1(a)	(gravitational) force is (directly) proportional to product of masses	**B1**
	force (between point masses) is inversely proportional to the square of their separation	**B1**

1(b)(i)	force $= (6.67 \times 10^{-11} \times 4.0 \times 10^{30} \times 2.0 \times 10^{30}) / (3.3 \times 10^{12})^2$	**C1**
	$= 4.9 \times 10^{25}$ N	**A1**

1(b)(ii)	$a = F / m = (4.9 \times 10^{25}) / (4.0 \times 10^{30})$ $= 1.2 \times 10^{-5}$ m s^{-2}	**A1**

1(b)(iii)	$a = r\omega^2$ **and** $\omega = 2\pi / T$ **or** $a = v^2 / r$ **and** $v = (2\pi r / T)$	**C1**
	$r = (3.3 \times 10^{12}) / 3$	**C1**
	$T = 2\pi\,[(3.3 \times 10^{12}) / (3 \times 1.2 \times 10^{-5})]^{½}$ $= 1.9 \times 10^9$ s	**A1**

1(b)(iv)	acceleration: B greater than A	**B1**
	linear speed: B greater than A	**B1**
	period: B equal to A	**B1**

Question 1

(a) Generally, this question was answered well and most candidates were awarded full credit. Some candidates stated that the force was proportional to the 'masses' rather than the product of the masses. Some candidates stated the force was inversely proportional to the 'distance' or 'radius' squared, rather than the 'separation' or 'distance of separation' of the masses squared. A small number of candidates referred to 'indirect' rather than 'inverse' proportion regarding the separation squared or omitted 'squared'. A small number of candidates did not refer to force and gained no credit.

(b) (i) The majority of the candidates gained full credit. The most common error involved using the incorrect distance for the separation of the stars.

(ii) A large proportion of candidates gave the correct answer. Some candidates did not realise that the radius of the path of star A was one-third of the separation of the stars, and a small number of candidates did not correctly identify appropriate starting equations.

(iii) Candidates were guided to use their answer from **(b)(ii)**. Those who ignored this were generally unsuccessful in reaching the correct answer.

(iv) The majority of the candidates placed their ticks in the correct cells of the table. Almost all candidates were able to gain at least partial credit.

2(a)	(gravitational) force is (directly) proportional to product of masses	**B1**
	force (between point masses) is inversely proportional to the square of their separation	**B1**

2(b)	*Any two points from*: • molecules are in <u>continuous</u> random motion • molecules have negligible volume compared with volume of gas • collisions (involving molecules) are (perfectly) elastic • collisions (of molecules) are instantaneous	**B2**

2(c)(i)	$pV = nRT$	**C1**
	$p = (0.0160 \times 8.31 \times 282) / (1.87 \times 10^{-4})$ $= 2.01 \times 10^{5}$ Pa	**A1**

2(c)(ii)	number of molecules $= 0.0160 \times 6.02 \times 10^{23}$	**C1**
	separation $= \sqrt[3]{[(1.87 \times 10^{-4}) / (0.0160 \times 6.02 \times 10^{23})]}$ $= 2.7 \times 10^{-9}$ m (*allow any answer that is 3×10^{-9} m to one significant figure*)	**A1**

2(d)(i)	$F = 6.67 \times 10^{-11} \times (3.34 \times 10^{-27})^2 / (2.7 \times 10^{-9})^2$	**C1**
	$= 1.0 \times 10^{-46}$ N	**A1**

2(d)(ii)	numerical comparison between 10^{-46} N (F) and 10^{-26} N (the weight of molecule) leading to a conclusion that the assumption is supported	**B1**

Question 2

(a) This question was generally well answered, with most candidates able to give a correct statement of Newton's law of gravitation.

(b) Whilst candidates generally had a reasonable understanding of what the assumptions of the kinetic theory are, many did not articulate clearly enough that they were discussing the molecules of the gas rather than the gas itself. For example, responses such as 'gases have negligible volume' and 'gases undergo elastic collisions' were common incorrect answers. There was no credit available to candidates for repeating the assumption that was stated in the question.

(c) (i) Most candidates knew the correct starting equation and were able to use it. Some candidates did not notice that the data provided in the question was given to three significant figures and that therefore three significant figures should be given in the answer.

(ii) Many candidates realised that the starting point for this question was to determine the number of molecules in the sample. Many candidates then stopped after determining the effective volume occupied per molecule, without converting the volume into an effective distance of separation. In carrying out this last step, candidates could treat the effective space occupied by each molecule as a cube or a sphere, leading to an effective mean separation of the order of 10^{-9} m.

Many answers were seen that were many orders of magnitude away from being plausible, and this was a good example of a question in which taking time to consider whether the answer makes sense can lead to detection of an error in the working. For example, a candidate that stops at the volume and arrives at an answer of 10^{-27} m ought to realise that it cannot make sense for the effective separation to be smaller than the diameter of the nucleus of an atom.

(d) (i) Most candidates that obtained an answer in **(c)(ii)** were able to use their separation with Newton's law of gravitation to determine the gravitational force between adjacent molecules. Some weaker candidates used the equation for gravitational field strength rather than gravitational force and omitted to square the mass in the numerator.

(ii) The hint in the question was that candidates needed to determine an order of magnitude for the weight of a molecule. Those that determined the 10^{-26} N figure and then drew a consistent conclusion about the validity of the assumption based on comparing 10^{-26} N with their answer in **(d)(i)** were awarded credit.

3(a)	force per unit mass	**B1**

3(b)(i)	$F = GMm / x^2$	**C1**
	$g = F / m$ $g = [GMm / x^2] / m = GM / x^2$ **and** G = gravitational constant	**A1**

3(b)(ii)	arrow drawn at P pointing directly towards the point mass	**B1**

3(b)(iii)	fields are in opposite directions	**B1**
	field strength at Q is four times the field strength at P	**B1**

3(c)	line starting at (R, $-g_0$) and ending at ($L - R$, $+g_0$)	**B1**
	line passing through (L / 2, 0)	**B1**
	curve becoming shallower from R to (L / 2) and then steeper from (L / 2) to ($L - R$)	**B1**

Question 3

(a) In general, the ratio of force per unit mass was clearly expressed.

(b) (i) The word ‘derive’ in the question implied a starting point of the expression for gravitational force due to a point mass. Stronger candidates correctly combined this with their answer in **(a)**, and also identified the gravitational constant symbol.

(ii) The drawing of the gravitational field direction on Fig. 3.1 was improved by the use of a ruler to ensure that the field direction extrapolated through both the test mass at P and mass M. Where lines were inaccurately drawn, this prevented candidates from gaining credit. Weaker answers mistakenly considered the gravitational field of the test mass at P.

(iii) The majority of the candidates understood the inverse-square nature of the gravitational field and were able to deduce the factor of four as being the difference between the fields at P and Q. Stronger candidates also identified that the fields were in opposite directions.

(c) In general, the graph was well drawn. Credit could be gained for showing the correct start and end points, the correct point at which the field strength was zero, and the increasing steepness of the curve away from the midpoint. Candidates who used a pencil, and could therefore adjust their sketch where it was inaccurate, were at an advantage.

1(a)	force per unit mass	**B1**
1(b)(i)	radial	**B1**
	towards (centre of) planet	**B1**
1(b)(ii)	(changes in) height (very) much smaller than radius	**B1**
	$(\text{radius} + \text{height})^2 \approx \text{radius}^2$ **or** field lines are approximately parallel	**B1**
1(c)(i)	$9.81 \times R^2 = 3.99 \times 10^{14}$	**C1**
	$R = 6.38 \times 10^6$ m	**A1**
1(c)(ii)	gravitational potential $= -(GM / R)$ $= -(3.99 \times 10^{14}) / (6.38 \times 10^6)$	**C1**
	$= -6.25 \times 10^7 \text{ J kg}^{-1}$	**A1**
1(d)	potential (energy) zero at infinite separation	**B1**
	(gravitational) force is attractive	**B1**

Question 1

(a) Most candidates correctly provided the correct ratio of force per unit mass. A significant number described qualitatively a general region in which a gravitational force occurs, which is not a definition. Some candidates gave both of these descriptions.

(b) (i) More candidates were able to give the correct direction of the gravitational field lines than the correct pattern.

(ii) Candidates usually used appropriate wording to compare the small change in vertical height with the radius of the planet. Stronger candidates understood that the field lines were approximately (or could be assumed to be) parallel. Weaker candidates often thought that the planet mass was the relevant quantity to compare with, rather than the planet radius. The minimal impact of squaring the two distances was rarely mentioned.

(c) (i) A high proportion of candidates correctly read the question and gave their answer to exactly three significant figures.

(ii) In addition to the need to express their answer to at least three significant figures to match that of the given data, stronger candidates also appreciated that the gravitational potential had a negative value.

(d) Most candidates understood the importance of infinity as a reference point for gravitational potential. Fewer candidates appreciated that any mention of 'work done' required them to say what was doing the work, and in what direction the masses were moving relative to each other.

2(a)(i)	direction of force	**B1**
	force acting on a (test) mass	**B1**

2(a)(ii)	at least four radial lines from the Earth's surface, equally spaced around the surface	**B1**
	arrows indicating direction towards Earth	**B1**

2(b)(i)	top pole labelled S and bottom pole labelled N	**B1**

2(b)(ii)	solenoid field pattern at the poles: at least two field lines either side of both poles, close to the poles, clustered closely together, leaving the surface approximately perpendicularly to the surface and curving away from the axis of the poles as their distance from the surface increases	**B1**
	solenoid field pattern above the equator: at least one field line either side of the Earth connecting two points on the surface that are on the same side of the poles, one north of the equator and one south of it, passing above the surface near the magnetic equator approximately parallel to the surface	**B1**

2(c)(i)	(around the surface) lines are evenly spaced	**B1**
	all lines perpendicular to surface **or** pointing down towards surface (at all points around the surface)	**B1**

2(c)(ii)	*Any three bulleted points from:* • strongest at the poles • weakest near the Equator *Up to two points from:* • perpendicular to surface at the poles • parallel to the surface near the Equator • angle to surface increases from Equator to poles	**B3**

Question 2

(a) (i) Many candidates attempted to answer a different question from the one asked, and either gave the definition of gravitational field or an explanation of what is meant by a gravitational field. Of those candidates that did address the question of what is represented by a gravitational field line, many correctly stated that a field line represents the direction of the force exerted on a test mass. Other candidates incorrectly thought that a single field line represents the magnitude of the field. Another weak answer was that a field line represents the direction in which a test mass will move or accelerate, not appreciating that the motion of a particle depends on the resultant of all the forces acting on it, not just the gravitational force.

(ii) This question was generally well answered, with most candidates making an attempt to draw a radial field pattern towards the centre of the planet.

(b) (i) Many candidates did not know that magnetic field lines point away from magnetic N poles and towards magnetic S poles.

(ii) Many candidates found it difficult to apply their knowledge of the magnetic field pattern due to a solenoid to the scenario of the magnetic field due to the Earth. Candidates should remember that magnetic field lines cannot cross each other.

(c) (i) Many candidates answered a different question from the one asked here, and gave explanations of how the Earth's gravitational field varies with height above the surface for small changes in height. This question was about how the gravitational field around the surface varied around the surface, and many candidates missed this. Since gravitational field is a vector quantity, examiners were looking for an explanation for the constant magnitude (in terms of uniform spacing of field lines at the surface), and for an explanation of constant direction by observing that the gravitational field is downwards wherever one stands on the surface of the Earth.

(ii) Again, magnetic field is a vector quantity, and so, for full credit, candidates needed to address both the variation in magnitude of the magnetic field around the surface and the variation in its direction.

Only the strongest candidates addressed the issue of direction, but many were able to achieve partial credit by observing that the magnitude of the Earth's magnetic field is strongest at the poles and weakest at the Equator. As with **(c)(ii)**, some candidates discussed the variation with altitude above the surface rather than variation around the surface.

1(a)	work done per unit mass	**B1**
	work (done in) moving mass from infinity (to the point)	**B1**

1(b)(i)	evidence of addition of 3.4×10^6 to 1.7×10^6 **or** 6.8×10^6	**C1**
	$GM \times 122 / (5.1 \times 10^6)$ **or** $GM \times 122 / (10.2 \times 10^6)$	**C1**
	$6.67 \times 10^{-11} \times M \times 122 \times [(5.1 \times 10^6)^{-1} - (10.2 \times 10^6)^{-1}] = 5.1 \times 10^8$ leading to $M = 6.4 \times 10^{23}$ kg	**A1**

1(b)(ii)	$\phi = (-)(6.67 \times 10^{-11} \times 6.4 \times 10^{23}) / (3.4 \times 10^6)$	**C1**
	$= -1.3 \times 10^7$ J kg^{-1}	**A1**

1(c)(i)	Mars takes (just under) 25 hours to rotate once on its axis	**B1**

1(c)(ii)	orbit is equatorial **or** orbit is in same direction as direction of rotation of Mars	**B1**

Question 1

(a) Most candidates gave a correct definition of gravitational potential. Some candidates' responses did not make the ratio work done per unit mass clear or specified a unit of mass as part of their definition, and so were not able to gain full credit.

(b) (i) A common mistake was to equate the change in gravitational potential with the potential energy in the higher orbit (omitting the potential energy in the lower orbit). This resulted in the same numerical value for the mass of Mars but only earned partial credit.

(ii) Most candidates were awarded credit for the correct substitution of values into the correct equation. Many candidates were not awarded full credit because they omitted the minus sign or had an incorrect unit.

(c) (i) Most candidates were awarded credit for this question. Some weaker candidates confused rotation with orbit.

(ii) Common answers which did not earn credit described the orbit as geostationary (which describes an orbit around Earth) or as 'on' the equator of Mars rather than above it.

2(a)	<u>sketch:</u> line from $x = R$ to $x = 4R$ entirely in the negative ϕ region	**B1**
	curve with continuously decreasing magnitude and with gradient of continuously decreasing magnitude, starting at $(R, \pm\phi)$	**B1**
	line passing through $(2R, \pm\frac{1}{2}\phi)$ <u>and</u> $(4R, \pm\frac{1}{4}\phi)$	**B1**

2(b)	horizontal straight line from $t = 0$ to $t = 24$ hours	**B1**
	line starting at $(0, -\phi)$	**B1**

2(c)	straight line with non-zero gradient from 0 to d	**B1**
	line with negative gradient from $(0, V)$ to $(d, 0)$	**B1**

Question 2

(a) Candidates who knew the inverse relationship, understood that gravitational potential is always negative, and took care over their diagrams, were generally able to achieve the marks.

(b) Many candidates realised that, at a constant distance from the Earth's surface, the gravitational potential must be constant.

(c) This question required candidates to realise two things. One, that the potential is zero at the earthed plate and +*V* at the upper plate. Two, that the electric field between parallel plates is uniform. Candidates who realised both aspects, and took care over the start and end points of their line, were generally able to achieve the marks.

2(a)	force per unit mass	**B1**

2(b)(i)	$g = GM / x^2$	**C1**
	$= (6.67 \times 10^{-11} \times 1.99 \times 10^{30}) / (1.47 \times 10^{11})^2$ $= 6.14 \times 10^{-3}$ N kg^{-1}	**A1**

2(b)(ii)	$E_P = -GMm / x$ $= -(6.67 \times 10^{-11} \times 1.99 \times 10^{30} \times 2.63) / (1.47 \times 10^{11})$	**C1**
	$= -2.37 \times 10^9$ J	**A1**

2(c)(i)	$F = L / 4\pi x^2$	**C1**
	($g = GM / x^2$ and so) $x^2 = GM / g$ **and** $x^2 = L / 4\pi F$	**M1**
	elimination of x and subsequent algebra shown leading to $g = 4\pi GMF / L$	**A1**

2(c)(ii)	correct read-off of pair of values of g and F and full substitution of values of g, G, M and F into equation e.g. $L = (4\pi \times 6.67 \times 10^{-11} \times 1.99 \times 10^{30} \times 1.83 \times 10^3) / (8.0 \times 10^{-3})$	**C1**
	$L = 3.8 \times 10^{26}$ W	**A1**

2(c)(iii)	$L = 4\pi\sigma r^2 T^4$ $3.8 \times 10^{26} = (4\pi \times 5.67 \times 10^{-8} \times 5780^4) \times r^2$	**C1**
	$r = 6.9 \times 10^8$ m	**A1**

Question 2

(a) A significant minority of candidates did not give a definition of a quantity, but those that did answer the question were mostly able to correctly define the vector quantity gravitational field as force per unit mass (placed in the field).

(b)(i) There was some confusion among weaker candidates between the equations for gravitational force between point masses and the scalar quantity gravitational field strength due to a point mass. The more able candidates generally used the correct equation, but some did not appreciate that the precision of the data provided in the question warranted a three significant figure answer.

(ii) Most candidates were able to substitute the correct values into the equation for gravitational potential energy. Some candidates gave answers that did not reflect the precision of the data and others forgot that gravitational potential energy is always negative.

(c) (i) Many candidates were able to put together the equation for radiant flux intensity and the equation for gravitational field strength, and to eliminate x between them to arrive at the correct equation. Candidates that used letters other than x from the question sometimes struggled with the elimination if the distances they used in the two equations were not the same. Candidates should be advised that it is always better to use the symbols defined for them in the question.

(ii) This question was well answered by many candidates. Of those that correctly read a pair of values of g and L from the graph and substituted them together with the other relevant data into the given equation, the common reasons for not going on to achieve full credit were either making a mistake with the powers of ten in those values from the graph, or forgetting that luminosity is a power and giving the answer with an incorrect unit.

(iii) Many candidates answered correctly. Some struggled with the use of the Stefan–Boltzmann law, with use of the permittivity of free space for the Stefan–Boltzmann constant not unusual, and various arithmetic errors such as forgetting to raise the temperature to the power 4 or forgetting to take the square root of r^2 at the end. Some weaker candidates attempted to use the radiant flux intensity formula.

1(a)	(gravitational) force is (directly) proportional to product of masses	**B1**
	force (between point masses) is inversely proportional to the square of their separation	**B1**

1(b)(i)	(gravitational) force acts perpendicular to direction of motion	**B1**
	gravitational force provides centripetal acceleration	**B1**

1(b)(ii)	(F =) $GMm / x^2 = mx\omega^2$ **and** $\omega = 2\pi / T$ **or** $GMm / x^2 = 4\pi^2 mx / T^2$	**M1**
	completion of algebra leading to $x^3 = GMT^2 / 4\pi^2$	**A1**
	clear indication that B = radius of planet **and** that A = mass (of planet)	**B1**

1(b)(iii)	gradient = $\sqrt[3]{(4\pi^2 / GA)}$	**C1**
	e.g. $(1280 - 360) / (12 \times 10^6) = \sqrt[3]{(4\pi^2 / [6.67 \times 10^{-11} \times A])}$	**C1**
	$A = 1.3 \times 10^{24}$ kg	**A1**
	intercept = gradient × B	**C1**
	e.g. $360 = ((1280 - 360) \times B) / (12 \times 10^6)$ $B = 4.7 \times 10^6$ m	**A1**

NOT FOUND:

9702_w24_qp_41 EXAMINER REPORT (Qu 1)

1(a)	work done per unit mass	**B1**
	work done moving mass from infinity (to the point)	**B1**

1(b)(i)	potential is zero at infinity	**B1**
	work is done **by** (two) masses in moving them **closer** together **or** work is done **on** (two) masses in moving them **apart**	**B1**

1(b)(ii)	magnitude of potential shown as 4Φ	**B1**
	potential negative **and** shown as a multiple of $-\Phi$ [potential = -4Φ if fully correct]	**B1**

1(b)(iii)	field strength at X: $\Phi / 4R$	**A1**
	field strength at Y: $4\Phi / R$	**A1**
	potential energy at X: $-M\Phi$	**A1**
	potential energy at Y: $-8M\Phi$	**A1**

Question 1

(a) Most candidates understood that the definition involved work done moving a mass from infinity, but fewer candidates appreciated that gravitational potential equated to the work done per unit mass (or the equivalent ratio).

(b) (i) The reference point of zero potential at infinity was well understood. Candidates often did not refer to what was doing the work to bring the masses closer together. Any reference made to work being done usually referred to only the satellite rather than both masses.

(ii) A significant number of candidates were unable to gain credit because they did not give answers in terms of Φ. Those candidates who also appreciated that the expression for Φ should be negative could receive full credit.

(iii) Stronger candidates were able to achieve full credit in this question, and many weaker candidates were also awarded credit by the principle of error carried forward.

1(a)	(gravitational) potential is zero at infinity	**B1**
	(gravitational force between two masses is attractive so)	
	either work is done on a mass to move it away from another mass **or** work is done on a mass to move it to infinity	**B1**

1(b)(i)	$M = (–)$ gradient / G	**C1**
	e.g. $M = (1.76 \times 10^{8}) / (3.0 \times 10^{-8} \times 6.67 \times 10^{-11}) = 8.8 \times 10^{25}$ kg	**A1**

1(b)(ii)	**either** $GMm / r^2 = mr\omega^2$ **and** $\omega = 2\pi / T$ **or** $GMm / r^2 = mv^2 / r$ **and** $v = 2\pi r / T$ **or** $GMm / r^2 = 4\pi^2 mr / T^2$	**C1**
	$R^3 = 6.67 \times 10^{-11} \times 8.8 \times 10^{25} \times (0.72 \times 24 \times 60 \times 60)^2 / 4\pi^2$	**C1**
	$R = 8.3 \times 10^{7}$ m	**A1**

1(b)(iii)	$\Delta E = (GMm / r) - ½mv^2$	**C1**
	kinetic energy = $(½ \times 1200 \times 8400^2)$	
	potential energy = $(–)[(6.67 \times 10^{-11} \times 8.8 \times 10^{25} \times 1200) / (8.3 \times 10^{7})]$	**C1**
	$\Delta E = [(6.67 \times 10^{-11} \times 8.8 \times 10^{25} \times 1200) / (8.3 \times 10^{7})] - (½ \times 1200 \times 8400^2)$ $= 4.3 \times 10^{10}$ J	**A1**

NOT FOUND:

9702_m24_qp_42 EXAMINER REPORT (Qu 1)

2(a)(i)	work done per unit mass	**B1**
	work (done) moving mass from infinity (to the point)	**B1**
2(a)(ii)	$\phi = -GM / r$ $= -(6.67 \times 10^{-11} \times 7.3 \times 10^{22}) / (1.7 \times 10^{6})$	**C1**
	$= -2.9 \times 10^{6}$ J kg^{-1}	**A1**
2(b)(i)	$E_P = m\phi$	**B1**
2(b)(ii)	$\frac{1}{2}mv^2 + m\phi = 0$	**M1**
	correct algebra leading to $v = \sqrt{(-2\phi)}$	**A1**
2(c)	speed $= \sqrt{(2 \times 2.9 \times 10^{6})}$ $= 2400$ m s^{-1}	**A1**
2(d)	$\frac{1}{2}m\langle c^2\rangle = (3/2)kT$	**C1**
	$3.34 \times 10^{-27} \times \langle c^2\rangle = 3 \times 1.38 \times 10^{-23} \times 400$	**C1**
	$c_{r.m.s.} = 2200$ m s^{-1}	**A1**
2(e)	r.m.s. speed is an average so many molecules have speeds greater than the escape speed **or** there is a distribution of molecular speeds (around the r.m.s. value) so many molecules have speeds greater than the escape speed	**B1**

Question 2

(a) (i) Most candidates were awarded at least partial credit, but full credit was often not possible because of a dimensionally incorrect definition that gave an energy rather than an energy per unit mass.

(ii) Most candidates were able to be awarded credit for the substitution of the given numbers into the equation for gravitational potential. Some candidates did not realise that gravitational potential must be negative or did not know the unit.

(b) (i) Most candidates realised that the magnitude of potential energy is obtained by multiplying the potential by the mass, but a significant minority thought that there is a negative relationship between gravitational potential and gravitational potential energy. Some weaker candidates attempted to give expressions in terms of quantities other than the two asked for in the question.

(ii) This was generally well answered by candidates who realised that the loss in kinetic energy of the particle must equal the gain in gravitational potential energy, though some were a little confused over signs in the starting equation. Many weaker candidates tried to answer this question by equating gravitational and centripetal forces.

(c) This question was generally well answered, with most candidates able to use their answer to **(a)(ii)** with the given equation to calculate a speed.

(d) Many of the more able candidates calculated the correct answer with relative ease, although a significant minority forgot to take the square root of their value of mean-square speed at the end. Some of the weaker candidates realised that the starting point required the mean kinetic energy to be equated with $(3/2)kT$, but then found the subsequent arithmetic difficult. Many others were a little confused and attempted to equate $(3/2)kT$ with $(1/3)Nm\langle c^2\rangle$.

(e) This was another challenging question. Even many of the stronger candidates missed the point that, even though the r.m.s. speed of the molecules is a little less than the escape speed, there is a *distribution* of molecular speeds in which the r.m.s. value is only an average. As a result, many of the molecules do have the speed required to escape, and over time all will do so. Many responses did not discuss molecular speeds at all, and only referred to the speed of the gas or of the Moon.

1(a)(i)	direction of the force acting on a (test) mass placed at the point	**B1**

1(a)(ii)	change in height negligible compared with radius (of Earth)	**B1**
	(so) field lines are (effectively) parallel	**B1**

1(b)(i)	$Y = GM / R^2$	**M1**
	G is the gravitational constant	**A1**

1(b)(ii)	gravitational force is (always) attractive **or** gravitational force (always) acts towards the centre of the sphere	**B1**
	force is in opposite direction to displacement **or** at a point to the right of the centre, force acts to the left **or** at a point to the left of the centre, force acts to the right	**B1**

1(b)(iii)	sketch: smooth curve with decreasing positive gradient, starting at (R, $-Y$) and reaching $3R$ with g still negative **or** smooth curve with increasing positive gradient, ending at ($-R$, Y) and reaching $-3R$ with g still positive	**B1**
	both of the above curves, in correct quadrants	**B1**
	curve passing through ($\pm 2R$, $\pm 0.25Y$) and ($\pm 3R$, $\pm 0.11Y$)	**B1**

NOT FOUND:

9702_w23_qp_41 EXAMINER REPORT (Qu 1)

1(a)	(gravitational) force is (directly) proportional to product of masses	**B1**
	force (between point masses) is inversely proportional to the square of their separation	**B1**

1(b)	$GMm / R^2 = mR\omega^2$	**M1**
	$\omega = 2\pi / T$ <u>and</u> algebra leading to $4\pi^2R^3 = GMT^2$	**A1**
	or	
	$GMm / R^2 = mv^2 / R$	**(M1)**
	$v = 2\pi R / T$ <u>and</u> algebra leading to $4\pi^2R^3 = GMT^2$	**(A1)**

1(c)	$4\pi^2 \times R^3 = 6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times (24 \times 60 \times 60)^2$ ($R = 4.22 \times 10^7$ m)	**C1**
	$h = R - (6.37 \times 10^6)$	**C1**
	$h = (4.22 \times 10^7) - (6.37 \times 10^6)$ $= 3.6 \times 10^7$ m	**A1**

1(d)(i)	$\omega = 2\pi / T$	**C1**
	$= 2\pi / (24 \times 60 \times 60)$ $= 7.3 \times 10^{-5}$ rad s^{-1}	**A1**

1(d)(ii)	orbit is from east to west	**B1**
	orbit is not equatorial / orbit is polar	**B1**

Question 1

(a) This question was generally well answered, with most candidates able to give a correct statement of Newton's law of gravitation.

(b) This question was also well answered. Most candidates were able to equate the expression for gravitational force, from Newton's law of gravitation, with an expression for centripetal force as the starting point. The substitution for T and completion of the algebra to obtain the given equation was also done correctly by many candidates.

(c) Candidates who appreciated that the period of a geostationary orbit is 24 hours and that the height above the surface is equal to the radius of the orbit minus the radius of the Earth were able to be awarded at least partial credit, and full credit for the correct answer was common. Many of the weaker candidates started incorrectly by inserting the radius of the Earth into the given equation to find the period for a hypothetical orbit at the level of the Earth's surface.

(d) (i) The more able candidates had little difficulty with this question, but a significant number of the weaker candidates did not know the difference between angular speed and linear speed.

(ii) Candidates needed to read this question carefully. The question asked about the orbit of the satellite that is not in geostationary orbit, so candidates who simply listed properties of a geostationary orbit did not answer the question and could not be awarded credit. Some of the weaker candidates discussed different periods or orbital radius, despite it being stated in the question that these properties of the orbit were the same as that of the geostationary satellite. Most candidates who read and answered the question carefully gave responses that were awarded credit.

1(a)(i)	force per unit mass	**B1**

1(a)(ii)	force per unit positive charge	**B1**

1(a)(iii)	similarity: • inversely proportional to distance (from point) • points of equal potential lie on concentric spheres • zero at infinite distance *Any point, 1 mark*	**B1**
	difference: • gravitational potential is (always) negative • electric potential can be positive or negative *Any point, 1 mark*	**B1**

1(b)(i)	$g = GM / r^2$	**M1**
	$E = Q / 4\pi\varepsilon_0 r^2$	**M1**
	algebra showing the elimination of r leading to $M / Q = (1 / 4\pi G\varepsilon_0)\ (g / E)$	**A1**

1(b)(ii)	$\alpha = 1 / (4\pi \times 6.67 \times 10^{-11} \times 8.85 \times 10^{-12}) = 1.35 \times 10^{20}$ (kg^2 C^{-2}) **or** $\alpha = (8.99 \times 10^9) / (6.67 \times 10^{-11}) = 1.35 \times 10^{20}$ (kg^2 C^{-2})	**A1**

1(c)(i)	$E = \alpha gQ / M$ $= (1.35 \times 10^{20} \times 9.81 \times 4.80 \times 10^5) / (5.98 \times 10^{24})$	**C1**
	$= 106$ N C^{-1} **or** 106 V m^{-1}	**A1**

1(c)(ii)	same (direction)	**B1**

Question 1

(a) (i) Only a minority of candidates knew the syllabus ‘bookwork’ that defines gravitational field as force per unit mass. Many candidates did not give the definition of a quantity but instead answered a different question, asking what is meant by the concept of a gravitational field. As this was such a common misunderstanding of the question, the Examiners did award credit on this occasion for responses that answered the latter question. However, teachers should be aware that candidates are expected to know the syllabus definition that gravitational field is a vector quantity, given by the force per unit mass on an object.

(ii) The comments for **(a)(i)** are also relevant here for the definition of electric field. Candidates are expected to know the syllabus definition that electric field is force per unit positive charge.

(iii) There were many correct similarities and differences stated here. Some candidates gave responses that were correct for forces or fields rather than potentials, such as “both are inversely proportional to distance squared” or “one is attractive and the other is repulsive”.

(b) (i) This proof proved to be challenging for many candidates. A significant number of candidates started with the definition of electric field strength as F / Q which is correct, but they needed to extend it to the field due to a point charge. Some candidates were attempted to equate the two field strengths, when they have different dimensions so cannot be equated.

(ii) Candidates who did not reach the required expression in **(b)(i)** were unable to show the numerical value for α here. They did not know the combination of constants that was represented by α. It should be noted that full substitution is required in ‘show that’ calculations, including all constants. Here it was necessary to see the numerical values for ε_0 and G being used to determine the value of α.

(c) (i) Many candidates used the expression stated in **(b)(i)** to calculate the electric field strength at the surface of the Earth. However, some then gave their answer to two significant figures when the data were given to three significant figures. The requirement for a unit also proved challenging to many candidates. Weaker candidates often tried to answer this by starting once again from first principles, only to find that they did not have enough information to do this.

(ii) There were many correct answers here comparing the directions of the two fields. Some candidates did not realise the significance of the information at the start of **(c)** that the charge carried by the Earth is negative. Some gave the general case and said the direction of the electric field could be towards or away from the surface of the Earth. Some candidates said the directions were opposite, presumably assuming that the charge of the Earth was positive.

1(a)	work done per unit mass	**B1**
	work (done on mass) moving mass from infinity (to the point)	**B1**

1(b)(i)	$-3.55 \times 10^7\ \text{J kg}^{-1}$	**B1**

1(b)(ii)	$\phi = -\dfrac{GM}{r}$ $M = -\dfrac{-3.55 \times 10^7 \times 4800000}{6.67 \times 10^{-11}}$ $= 2.55 \times 10^{24}\ \text{kg}$	**B1**

1(b)(iii)	$g = \dfrac{GM}{r^2}$ **or** $g = -\dfrac{\phi}{r}$	**C1**
	$= \dfrac{6.67 \times 10^{-11} \times 2.55 \times 10^{24}}{4800000^2}$ **or** $= \dfrac{3.55 \times 10^7}{4800000}$ $= 7.4\ \text{N kg}^{-1}$	**A1**

1(b)(iv)	r in range 2.60×10^7 to 2.65×10^7 m	C1
	$\dfrac{mv^2}{r} = \dfrac{GMm}{r^2}$ **and** $v = \dfrac{2\pi r}{T}$ **or** $mr\omega^2 = \dfrac{GMm}{r^2}$ **and** $\omega = \dfrac{2\pi}{T}$	C1
	$T^2 = \dfrac{4\pi^2 r^3}{GM} = \dfrac{4\pi^2 \times (2.65 \times 10^7)^3}{6.67 \times 10^{-11} \times 2.55 \times 10^{24}} = 4.20 \times 10^9$	C1
	$T = 64\,800$ s $= 18$ hours	A1

1(c)	similarity – any one point from • inversely proportional to distance (from point) • points of equal potential lie on concentric spheres • zero at infinite distance	B1
	difference – any one point from • gravitational potential is (always) negative • electric potential can be positive or negative	B1

Question 1

(a) A good number of correct definitions were seen. However, some candidates used the phrase ‘work done to move unit mass from infinity’. The idea of ‘per unit mass’ is vital and coveys the division required.

There was an error in Fig. 1.1, with the gravitational potential ϕ axis plotted as positive numbers instead of negative numbers. This has been corrected in the published version of the paper. Please note that due to this issue with the question full marks have been awarded to all candidates for question **1(b)** and **(c)** to make sure that no candidates were disadvantaged.

1(a)	force per unit mass	**B1**

1(b)(i)	lines drawn are radial from the surface	**B1**
	arrows show pointing towards planet	**B1**

1(b)(ii)	field lines show force (on satellite) is towards centre of planet **or** velocity of satellite is perpendicular to field lines	**B1**
	(gravitational) force perpendicular to velocity causes centripetal <u>acceleration</u>	**B1**

1(c)(i)	$T = 24$ hours	**C1**
	$a = r\omega^2$ **and** $\omega = 2\pi / T$ **or** $a = v^2 / r$ **and** $v = 2\pi r / T$ **or** $a = 4\pi^2 r / T^2$	**C1**
	$a = (4\pi^2 \times 6.4 \times 10^6) / (24 \times 60 \times 60)^2$ $= 0.034\ \text{m s}^{-2}$	**A1**

1(c)(ii)	identification of the two forces acting on the object as gravitational force and (normal) contact force	**M1**
	gravitational force and normal contact force are in opposite directions, and their resultant causes the (centripetal) acceleration	**A1**

Question 1

(a) Only a minority of candidates knew the syllabus 'bookwork' that defines gravitational field as force per unit mass. Many candidates did not give the definition of a quantity but instead answered a different question, asking what is meant by the concept of a gravitational field. As this was such a common misunderstanding of the question, the Examiners did award credit on this occasion for responses that answered the latter question. However, teachers should be aware that candidates are expected to know the syllabus definition that gravitational field is a vector quantity, given by the force per unit mass on an object. Conversely, gravitational field strength is a scalar quantity representing the magnitude of that gravitational field.

(b) (i) This question was generally well answered, and most candidates knew that the gravitational field pattern around a spherical planet is radial and directed towards the centre of the planet.

(ii) This is a good example of a question that candidates need to read carefully to understand what was being asked. Most responses seen were recalled from previous mark schemes relating to past questions that were similar but not the same. This question asked candidates to make reference to their answer in **(b)(i)**. This meant that responses needed to make clear the relevance of the radial field pattern to the motion of the satellite. For full credit, responses needed to consider the direction of the gravitational field, the force this caused on the satellite and the orientation of this force relative to the velocity of the satellite. Most responses seen omitted most of the connections between quantities, and as a consequence it was not a question that was answered well.

(c) (i) This question was generally well answered by candidates who knew that the period of the circular motion of an object at the Equator is 24 hours. Candidates who did not use this as a starting point tended to treat the object at the Equator as a satellite in orbit and were, therefore, unable to be awarded credit.

(ii) Only the most able candidates had an understanding that the two forces acting on the object are the weight of the object downwards and the normal contact force upwards from the Earth's surface. Even some of those who did get this far often had those two forces being equal to each other, leading to a centripetal acceleration of zero. The strongest candidates realised that the contact force is slightly less than the weight, leading to a resultant force towards the centre of the Earth that gives rise to the centripetal acceleration. A large number of weaker candidates again treated the object as a satellite in orbit, and responses that gave the centripetal force as one of the two forces acting (as opposed to understanding this as the resultant force) were very common.

1(a)	$F = (Gm_1m_2) / r^2$	**M1**
	where G is the gravitational constant	**A1**

1(b)	gravitational force provides the centripetal force	**B1**
	$mR\omega^2 = GMm / R^2$ **and** $\omega = 2\pi / T$ **or** $mv^2 / R = GMm / R^2$ **and** $v = 2\pi R / T$ **or** $4\pi^2 mR / T^2 = GMm / R^2$	**M1**
	correct completion of algebra to get $T^2 = (4\pi^2 / GM)\ R^3$, with identification of $(4\pi^2 / GM)$ as k	**A1**

1(c)(i)	$(24 \times 3600)^2 = (4\pi^2 \times R^3) / (6.67 \times 10^{-11} \times 6.0 \times 10^{24})$	**C1**
	$R = 4.2 \times 10^7$ m	**A1**

1(c)(ii)	(orbit) must be above the Equator	**B1**
	(direction) must be from west to east	**B1**

Question 1

(a) Most candidates had little difficulty in stating the correct formula and in naming the gravitational constant *G*.

(b) A significant number of candidates were able to show the required relationship. However, many candidates did not explain their reasoning by writing that the gravitational force provides the centripetal force. A few candidates made algebraic errors and the π was sometimes not squared.

(c) (i) This calculation was completed well by many candidates. Some candidates did not convert correctly from 24 hours into seconds, and some did not square the period.

(ii) Most candidates were able to state two further conditions for the orbit of a satellite to be geostationary.