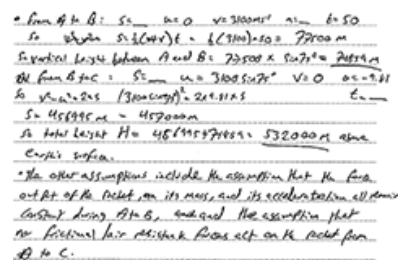


Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1			Level 3 (5–6 marks) Expect a correct calculation of H with correct assumptions and a clear evaluation supported with a calculation <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Expect Either a correct calculation of H but no evaluation or Some calculation and some evaluation or Incorrect calculations but a clear evaluation <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Expect Either Limited calculation (e.g. $3100 \sin 75^\circ$ seen, AB or BC calculated but not H, use of suvat but with wrong v) or Limited assumptions stated (note that 'g is always 9.81' is in stem) or Limited evaluation (e.g. g would be smaller at C than A) <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 mark	B1 x 6	Use level of response annotations in RM Assessor Indicative scientific points may include: Calculation vertical component of velocity at B = $3100 \sin 75^\circ (= 2994 \text{ ms}^{-1})$ <u>AB</u> - Assume (force and mass constant so) constant acceleration - Use of suvat, $u = 0$, $v = 2994$, $t = 50$ $s = 74.9 \text{ km}$ <u>BC</u> - Assume no air resistance - Use of suvat, $u = 2994$, $v = 0$, $a = -9.81$ $s = 457 \text{ km}$ Total $H = 457 + 74.9 \approx 530 \text{ km}$ Evaluation $g \propto \frac{1}{r^2}$ $\frac{g_C}{g_A} = \frac{r_A^2}{r_C^2} = \frac{6400^2}{(5400+530)^2} = 0.85$ 15% drop in g from A to C (or 17% increase from C to A) but use ECF for H - therefore constant g is a poor assumption $g_C \approx 8.3$ or 8.4 if $g_A = 9.81$ but use ECF for H - If g is smaller, then H would increase <u>Examiner's Comments</u> Level 3 candidates set out a correct calculation of H, together with the assumptions required at each stage,

			No response or no response worthy of credit.	plus an evaluation of the assumption that g remains constant at 9.81 ms^{-2} throughout. Level 2 candidates missed out one or more of these three parts, usually the evaluation at the end, which they found quite difficult. Level 1 candidates were often unable to calculate H, or the value of g at height H, correctly Common problems in 3 (b) • omission of $\sin 75^\circ$ (or using $\cos 75^\circ$) when calculating velocity • not converting from m to km correctly • not squaring the r term in the calculation for g Exemplar 1  Exemplar 1 demonstrates good practice in answering a LoR question. The candidate has made sure they have answered each part of the question by using bullet points. Their calculations are clearly set out and so easy to follow, and their handwriting is legible. Instead of just calculating a value for g at height H, they have also given an explicit evaluation: 'The assumption that g remains constant is not reasonable'. Other candidates went on to say that this means that the rocket would reach an even greater height.  OCR support
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					OCR has a Guide to Level of Response Questions . This includes guidance on communication and the use of bullet points (page 5).
			Total	6	
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. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Correct calculations and an advantages discussed or Correct calculations and a limitation discussed. <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Attempted calculations or a single correct calculation or incomplete explanations of advantages and/or limitations. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 mark <i>No response or no response worthy of credit.</i>	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.
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				- 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 <i>The initial kinetic energy + GPE will give the total energy gained by the satellite. On Earth $\frac{1}{2} \times 4000 = 0.1008 \text{ MJ}$ of kinetic energy. On the aircraft, $\frac{1}{2} \times 1 \times 230^2 = 0.02645 \text{ MJ}$. However, on the aircraft, the GPE will be higher, and $\therefore$ satellite will need to gain less GPE. $6.67 \times 10^{-11} \times 6 \times 10^3 \times 1 = \text{GPE advantage}$. Earth = 10000</i> <i>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.</i> 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
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					of rotation of the Earth and the time of an orbit of the Earth around the Sun.
		ii	Use of $T=3600 \times 24$ (or 86,400 from data book) Substitution into $T^2 = \frac{4\pi^2}{GM} r^3$ i.e. $(86400)^2 = (4\pi^2 / (G \times 6.0 \times 10^{24})) r^3$ $r = 4.2 \times 10^7$ (m)	C1 C1 A1	<u>Examiner's Comments</u> Most candidates correctly used the equation representing Kepler's Third Law to find the orbital radius. Common errors included mis-converting or mis-remembering the time for one complete orbit.
			Total	14	
3			C	1	<u>Examiner's Comments</u> By considering the GPE at the planet's surface of $-GMm / r$ and the KE of $\frac{1}{2} m v^2$, the condition for 'escape' is that the total energy is zero at infinity. This gives the condition $GMm / r = \frac{1}{2} m v^2$. The gravitational field strength at the surface of the planet is GMm / r^2 i.e. g, giving $g r = \frac{1}{2} m v^2$. When rearranged this gives answer C.
			Total	1	
4	a	i	X marked on orbit at closest point to Mars	B1	Horizontal line through centre of X must pass through or touch the label 'Mars' Allow a single dot/circle marked on the orbit <u>Examiner's Comments</u> Most candidates put their cross in the correct place. The most common wrong response was to place a cross placed at the furthest point from Mars.
		ii	orbits in an <u>ellipse</u> / orbit is <u>elliptical</u> with (COG of) Mars at one focus	B1 B1	Allow a general statement even if not applied to MAVEN eg (all) orbits are elliptical Ignore references to Sun or other planets Not the Sun at one focus <u>Examiner's Comments</u> The main difficulty here was remembering which was Kepler's 1st Law. Many candidates described how a line between Mars and MAVEN

					would sweep out equal areas in equal times. Sometimes valuable time was spent describing planetary orbits before restating the salient points for MAVEN.																													
	b	i	$T^2 \propto r^3$ Correct calculations involving at least two sets of data which lead to a (reasonably) constant value	C1 A1	Not $T^2 = r^3$ Allow $T^2 / r^3 = (\text{any}) \text{ constant}$ or $T^2 = (\text{any}) \text{ constant} \times r^3$ Allow $T_1^2 / T_2^2 = r_1^3 / r_2^3$ May be inferred from a subsequent calculation For example, T^2/r^3 (or r^3/T^2) calculated correctly at least twice: Allow a constant value calculated for one set of data and then applied to at least one other object Calculations do not need corresponding names of objects Ignore number of sf; ignore any incorrect calculations Ignore statements about whether or not Kepler's 3rd Law applies Values below are for benefit of markers, POTs removed <table><tr><th rowspan="2">Object</th><th colspan="2">T^2 / r^3</th><th colspan="2">r^3 / T^2</th></tr><tr><th>$T(\text{hr})$</th><th>$T(\text{s})$</th><th>$T(\text{hr})$</th><th>$T(\text{s})$</th></tr><tr><td>MAVEN</td><td>7.4</td><td>9.6</td><td>1.4</td><td>10.5</td></tr><tr><td>Phobos</td><td>7.1</td><td>9.3</td><td>1.4</td><td>10.8</td></tr><tr><td>Deimos</td><td>7.4</td><td>9.6</td><td>1.4</td><td>10.4</td></tr><tr><td>Areostationary</td><td>7.8</td><td>10.1</td><td>1.3</td><td>9.9</td></tr></table> <u>Examiner's Comments</u> The majority of candidates remembered Kepler's 3rd Law correctly. There were a number of different approaches which could gain credit here. The main one used was to find the ratio of T^2/r^3 for corresponding pairs of values, showing that this ratio was approximately constant. Another common approach was calculating the constant k in $T^2 = kr^3$ using the data for	Object	T^2 / r^3		r^3 / T^2		$T(\text{hr})$	$T(\text{s})$	$T(\text{hr})$	$T(\text{s})$	MAVEN	7.4	9.6	1.4	10.5	Phobos	7.1	9.3	1.4	10.8	Deimos	7.4	9.6	1.4	10.4	Areostationary	7.8	10.1	1.3	9.9
Object	T^2 / r^3		r^3 / T^2																															
	$T(\text{hr})$	$T(\text{s})$	$T(\text{hr})$	$T(\text{s})$																														
MAVEN	7.4	9.6	1.4	10.5																														
Phobos	7.1	9.3	1.4	10.8																														
Deimos	7.4	9.6	1.4	10.4																														
Areostationary	7.8	10.1	1.3	9.9																														

				MAVEN and then applying it to the distance of Phobos, for example, to show that it gave the correct value for the time period. The best responses were those where candidates thought carefully about how they were going to set out their calculations, naming the orbits under consideration or tabulating their values, whereas other responses were characterised by a sprawl of figures leaving the examiner to hunt for appropriate values.
		ii	(MAVEN needs) to see the whole planet / atmosphere or not just part of the planet / atmosphere (MAVEN needs) to be in / near to the atmosphere	Ignore comments about potential collisions / mass / orbital period / speed / direction Allow (if placed in an areostationary orbit, then) MAVEN would always orbit above the same place / it could only see one location / it could not see multiple locations / it could not see (atmosphere at) the poles / it could only see part of the (atmosphere of) Mars Allow (if placed in an areostationary orbit, MAVEN's orbital radius would be large that) it would not pass through the atmosphere / it could not analyse the atmosphere Not MAVEN is too close to see the atmosphere properly Note: Atmosphere does not need to be seen to award first B1 Atmosphere must be mentioned somewhere in the response to award second B1 <u>Examiner's Comments</u> The strongest responses were given in terms of the function of MAVEN, which was to study the upper atmosphere of Mars. An areostationary orbit would be too far from Mars for this purpose, plus it would only allow MAVEN to sample one small part of its atmosphere. A common approach was to make

					partial statements such as 'MAVEN would be too far away...' and such responses were often too vague to be creditworthy. A few candidates misread the question and were obviously attempting to answer the question. 'How do we know that MAVEN is not in an areostationary orbit?'.
			Total	7	
5		i	Use of $KE_{\text{mean}} = \frac{3}{2} kT = \frac{3}{2} \times k \times 4.0 \times 10^6$ $= \frac{3}{2} \times 1.38 \times 10^{-23} \times 4 \times 10^6$ $= 8.3 \times 10^{-17} \text{ J.}$	C1 A1	Allow k Unrounded answer is $8.28... \times 10^{-17}$ <u>Examiner's Comments</u> Candidates answered Question 23 (b) (i) well, provided that they used the correct temperature i.e. that of the stellar atmosphere and not the surface temperature.
		ii	$= -2.3 \times 10^{-16} + 8.3 \times 10^{-17}$ $= -1.5 \times 10^{-16} \text{ J.}$	B1	Allow use of 10^{-16} J from stem to give $-1.3 \times 10^{-16} \text{ J}$ Reject response without negative sign <u>Examiner's Comments</u> The helium nucleus in parts (b) (ii) and (b) (iii) has a KE of 10^{-16} J and a GPE of $-2.3 \times 10^{-16} \text{ J}$. This helium nucleus cannot therefore escape and so the GPE at the further possible point of the helium nucleus must be negative. The GPE at this furthest possible point is where the KE is zero and there has been a gain of 10^{-16} J of GPE, giving the GPE $= -1.3 \times 10^{-16} \text{ J}$, using the values in the question. Of course, we used the exact value calculated in part (b) (i) instead of 10^{-16} J, giving $U = -1.5 \times 10^{-16} \text{ J}$ as the 'correct' answer.
		iii	selection of GMm/r Substitution of values for M, m and energy and rearrangement $3.2 \times 10^{10} \text{ m}$ e.g.	C1 C1 A1	Allow ECF from (b)(ii) NB Use of values in stem gives 3.7×10^{10} <u>Examiner's Comments</u>

			$(-) \frac{GMm}{r} = (-) 1.5 \times 10^{-16}$ $r = \frac{6.67 \times 10^{-11} \times 1.1 \times 10^{31} \times 6.6 \times 10^{-27}}{1.5 \times 10^{-16}}$ $= 3.2 \times 10^{10} \text{m}$		The helium nucleus in parts (b) (ii) and (b) (iii) has a KE of 10^{-16} J and a GPE of -2.3×10^{-16} J. This helium nucleus cannot therefore escape and so the GPE at the further possible point of the helium nucleus must be negative. The GPE at this furthest possible point is where the KE is zero and there has been a gain of 10^{-16} J of GPE, giving the GPE = -1.3×10^{-16} J, using the values in the question. Of course, we used the exact value calculated in part (b) (i) instead of 10^{-16} J, giving $U = -1.5 \times 10^{-16}$ J as the 'correct' answer.
		iv	Reference to Boltzmann distribution / AW OR Some particles will have greater kinetic energies / lower masses	B1	<u>Examiner's Comments</u> Question 23 (b) (iv) has several acceptable responses yet the predominant correct candidate answers were that the solar wind particles might be lighter (i.e. hydrogen) or that the Maxwell-Boltzmann distribution of KE values in a gas of particles would mean that some particles would have greater than average KE.  Assessment for learning Usually in physics calculations, we use the calculator value all the way through the calculation. Any rounding should take place at the very end of the calculation.
		Total		7	
6		B		1	
		Total		1	
7		D		1	<u>Examiner's Comments</u> 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, $FG = GMm/r^2$, with the centripetal force required for that orbit, $FC = mv^2/r$, 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	
8			$g = GM/r^2$ $g = \frac{6.67 \times 10^{-11} \times 4.87 \times 10^{24}}{(6\,050 \times 10^3)^2}$ $g = 8.87 \text{ (N kg}^{-1}\text{)}$	C1 C1 A1	Allow m for M Allow d or D or x or X or R for r Full substitution needed Allow $r = 6\,050$ for this C1 mark Allow a negative answer Answer must be to exactly 3sf for the A1 mark. Do not use the SF penalty for the paper here <u>Examiner's Comments</u> This was a gentle start to the paper, with the formula $g = GM/r^2$ being provided in the data, formulae and relationships booklet. Common problems in 1(a) • omitting to convert r from km to m and so incurring a power of ten (POT) error • using a value of G from a calculator or from memory rather than copying the 3 significant figure (3sf) value given in the formula sheet • writing the answer to more (or less) than the 3sf specified in the question
			Total	3	
9	a		$G \frac{Mm}{r^2} = \frac{mv^2}{r} \quad \text{or} \quad G \frac{Mm}{r^2} = mr\omega^2$ $v = \frac{2\pi r}{T} \quad \text{or} \quad \omega = \frac{2\pi}{T}$ Substitution and manipulation to give $T^2 = \frac{4\pi^2}{GM} r^3 \text{ (with } \frac{4\pi^2}{GM} \text{ is constant)}$	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.

	b	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 $9(.0) \times 10^{10}$ (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	($\Delta GPE = \Delta KE$) $GMm \left(\frac{1}{4.20 \times 10^{10}}\right) \text{ or } GMm \left(\frac{1}{1.37 \times 10^{11}}\right)$ (change in KE =) $6.67 \times 10^{-11} \times 2.0 \times 10^{30} \times m \left(\frac{1}{4.20 \times 10^{10}} - \frac{1}{1.37 \times 10^{11}}\right)$ 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. $\Delta E_{\text{grav}} = -\frac{GMm}{r} \quad \Delta E_{\text{K}} = \left(-\frac{G(2.0 \times 10^{30})(100)}{1.37 \times 10^{11}} \right) - \left(-\frac{G(2.0 \times 10^{30})(100)}{4.2 \times 10^{10}} \right)$ $\Delta E_{\text{K}} = 4.60 \times 10^{11} \text{ J}$ change in kinetic energy = 4.60×10^{11} J [3] 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	9	
10			C	1	<u>Examiner's Comments</u> Most candidates suggested that angular frequency and angular velocity do not have the same or equivalent units. The correct answer is C, because gravitational potential is measured in J kg^{-1} and kinetic energy is measured in J.
			Total	1	