r}$ **or** $G\frac{Mm}{r^2} = mr\omega^2$ $v = \frac{2\pi r}{T}$ **or** $\omega = \frac{2\pi}{T}$ Substitution **and** manipulation to give $T^2 = \frac{4\pi^2}{GM}r^3$ (with $\frac{4\pi^2}{GM}$ is constant)	M1 M1 A1	**Allow** any subject **<u>Examiner's Comments</u>** The demonstration of Kepler's 3rd Law was well-remembered by the vast majority of candidates.
			Total	**3**	