CAMBRIDGE INTERNATIONAL AS & A LEVEL PHYSICS · 9702

PHYSICS



MARK SCHEME

13 GRAVITATIONAL FIELDS

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3. 9702_w21_MS_43 Q: 1

	Answer	Marks
(a)	constant speed **or** constant magnitude of velocity	**B1**
	acceleration (always) perpendicular to velocity	**B1**
(b)(i)	$F = mv^2 / r$ **or** $v = r\omega$ **and** $F = mr\omega^2$	**C1**
	$F = 790 \times 94^2 / 318$ $= 22\,000$ N	**A1**
(b)(ii)	centripetal acceleration: same	**B1**
	maximum speed: greater	**B1**
	time taken for one lap of the track: greater	**B1**

4. 9702_s20_MS_41 Q: 1

	Answer	Marks
(a)	force acting between two masses **or** force on mass due to another mass **or** force on mass in a gravitational field	**B1**
(b)	arc length = $r\theta$ $d = 1.5 \times 10^{17} \times 1.2 \times 10^{-5} = 1.8 \times 10^{12}$ m	**A1**
(c)(i)	$\omega = 2\pi / T$	**C1**
	$= 2\pi / (44.2 \times 365 \times 24 \times 3600)$ $= 4.5 \times 10^{-9}$ rad s^{-1}	**A1**
(c)(ii)	gravitational forces are equal **or** centripetal force about P is the same	**C1**
	$M_1 x\omega^2 = M_2(d - x)\omega^2$ so $M_1 / M_2 = (d - x) / x$	**A1**
(c)(iii)	$x = 0.4d$	**C1**
	$6.67 \times 10^{-11} \times M_1 = (1.0 - 0.4) \times (1.8 \times 10^{12})^3 \times (4.5 \times 10^{-9})^2$	**C1**
	$M_1 = 1.1 \times 10^{30}$ kg	**A1**

5. 9702_s20_MS_43 Q: 1

	Answer	Marks
(a)	force acting between two masses **or** force on mass due to another mass **or** force on mass in a gravitational field	**B1**
(b)	arc length = $r\theta$ $d = 1.5 \times 10^{17} \times 1.2 \times 10^{-5} = 1.8 \times 10^{12}$ m	**A1**
(c)(i)	$\omega = 2\pi / T$	**C1**
	$= 2\pi / (44.2 \times 365 \times 24 \times 3600)$ $= 4.5 \times 10^{-9}$ rad s^{-1}	**A1**
(c)(ii)	gravitational forces are equal **or** centripetal force about P is the same	**C1**
	$M_1 x\omega^2 = M_2(d - x)\omega^2$ so $M_1 / M_2 = (d - x) / x$	**A1**
(c)(iii)	$x = 0.4d$	**C1**
	$6.67 \times 10^{-11} \times M_1 = (1.0 - 0.4) \times (1.8 \times 10^{12})^3 \times (4.5 \times 10^{-9})^2$	**C1**
	$M_1 = 1.1 \times 10^{30}$ kg	**A1**

6. 9702_w19_MS_41 Q: 1

	Answer	Marks
(a)	force proportional to product of masses and inversely proportional to square of separation	**B1**
	idea of (gravitational) force between point masses	**B1**
(b)(i)	above the equator	**B1**
	from west to east	**B1**
(b)(ii)	gravitational force provides/is the centripetal force	**B1**
	$GM / r^2 = r(2\pi / T)^2$	**C1**
	$(6.67 \times 10^{-11} \times M) = \{(4.23 \times 10^7)^3 \times 4\pi^2\} / (24 \times 3600)^2$	**C1**
	$M = 6.0 \times 10^{24}$ kg	**A1**

7. 9702_w19_MS_42 Q: 1

	Answer	Marks
(a)	force proportional to product of masses and inversely proportional to square of separation	**B1**
	idea of (gravitational) force between point masses	**B1**
(b)	gravitational force provides/is the centripetal force	**B1**
	$GM / R^2 = R\omega^2$ **or** $GM / R^2 = v^2 / R$	**M1**
	$\omega = 2\pi / T$ **or** $v = 2\pi R / T$	**M1**
	algebra leading to $R^3/T^2 = GM / 4\pi^2$	**A1**
(c)	$(6.67 \times 10^{-11} \times M) / 4\pi^2 = (4.38 \times 10^6)^3 / (2.44 \times 3600)^2$	**C1**
	$M = 6.45 \times 10^{23}$ kg	**A1**

8. 9702_w19_MS_43 Q: 1

	Answer	Marks
(a)	force proportional to product of masses and inversely proportional to square of separation	B1
	idea of (gravitational) force between point masses	B1
(b)(i)	above the equator	B1
	from west to east	B1
(b)(ii)	gravitational force provides/is the centripetal force	B1
	$GM / r^2 = r(2\pi / T)^2$	C1
	$(6.67 \times 10^{-11} \times M) = \{(4.23 \times 10^7)^3 \times 4\pi^2\} / (24 \times 3600)^2$	C1
	$M = 6.0 \times 10^{24}$ kg	A1

9. 9702_s18_MS_41 Q: 1

	Answer	Marks
(a)	force proportional to product of masses and inversely proportional to square of separation	B1
	idea of force between point masses	B1
(b)(i)	velocity changes/direction of motion changes/there is an acceleration/there is a resultant force so not in equilibrium	B1
(b)(ii)1.	gravitational force equals/is centripetal force	C1
	$GMm / R^2 = mR\omega^2$ **and** $\omega = 2\pi / T$ **or** $Gm / R^2 = mv^2 / R$ **and** $v = 2\pi r / T$ **or** $GMm / R^2 = mR(2\pi / T)^2$	M1
	convincing algebra leading to $k = GM / 4\pi^2$	A1
1(b)(ii)2.	correct use of R^3 / T^2 for one planet (c gives 3.54×10^{21}; e and g both give 3.56×10^{21})	C1
	$3.5(5) \times 10^{21} = (6.67 \times 10^{-11} \times M) / 4\pi^2$ $M = 2.1 \times 10^{33}$ kg	A1
	two or three values of R^3 / T^2 correctly calculated and used in a valid way to find a value for M based on more than one k	B1

10. 9702_s18_MS_43 Q: 1

	Answer	Marks
(a)	force proportional to product of masses and inversely proportional to square of separation	B1
	idea of force between point masses	B1
(b)(i)	velocity changes/direction of motion changes/there is an acceleration/there is a resultant force so not in equilibrium	B1
(b)(ii)1.	gravitational force equals/is centripetal force	C1
	$GMm/R^2 = mR\omega^2$ **and** $\omega = 2\pi/T$ **or** $Gm/R^2 = mv^2/R$ **and** $v = 2\pi r/T$ **or** $GMm/R^2 = mR(2\pi/T)^2$	M1
	convincing algebra leading to $k = GM/4\pi^2$	A1
(b)(ii)2.	correct use of R^3/T^2 for one planet (c gives 3.54×10^{21}; e and g both give 3.56×10^{21})	C1
	$3.5(5) \times 10^{21} = (6.67 \times 10^{-11} \times M)/4\pi^2$ $M = 2.1 \times 10^{33}$ kg	A1
	two or three values of R^3/T^2 correctly calculated and used in a valid way to find a value for M based on more than one k	B1

11. 9702_s17_MS_43 Q: 1

	Answer	Marks
(a)	gravitational force (of attraction between satellite and planet)	B1
	provides / is centripetal force (on satellite about the planet)	B1
(b)	$M = (4/3) \times \pi R^3 \rho$	B1
	$\omega = 2\pi / T$ or $v = 2\pi nR / T$	B1
	$GM/(nR)^2 = nR\omega^2$ or v^2/nR	M1
	substitution clear to give $\rho = 3\pi n^3 / GT^2$	A1
(c)	$n = (3.84 \times 10^5) / (6.38 \times 10^3) = 60.19$ or 60.2	C1
	$\rho = 3\pi \times 60.19^3 / [(6.67 \times 10^{-11}) \times (27.3 \times 24 \times 3600)^2]$	C1
	$\rho = 5.54 \times 10^3$ kg m^{-3}	A1

12. 9702_w17_MS_42 Q: 1

	Answer	Marks
(a)	force proportional to product of masses and inversely proportional to square of separation	B1
	idea of force between point masses	B1
(b)	mass of Jupiter (M) = $(4/3)\pi R^3\rho$	B1
	$\omega = 2\pi/T$ **or** $v = 2\pi nR/T$	B1
	$(m)\omega^2 x = GM(m)/x^2$ **or** $(m)v^2/x = GM(m)/x^2$	M1
	substitution and correct algebra leading to $\rho T^2 = 3\pi n^3/G$	A1
(c)(i)	$n = (4.32 \times 10^5)/(7.15 \times 10^4)$ **or** $n = 6.04$	C1
	$\rho \times (42.5 \times 3600)^2 = (3\pi \times 6.04^3)/(6.67 \times 10^{-11})$	C1
	$\rho = 1.33 \times 10^3\,\text{kg m}^{-3}$	A1
(c)(ii)	Jupiter likely to be a gas/liquid (at high pressure) [allow other sensible suggestions]	B1

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13. 9702_w16_MS_41 Q: 1

(a) gravitational force provides/is the centripetal force B1

$GMm/r^2 = mv^2/r$ *or* $GMm/r^2 = mr\omega^2$
and $v = 2\pi r/T$ *or* $\omega = 2\pi/T$ M1

with algebra to $T^2 = 4\pi^2 r^3/GM$ A1 [3]

or

acceleration due to gravity is the centripetal acceleration (B1)

$GM/r^2 = v^2/r$ *or* $GM/r^2 = r\omega^2$
and $v = 2\pi r/T$ *or* $\omega = 2\pi/T$ (M1)

with algebra to $T^2 = 4\pi^2 r^3/GM$ (A1)

(b) **(i)** equatorial orbit/orbits (directly) above the equator B1

from west to east B1 [2]

(ii) $(24 \times 3600)^2 = 4\pi^2 r^3/(6.67 \times 10^{-11} \times 6.0 \times 10^{24})$ C1

$r^3 = 7.57 \times 10^{22}$

$r = 4.2 \times 10^7$ m A1 [2]

(c) $(T/24)^2 = \{(2.64 \times 10^7)/(4.23 \times 10^7)\}^3$ B1
$= 0.243$

$T = 12$ hours A1 [2]

or

$k\ (= T^2/r^3) = 24^2/(4.23 \times 10^7)^3$ (B1)
$= 7.61 \times 10^{-21}$

$T^2\ (= kr^3) = 7.61 \times 10^{-21} \times (2.64 \times 10^7)^3$
$= 140$

$T = 12$ hours (A1)

14. 9702_w16_MS_43 Q: 1

(a) gravitational force provides/is the centripetal force B1

$GMm/r^2 = mv^2/r$ *or* $GMm/r^2 = mr\omega^2$
and $v = 2\pi r/T$ *or* $\omega = 2\pi/T$ M1

with algebra to $T^2 = 4\pi^2 r^3/GM$ A1 [3]

or

acceleration due to gravity is the centripetal acceleration (B1)

$GM/r^2 = v^2/r$ *or* $GM/r^2 = r\omega^2$
and $v = 2\pi r/T$ *or* $\omega = 2\pi/T$ (M1)

with algebra to $T^2 = 4\pi^2 r^3/GM$ (A1)

(b) **(i)** equatorial orbit/orbits (directly) above the equator B1

from west to east B1 [2]

(ii) $(24 \times 3600)^2 = 4\pi^2 r^3/(6.67 \times 10^{-11} \times 6.0 \times 10^{24})$ C1

$r^3 = 7.57 \times 10^{22}$

$r = 4.2 \times 10^7$ m A1 [2]

(c) $(T/24)^2 = \{(2.64 \times 10^7)/(4.23 \times 10^7)\}^3$
$= 0.243$ B1

$T = 12$ hours A1 [2]

or

$k\ (= T^2/r^3) = 24^2/(4.23 \times 10^7)^3$
$= 7.61 \times 10^{-21}$ (B1)

$T^2\ (= kr^3) = 7.61 \times 10^{-21} \times (2.64 \times 10^7)^3$
$= 140$

$T = 12$ hours (A1)

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15. 9702_s21_MS_42 Q: 1

	Answer	Marks
(a)	(gravitational) force per unit mass	B1
(b)(i)	$g = GM / r^2$	C1
	$= (6.67 \times 10^{-11} \times 6.42 \times 10^{23}) / (3.39 \times 10^6)^2$ $= 3.73\ \text{N kg}^{-1}$	A1
(b)(ii)	$a = r\omega^2$ **and** $\omega = 2\pi / T$ **or** $a = v^2 / r$ **and** $v = 2\pi r / T$	C1
	$a = 3.39 \times 10^6 \times (2\pi / (24.6 \times 3600))^2$ $= 0.0171\ \text{m s}^{-2}$	A1
(b)(iii)	force per unit mass $= 3.73 - 0.0171$ $= 3.71\ \text{N kg}^{-1}$	A1

16. 9702_s19_MS_42 Q: 1

	Answer	Marks
(a)	($F =$) GMm / x^2, where G is the (universal) gravitational constant	B1
(b)(i)	angle $= (1.2 \times 10^{-3}) / (8.0 \times 10^{-2}) = 1.5 \times 10^{-2}$ (rad)	B1
(b)(ii)	torque $= 1.5 \times 10^{-2} \times 9.3 \times 10^{-10}$ $= 1.4 \times 10^{-11}\ \text{N m}$	A1
(c)(i)	force $\times\ 8.0 \times 10^{-2} = 1.4 \times 10^{-11}$	C1
	$(G \times 1.3 \times 7.5 \times 10^{-3} \times 8.0 \times 10^{-2}) / (6.0 \times 10^{-2})^2 = 1.4 \times 10^{-11}$	C1
	$G = 6.4 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$	A1
(c)(ii)	Any one from: • law applies only to point masses/spheres are not point masses • radii of spheres not small compared with separation • spheres may not be uniform • the masses are not isolated • force between L and rod • spheres may be charged/may be electrostatic force (between spheres)	B1

17. 9702_m18_MS_42 Q: 1

	Answer	Marks
(a)(i)	*either* direction of force on a (small test) mass *or* direction of acceleration of a (small test) mass	**B1**
(a)(ii)	Any three from: • the lines are radial • near the surface the lines are (approximately) parallel • parallel lines so constant field strength • constant field strength hence constant acceleration of free fall	**B3**
(b)(i)	$g = GM/R^2$ $g = (6.67 \times 10^{-11} \times 7.35 \times 10^{22}) / (1.74 \times 10^3 \times 10^3)^2$	**C1**
	g = **1.62 N kg^{-1}**	**A1**
(b)(ii)	*either* $x\omega^2 = GM/x^2$ and $\omega = 2\pi / T$ *or* $v^2/x = GM/x^2$ and $v = 2\pi r / T$	**C1**
	$(1.74 \times 10^6 + 320 \times 10^3)^3 \times 4\pi^2 / T^2 = (6.67 \times 10^{-11} \times 7.35 \times 10^{22})$	**C1**
	$T^2 = 7.04 \times 10^7$ T = **8400 s** (8390)	**A1**

18. 9702_s18_MS_42 Q: 1

	Answer	Marks
(a)(i)	direction of force on a (small test) mass **or** path in which a (small test) mass will move	**B1**
(a)(ii)	(at surface,) lines (of force) are radial	**B1**
	Earth has large radius/height above surface is small so lines are (approximately) parallel	**B1**
	parallel lines → constant field strength	**B1**
(b)	(change in) KE of rock = (change in) PE **or** $\frac{1}{2}mv^2 = GMm/R$	**C1**
	$(m)v^2 = (m)(2 \times 6.67 \times 10^{-11} \times 7.4 \times 10^{22}) / (1.7 \times 10^3 \times 10^3)$	**C1**
	$v = 2.4 \times 10^3$ m s^{-1}	**A1**
	correct conclusion based on comparison of v with 2.8 km s^{-1}	**B1**
	or	
	(change in) KE of rock = (change in) PE	**(C1)**
	(at infinity) $E_P = (6.67 \times 10^{-11} \times 7.4 \times 10^{22} \times m) / (1.7 \times 10^3 \times 10^3)$ $= 2.9 \times 10^6 m$	**(C1)**
	E_K of rock = $\frac{1}{2} \times m \times (2.8 \times 10^3)^2 = 3.9 \times 10^6 m$	**(A1)**
	correct conclusion based on comparison of E_K and E_P values	**(B1)**
	or	

	Answer	Marks
	(change in) KE of rock = (change in) PE **or** $\frac{1}{2}mv^2 = GMm/R$	**(C1)**
	$(m)\ (2800)^2 = (m)\ (2 \times 6.67 \times 10^{-11} \times 7.4 \times 10^{22}) / R$	**(C1)**
	$R = 1.3 \times 10^3$ km	**(A1)**
	correct conclusion based on comparison of R with 1.7×10^3 km	**(B1)**
	or	
	(change in) KE of rock = (change in) PE **or** $\frac{1}{2}mv^2 = GMm/R$	**(C1)**
	$(m)\ (2800)^2 = (m)\ (2 \times 6.67 \times 10^{-11} \times M) / (1.7 \times 10^6)$	**(C1)**
	$M = 1.0 \times 10^{23}$ kg	**(A1)**
	correct conclusion based on comparison of M with 7.4×10^{22} kg	**(B1)**

19. 9702_w18_MS_42 Q: 1

	Answer	Marks
(a)(i)	force per unit mass	**B1**
(a)(ii)	acceleration = F/m, field strength = F/m, so equal	**B1**
(b)	smooth curve between R and $4R$ with negative gradient of decreasing magnitude	**B1**
	line passing through (R, $1.00g$) and ($2R$, $0.25g$)	**B1**
	line ending at ($4R$, $0.0625g$)	**B1**
(c)	$M = (4/3 \times \pi R^3)\rho$	**C1**
	$g = GM/(2R)^2$	**C1**
	$g = \frac{1}{3} \times 6.67 \times 10^{-11} \times \pi \times 3.4 \times 10^6 \times 4.0 \times 10^3$ $= 0.95\ \text{m s}^{-2}$	**A1**

20. 9702_s17_MS_41 Q: 1

	Answer	Marks
(a)	gravitational force (of attraction between satellite and planet)	**B1**
	provides / is centripetal force (on satellite about the planet)	**B1**
(b)	$M = (4/3) \times \pi R^3 \rho$	**B1**
	$\omega = 2\pi / T$ **or** $v = 2\pi nR / T$	**B1**
	$GM/(nR)^2 = nR\omega^2$ **or** v^2/nR	**M1**
	substitution clear to give $\rho = 3\pi n^3 / GT^2$	**A1**
(c)	$n = (3.84 \times 10^5) / (6.38 \times 10^3) = 60.19$ or 60.2	**C1**
	$\rho = 3\pi \times 60.19^3 / [(6.67 \times 10^{-11}) \times (27.3 \times 24 \times 3600)^2]$	**C1**
	$\rho = 5.54 \times 10^3\ \text{kg m}^{-3}$	**A1**

21. 9702_s17_MS_42 Q: 1

	Answer	Marks
(a)	force per unit mass	B1
(b)(i)	$g = GM/r^2$ $= (6.67 \times 10^{-11} \times 1.0 \times 10^{13}) / (3.6 \times 10^3)^2$	C1
	$= 5.1 \times 10^{-5}$ N kg^{-1}	A1
(b)(ii)	mass = (960 / 9.81) kg weight on comet = $(960 / 9.81) \times 5.1 \times 10^{-5}$	C1
	$= 5.0 \times 10^{-3}$ N	A1
(c)	similarity: e.g. both attractive/pointed towards the comet e.g. same order of magnitude	B1
	difference: e.g. radial/non-radial e.g. same (over surface)/varies (over surface)	B1

22. 9702_w17_MS_41 Q: 3

	Answer	Marks
(a)	force per unit mass	B1
(b)	changes in height <u>much</u> less than radius of Earth	M1
	so (radial) field lines are almost parallel **or** $g = GM/R^2 \approx GM/(R + h)^2$	A1

	Answer	Marks
(c)	gravitational force provides/is centripetal force	B1
	$GMm/r^2 = mv^2/r$	C1
	$v = (2\pi \times 1.5 \times 10^{11})/(3600 \times 24 \times 365) = 2.99 \times 10^4$ (m s^{-1})	C1
	$6.67 \times 10^{-11} M = 1.5 \times 10^{11} \times (2.99 \times 10^4)^2$	C1
	$M = 2.0 \times 10^{30}$ kg	A1
	or	
	$GMm/r^2 = mr\omega^2$	(C1)
	$\omega = 2\pi/(3600 \times 24 \times 365) = 1.99 \times 10^{-7}$ (rad s^{-1})	(C1)
	$6.67 \times 10^{-11} M = (1.5 \times 10^{11})^3 \times (1.99 \times 10^{-7})^2$	(C1)
	$M = 2.0 \times 10^{30}$ kg	(A1)
	or	
	$T^2 = 4\pi^2 r^3/GM$	(C2)
	$M = 4\pi^2 \times (1.5 \times 10^{11})^3 / (\{3600 \times 24 \times 365\}^2 \times 6.67 \times 10^{-11})$	(C1)
	$= 2.0 \times 10^{30}$ kg	(A1)

23. 9702_w17_MS_43 Q: 3

	Answer	Marks
(a)	force per unit mass	B1
(b)	changes in height <u>much</u> less than radius of Earth	M1
	so (radial) field lines are almost parallel **or** $g = GM/R^2 \approx GM/(R + h)^2$	A1

	Answer	Marks
(c)	gravitational force provides/is centripetal force	B1
	$GMm/r^2 = mv^2/r$	C1
	$v = (2\pi \times 1.5 \times 10^{11})/(3600 \times 24 \times 365) = 2.99 \times 10^4$ (m s^{-1})	C1
	$6.67 \times 10^{-11} M = 1.5 \times 10^{11} \times (2.99 \times 10^4)^2$	C1
	$M = 2.0 \times 10^{30}$ kg	A1
	or	
	$GMm/r^2 = mr\omega^2$	(C1)
	$\omega = 2\pi/(3600 \times 24 \times 365) = 1.99 \times 10^{-7}$ (rad s^{-1})	(C1)
	$6.67 \times 10^{-11} M = (1.5 \times 10^{11})^3 \times (1.99 \times 10^{-7})^2$	(C1)
	$M = 2.0 \times 10^{30}$ kg	(A1)
	or	
	$T^2 = 4\pi^2 r^3/GM$	(C2)
	$M = 4\pi^2 \times (1.5 \times 10^{11})^3 / (\{3600 \times 24 \times 365\}^2 \times 6.67 \times 10^{-11})$	(C1)
	$= 2.0 \times 10^{30}$ kg	(A1)

24. 9702_m16_MS_42 Q: 1

(a) force proportional to product of the (two) masses and inversely proportional to the square of their separation — M1
either reference to point masses *or* separation << 'size' of masses — A1 [2]

(b) gravitational force provides / is the centripetal force — B1

$GMm/r^2 = mv^2/r$ *or* $GMm/r^2 = mr\omega^2$ *and* $v = r\omega$
and algebra leading to $v = (GM/r)^{1/2}$ — B1 [2]

(c) (i) 1. $v_A/v_B = (r_B/r_A)^{1/2}$
$= (2.2 \times 10^{10}/1.3 \times 10^8)^{1/2}$ — C1
$= 13$ (13.0) — A1 [2]

2. $v = 2\pi r/T$ *or* $v \propto r/T$ *or* $vT/r =$ constant — C1
$T_A/T_B = (r_A/r_B) \times (v_B/v_A)$
$= (1.3 \times 10^8/2.2 \times 10^{10}) \times (1/13)$ — C1
$= 4.5$ (4.54) $\times 10^{-4}$ — A1

or

$T^2 = 4\pi^2 r^3/GM$ *or* $T^2 \propto r^3$ *or* $T^2/r^3 =$ constant — (C1)
$T_A/T_B = (r_A^3/r_B^3)^{1/2}$
$= [(1.3 \times 10^8)^3/(2.2 \times 10^{10})^3]^{1/2}$ — (C1)
$= 4.5$ (4.54) $\times 10^{-4}$ — (A1) [3]

(ii) $T = 2\pi/1.7 \times 10^{-4}$
$= 3.70 \times 10^4$ s — C1
$T_B = 3.70 \times 10^4/4.54 \times 10^{-4}$
$= 8.1 \times 10^7$ s — A1 [2]
If identifies T_A as T_B then 0/2

25. 9702_w16_MS_42 Q: 1

(a) force per unit mass B1 [1]

(b) (i) radius/diameter/size (of Proxima Centauri) $\ll$ /is <u>much</u> less than 4.0×10^{13} km/separation (of Sun and star)
or
(because) it is a <u>uniform</u> sphere B1 [1]

(ii) 1. field strength $= GM/x^2$

$= (6.67 \times 10^{-11} \times 2.5 \times 10^{29})/(4.0 \times 10^{13} \times 10^{3})^2$ C1

$= 1.0 \times 10^{-14}\,\text{N kg}^{-1}$ A1 [2]

2. force = field strength $\times$ mass

$= 1.0 \times 10^{-14} \times 2.0 \times 10^{30}$ C1

or

force $= GMm/x^2$

$= (6.67 \times 10^{-11} \times 2.5 \times 10^{29} \times 2.0 \times 10^{30})/(4.0 \times 10^{13} \times 10^{3})^2$ (C1)

$= 2.0 \times 10^{16}\,\text{N}$ A1 [2]

(c) force (of 2×10^{16} N) would have little effect on (large) <u>mass</u> of Sun B1

would cause an acceleration of Sun of $1.0 \times 10^{-14}\,\text{m s}^{-2}$/very small/negligible acceleration B1 [2]

or

many stars all around the Sun (B1)
net effect of forces/fields is zero (B1)

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26. 9702_m21_MS_42 Q: 1

	Answer	Marks
(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
(b)	correct read offs from the graph with correct power of ten for R^3	C1
	$M = \frac{4\times\pi^2\times1.2\times10^{34}}{6.67\times10^{-11}\times2.4\times(365\times24\times3600)^2}$	C1
	$=3.0\times10^{30}$ kg	A1
(c)(i)	potential energy is zero at infinity	B1
	(gravitational) forces are attractive	B1
	work must be done on the rock to move it to infinity	B1
(c)(ii)	$\frac{GMm}{r^2}=\frac{mv^2}{r}$ OR $v^2=\frac{GM}{r}$ OR $v=\sqrt{\frac{GM}{r}}$	M1
	use of ½ mv^2 (e.g. multiplication by ½ m) leading to $\frac{GMm}{2r}$	A1
(c)(iii)	$E_p = \phi m$ and $\phi = \frac{-GM}{r}$ or $E_p = \frac{-GMm}{r}$ Total energy = $E_k + E_p$	C1
	Total energy $= \frac{GMm}{2r}+\frac{-GMm}{r}=\frac{-GMm}{2r}$	A1

27. 9702_s21_MS_41 Q: 1

	Answer	Marks
(a)	force per unit mass	B1
(b)	$GMm/r^2 = mr\omega^2$ **and** $\omega = 2\pi/T$ **or** $GMm/r^2 = mv^2/r$ **and** $v = 2\pi r/T$	C1
	$6.67\times10^{-11}\times6.0\times10^{24} = r^3\times[2\pi/(94\times60)]^2$	C1
	$r = 6.9\times10^6$ m	A1
(c)(i)	$r^3\omega^2$ = constant **or** r^3/T^2 = constant	C1
	$r^3/(6.9\times10^6)^3 = (150/94)^2$ so $r = 9.4\times10^6$ m	A1
	or	
	$GMT^2/4\pi^2 = r^3$ **and** clear that M is 6.0×10^{24}	(C1)
	$6.67\times10^{-11}\times6.0\times10^{24} = r^3\times[2\pi/(150\times60)]^2$ so $r = 9.4\times10^6$ m	(A1)
(c)(ii)	separation increases so (potential energy) increases **or** movement is against gravitational force so (potential energy) increases	B1
(c)(iii)	potential energy = (–)GMm/r	C1
	$\Delta E_P = 6.67\times10^{-11}\times6.0\times10^{24}\times1200\times[(6.9\times10^6)^{-1}-(9.4\times10^6)^{-1}]$	C1
	$= 1.9\times10^{10}$ J	A1

28. 9702_s21_MS_43 Q: 1

	Answer	Marks
(a)	force per unit mass	B1
(b)	$GMm / r^2 = mr\omega^2$ **and** $\omega = 2\pi/T$ **or** $GMm / r^2 = mv^2 / r$ **and** $v = 2\pi r / T$	C1
	$6.67 \times 10^{-11} \times 6.0 \times 10^{24} = r^3 \times [2\pi / (94 \times 60)]^2$	C1
	$r = 6.9 \times 10^6$ m	A1
(c)(i)	$r^3\omega^2$ = constant **or** r^3 / T^2 = constant	C1
	$r^3 / (6.9 \times 10^6)^3 = (150 / 94)^2$ so $r = 9.4 \times 10^6$ m	A1
	or	
	$GMT^2/4\pi^2 = r^3$ **and** clear that M is 6.0×10^{24}	(C1)
	$6.67 \times 10^{-11} \times 6.0 \times 10^{24} = r^3 \times [2\pi / (150 \times 60)]^2$ so $r = 9.4 \times 10^6$ m	(A1)
(c)(ii)	separation increases so (potential energy) increases **or** movement is against gravitational force so (potential energy) increases	B1
(c)(iii)	potential energy = $(-)GMm / r$	C1
	$\Delta E_P = 6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times 1200 \times [(6.9 \times 10^6)^{-1} - (9.4 \times 10^6)^{-1}]$	C1
	$= 1.9 \times 10^{10}$ J	A1

29. 9702_w21_MS_41 Q: 2

	Answer	Marks
(a)	work done per unit mass	B1
	(work done in) moving mass from infinity	B1
(b)(i)	(gravitational) fields from the Earth and Moon are in opposite directions	B1
	(resultant is zero where gravitational) fields are equal (in magnitude)	B1
(b)(ii)	$g \propto M / r^2$	C1
	$5.98 \times 10^{24} / x^2 = 7.35 \times 10^{22} / (3.84 \times 10^8 - x)^2$ leading to $x = 3.5 \times 10^8$ (m)	A1
(b)(iii)	ϕ (Earth) $= (-)6.67 \times 10^{-11} \times (5.98 \times 10^{24} / 3.5 \times 10^8)$ **and** ϕ (Moon) $= (-)6.67 \times 10^{-11} \times (7.35 \times 10^{22} / 0.38 \times 10^8)$	C1
	$\phi = (-)6.67 \times 10^{-11} \times [(5.98 \times 10^{24} / 3.5 \times 10^8) + (7.35 \times 10^{22} / 0.38 \times 10^8)]$	C1
	$= -1.3 \times 10^6$ J kg^{-1}	A1

30. 9702_w21_MS_42 Q: 2

	Answer	Marks
(a)	(gravitational) field strength equals (gravitational) potential gradient	**M1**
	reference to minus sign	**A1**
(b)(i)	potential is zero at infinity	**B1**
	(gravitational) force is attractive	**B1**
	(test) mass getting closer (from infinity) loses potential energy	**B1**
(b)(ii)	• potential at (surface of) planet is smaller than at (surface of) moon • potential gradient at (surface of) planet is smaller than at (surface of) moon • magnitude of potential varies inversely with distance from centre near the spheres • (point of) maximum potential is nearer to moon than planet *Any two points, 1 mark each*	**B2**
(b)(iii)	sketch: one curve, starting with gradient of decreasing magnitude at $2R$ and finishing with gradient of increasing magnitude at $D - R$	**B1**
	field strength shown as zero (only) near the point of maximum potential	**B1**
	negative field strength near one sphere and positive field strength near the other	**B1**

31. 9702_w21_MS_43 Q: 2

	Answer	Marks
(a)	work done per unit mass	**B1**
	(work done in) moving mass from infinity	**B1**
(b)(i)	(gravitational) fields from the Earth and Moon are in opposite directions	**B1**
	(resultant is zero where gravitational) fields are equal (in magnitude)	**B1**
(b)(ii)	$g \propto M / r^2$	**C1**
	$5.98 \times 10^{24} / x^2 = 7.35 \times 10^{22} / (3.84 \times 10^8 - x)^2$ leading to $x = 3.5 \times 10^8$ (m)	**A1**
(b)(iii)	ϕ (Earth) $= (-)6.67 \times 10^{-11} \times (5.98 \times 10^{24} / 3.5 \times 10^8)$ **and** ϕ (Moon) $= (-)6.67 \times 10^{-11} \times (7.35 \times 10^{22} / 0.38 \times 10^8)$	**C1**
	$\phi = (-)6.67 \times 10^{-11} \times [(5.98 \times 10^{24} / 3.5 \times 10^8) + (7.35 \times 10^{22} / 0.38 \times 10^8)]$	**C1**
	$= -1.3 \times 10^6$ J kg^{-1}	**A1**

32. 9702_m20_MS_42 Q: 1

	Answer	Marks
(a)	work done per unit mass	B1
	work done moving mass from infinity (to the point)	B1
(b)(i)	gravitational force provides centripetal force	C1
	$mv^2 / r = GMm / r^2$ and $v = 2\pi r / T$ OR $mr\omega^2 = GMm / r^2$ and $\omega = 2\pi / T$ OR $r^3 = GMT^2 / 4\pi^2$	C1
	$r^3 = 6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times (13.7 \times 24 \times 3600)^2 / 4\ \pi^2$ so r = 2.4×10^8 m	A1
(b)(ii)	$(E_P = -)\ GMm / r$ work done = $GMm / r_1 - GMm / r_2$	C1
	$= 6.67 \times 10^{-11} \times 360 \times 6.0 \times 10^{24}\ (1/6.4 \times 10^6 - 1 / 2.4 \times 10^8)$	C1
	$= \mathbf{2.2 \times 10^{10}}$ J	A1
(b)(iii)	$g = GM / r^2$	C1
	ratio $= r_{TESS}^2 / r_{earth}^2$ $= (2.4 \times 10^8 / 6.4 \times 10^6)^2$ **= 1400**	A1

33. 9702_s20_MS_42 Q: 1

	Answer	Marks
(a)	work done per unit mass	B1
	(work done to) move mass from infinity (to the point)	B1
(b)	curve from r to $4r$, with gradient of decreasing magnitude and starting at $(r, \pm\phi)$	B1
	line passing through $(2r, \pm 0.5\phi)$ and $(4r, \pm 0.25\phi)$	B1
	line showing potential is negative throughout	B1
(c)(i)	gravitational potential energy = $(-)\ GMm / R$	C1
	change $= (6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times 3.4 \times 10^3) / (6.4 \times 10^6) \times [1/3 - 1/4]$	C1
	$= 1.8 \times 10^{10}$ J	A1
(c)(ii)	rock loses potential energy	B1
	(so) kinetic energy increases so speed increases	B1
	or	
	force is attractive	(B1)
	moves towards planet so speeds up	(B1)

34. 9702_m19_MS_42 Q: 1

	Answer	Marks
(a)(i)	work done per unit mass	B1
	idea of work done moving mass from infinity (to the point)	B1
(a)(ii)	(gravitational) force is attractive	B1
	(gravitational) potential at infinity is zero	B1
	decrease in potential energy as masses approach *or* displacement and force in opposite directions	B1
(b)(i)	*Either* $mv^2 / R = GMm / R^2$ *Or* $v = \sqrt{(GM / R)}$ $v^2 = (6.67 \times 10^{-11} \times 6.00 \times 10^{24}) / (7.30 \times 10^6)$	C1
	giving $v = 7.4 \times 10^3$ m s^{-1}	A1
(b)(ii)	$V_P = -GMm / R$	C1
	$= -(6.67 \times 10^{-11} \times 6.00 \times 10^{24} \times 340) / (7.30 \times 10^6)$	C1
	$V_P = -1.9 \times 10^{10}$ J	A1
(c)	$v^2 \propto 1 / r$, (r smaller) so v greater	M1
	and E_K greater	A1

35. 9702_s19_MS_41 Q: 1

	Answer	Marks
(a)	($F =$) GMm / x^2, where G is the (universal) gravitational constant	B1
(b)(i)	$GMm / x^2 = mv^2 / x$ **or** $v^2 = GM / x$	C1
	$v^2 = (6.67 \times 10^{-11} \times 7.5 \times 10^{23}) / (3.4 \times 10^6 + 240 \times 10^3)$ so $v = 3.7 \times 10^3$ m s^{-1}	A1
(b)(ii)	potential energy = $(-)GMm / x$	C1
	$E_A = (-)(6.67 \times 10^{-11} \times 7.5 \times 10^{23} \times 650) / (3.64 \times 10^6)$ **or** $E_B = (-)(6.67 \times 10^{-11} \times 7.5 \times 10^{23} \times 650) / (5.00 \times 10^7)$	M1
	correct substitution and subtraction $E_B - E_A$ shown, leading to $\Delta E_p = 8.3 \times 10^9$ J	A1
	or	
	$\phi = (-)GM / x$ **and** potential energy = $m\phi$	(C1)
	$\Delta\phi = (6.67 \times 10^{-11} \times 7.5 \times 10^{23}) \times [(1 / (3.64 \times 10^6)) - (1 / (5.00 \times 10^7))]$ $(= 1.27 \times 10^7$ J kg$^{-1})$	(M1)
	$\Delta E_p = 1.27 \times 10^7 \times 650$ $= 8.3 \times 10^9$ J	(A1)
(c)	kinetic energy or potential energy decreases	B1
	kinetic energy and potential energy decrease so total energy decreases	B1

36. 9702_s19_MS_43 Q: 1

	Answer	Marks
(a)	(F =) GMm / x^2, where G is the (universal) gravitational constant	B1
(b)(i)	$GMm / x^2 = mv^2 / x$ **or** $v^2 = GM / x$	C1
	$v^2 = (6.67 \times 10^{-11} \times 7.5 \times 10^{23}) / (3.4 \times 10^6 + 240 \times 10^3)$ so $v = 3.7 \times 10^3$ m s^{-1}	A1
(b)(ii)	potential energy = $(-)GMm / x$	C1
	$E_A = (-)(6.67 \times 10^{-11} \times 7.5 \times 10^{23} \times 650) / (3.64 \times 10^6)$ **or** $E_B = (-)(6.67 \times 10^{-11} \times 7.5 \times 10^{23} \times 650) / (5.00 \times 10^7)$	M1
	correct substitution and subtraction $E_B - E_A$ shown, leading to $\Delta E_p = 8.3 \times 10^9$ J	A1
	or	
	ϕ = $(-)GM / x$ **and** potential energy = $m\phi$	(C1)
	$\Delta\phi$ = $(6.67 \times 10^{-11} \times 7.5 \times 10^{23}) \times [(1 / (3.64 \times 10^6)) - (1 / (5.00 \times 10^7))]$ $(= 1.27 \times 10^7$ J kg$^{-1})$	(M1)
	$\Delta E_p = 1.27 \times 10^7 \times 650$ $= 8.3 \times 10^9$ J	(A1)
(c)	kinetic energy or potential energy decreases	B1
	kinetic energy and potential energy decrease so total energy decreases	B1

37. 9702_w18_MS_41 Q: 1

	Answer	Marks
(a)(i)	work done per unit mass	B1
	work done moving mass from infinity (to the point)	B1
(a)(ii)	(near Earth's surface change in) height $\ll$ radius **or** height much less than radius	B1
	potential inversely proportional to radius **and** radius approximately constant (so potential approximately constant)	B1
(b)	initial kinetic energy = (–) potential energy (at surface) **or** $\frac{1}{2}mv^2 = GMm / r$	B1
	$v^2 = (2 \times 6.67 \times 10^{-11} \times 7.4 \times 10^{22}) / (0.5 \times 3.5 \times 10^6)$	C1
	$v = 2.4 \times 10^3$ m s^{-1}	A1

38. 9702_w18_MS_43 Q: 1

	Answer	Marks
(a)(i)	work done per unit mass	B1
	work done moving mass from infinity (to the point)	B1
(a)(ii)	(near Earth's surface change in) height $\ll$ radius **or** height much less than radius	B1
	potential inversely proportional to radius **and** radius approximately constant (so potential approximately constant)	B1
(b)	initial kinetic energy = (–) potential energy (at surface) **or** $\frac{1}{2}mv^2 = GMm / r$	B1
	$v^2 = (2 \times 6.67 \times 10^{-11} \times 7.4 \times 10^{22}) / (0.5 \times 3.5 \times 10^6)$	C1
	$v = 2.4 \times 10^3$ m s^{-1}	A1

39. 9702_m17_MS_42 Q: 1

	Answer	Marks
(a)	work done per unit mass	M1
	bringing (small test) mass from infinity (to the point)	A1
(b)(i)	$\Delta\phi = (GM/2R) - (GM/5R) = 3GM/10R$	A1
(b)(ii)	change in GPE = $(3 \times 4.0 \times 10^{14} / 10R) \times 4.7 \times 10^4$	C1
	$(3 \times 4.0 \times 10^{14} / 10R) \times 4.7 \times 10^4 = (1.70 - 0.88) \times 10^{12}$ $R = 6.88 \times 10^6$	C1
	distance $= 3 \times 6.88 \times 10^6$ $= 2.1 \times 10^7$ m	A1

40. 9702_w19_MS_41 Q: 2

	Answer	Marks
(a)	(total volume of molecules is) negligible	M1
	compared with volume occupied by the gas	A1
(b)(i)	$pV = NkT$	C1
	$4.60 \times 10^5 \times 2.40 \times 10^{-2} = N \times 1.38 \times 10^{-23} \times (273 + 23)$	C1
	or	
	$pV = nRT$	(C1)
	$4.60 \times 10^5 \times 2.40 \times 10^{-2} = n \times 8.31 \times (273 + 23)$ $n = 4.49$ (mol) $N = nN_A$ $= 4.49 \times 6.02 \times 10^{23}$	(C1)
	$N = 2.7 \times 10^{24}$	A1

Q1.

1	(a)		work done in bringing/moving unit mass	M1	
			from infinity to the point.....	A1	[2]
			(use of 1 kg in the definition – max 1/2)		
	(b)		potential at infinity defined as being zero.....	B1	
			forces are always attractive.....	B1	
			so work got out in moving to point.....	B1	[3]
			(max potential is at infinity – allow 1/3)		
	(c)	(i)	$\varphi = -GM/R$		
			change = $6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times (\{6.4 \times 10^{6}\}^{-1} - \{1.94 \times 10^{7}\}^{-1})$	C2	
			change = 4.19×10^{7} J kg^{-1} (ignore sign)	A1	
		(ii)	$\frac{1}{2}mv^2 = m\Delta\varphi$	C1	
			$v^2 = 2 \times 4.19 \times 10^{7} = 8.38 \times 10^{7}$		
			$v = 9150$ m s^{-1}	A1	[5]
	(d)		acceleration is not constant.....	B1	[1]

Q2.

3	(a)	(i)	(force) = $GM_1M_2/(R_1 + R_2)^2$	B1	
		(ii)	(force) = $M_1R_1\omega^2$ or $M_2R_2\omega^2$	B1	[2]
	(b)		$\omega = 2\pi/(1.26 \times 10^{8})$ or $2\pi/T$	C1	
			$= 4.99 \times 10^{-8}$ rad s^{-1}	A1	[2]
			allow 2 s.f.: $1.59\pi \times 10^{-8}$ scores 1/2		
	(c)	(i)	reference to either taking moments (about C) or same (centripetal) force	B1	
			$M_1R_1 = M_2R_2$ or $M_1R_1\omega^2 = M_2R_2\omega^2$	B1	
			hence $M_1/M_2 = R_2/R_1$	A0	[2]
		(ii)	$R_2 = 3/4 \times 3.2 \times 10^{11}$ m $= 2.4 \times 10^{11}$ m	A1	
			$R_1 = (3.2 \times 10^{11}) - R_2 = 8.0 \times 10^{10}$ m (allow *vice versa)*	A1	[2]
			if values are both wrong but have ratio of four to three, then allow 1/2		
	(d)	(i)	$M_2 = \{(R_1 + R_2)^2 \times R_1 \times \omega^2\} I G$ (any subject for equation)	C1	
			$= (3.2 \times 10^{11})^2 \times 8.0 \times 10^{10} \times (4.99 \times 10^{-8})^2/(6.67 \times 10^{-11})$	C1	
			$= 3.06 \times 10^{29}$ kg	A1	
		(ii)	less massive (only award this mark if reasonable attempt at (i))	B1	[4]
			(9.17×10^{29} kg for more massive star)		
			Total		**[12]**

Q3.

1 (a) (i) angular speed = $2\pi/T$ C1
= $2\pi/(3.2 \times 10^7)$
= 1.96×10^{-7} rad s^{-1} A1 [2]

(ii) force = $mr\omega^2$ or force = mv^2/r and $v = r\omega$ C1
= $6.0 \times 10^{24} \times 1.5 \times 10^{11} \times (1.96 \times 10^{-7})^2$
= 3.46×10^{22} N A1 [2]

(b) (i) gravitation/gravity/gravitational field (strength) B1 [1]

(ii) $F = GMm/x^2$ or $GM = r^3\omega^2$ C1
$3.46 \times 10^{22} = (6.67 \times 10^{-11} \times M \times 6.0 \times 10^{24})/(1.5 \times 10^{11})^2$ C1
$M = 1.95 \times 10^{30}$ kg A1 [3]

Q4.

1 (a) centripetal force is provided by gravitational force B1
$mv^2 / r = GMm / r^2$ B1
hence $v = \sqrt{(GM / r)}$ A0 [2]

(b) (i) E_K (= ½mv^2) = $GMm / 2r$ B1 [1]

(ii) $E_P = - GMm / r$ B1 [1]

(iii) $E_T = - GMm / r + GMm / 2r$ C1
$= - GMm / 2r$. A1 [2]

(c) (i) if E_T decreases then $- GMm / 2r$ becomes more negative
or $GMm / 2r$ becomes larger M1
so r decreases A1 [2]

(ii) $E_K = GMm / 2r$ and r decreases M1
so (E_K and) v increases A1 [2]

Q5.

1 (a) (region of space) where a mass experiences a force B1 [1]

(b) (i) potential energy = $(-)GMm / x$ C1
$\Delta E_P = GMm/2R - GMm/3R$ M1
$= GMm/6R$ A0 [2]

(ii) $E_K = ½m\,(7600^2 - 7320^2)$ M1
$= (2.09 \times 10^6)m$ A0 [1]

(c) (i) $2.09 \times 10^6 = (6.67 \times 10^{-11}\, M)/(6 \times 3.4 \times 10^6)$ C1
$M = 6.39 \times 10^{23}$ kg A1 [2]

(ii) e.g. no energy dissipated due to friction with atmosphere/air
rocket is outside atmosphere
not influenced by another planet etc. B1 [1]

Q6.

1 (a) force per unit mass *(ratio idea essential)* B1 [1]

(b) $g = GM / R^2$ C1
$8.6 \times (0.6 \times 10^7)^2 = M \times 6.67 \times 10^{-11}$ C1
$M = 4.6 \times 10^{24}$ kg A1 [3]

(c) (i) *either* potential decreases as distance from planet decreases
or potential zero at infinity and X is closer to zero
or potential $\alpha -1/r$ and Y more negative M1
so point Y is closer to planet. A1 [2]

(ii) idea of $\Delta\phi = \frac{1}{2}v^2$ C1
$(6.8 - 5.3) \times 10^7 = \frac{1}{2}v^2$
$v = 5.5 \times 10^3$ ms^{-1} A1 [2]

Q7.

1 (a) work done moving unit mass M1
from infinity to the point A1 [2]

(b) (i) at R, $\phi = 6.3 \times 10^7$ J kg^{-1} (allow $\pm 0.1 \times 10^7$) B1
$\phi = GM / R$
$6.3 \times 10^7 = (6.67 \times 10^{-11} \times M) / (6.4 \times 10^6)$ C1
$M = 6.0 \times 10^{24}$ kg (allow 5.95 → 6.14) A1 [3]
Maximum of 2/3 for any value chosen for ϕ not at R

(ii) change in potential $= 2.1 \times 10^7$ J kg^{-1} (allow $\pm 0.1 \times 10^7$) C1
loss in potential energy = gain in kinetic energy B1
$\frac{1}{2} mv^2 = \phi$ m or $\frac{1}{2} mv^2 = GM / 3R$ C1
$\frac{1}{2} v^2 = 2.1 \times 10^7$
$v = 6.5 \times 10^3$ m s^{-1} .....(allow 6.3 → 6.6) A1 [4]
(answer 7.9×10^3 m s^{-1}, based on $x = 2R$, allow max 3 marks)

(iii) e.g. speed / velocity / acceleration would be greater B1
deviates / bends from straight path B1 [2]
(any sensible ideas, 1 each, max 2)

Q8.

1 (a) (i) force proportional to product of masses B1
force inversely proportional to square of separation B1 [2]

(ii) separation much greater than radius / diameter of Sun / planet B1 [1]

(b) (i) e.g. force or field strength $\propto 1 / r^2$
potential $\propto 1 / r$ B1 [1]

(ii) e.g. gravitational force (always) attractive B1
electric force attractive or repulsive B1 [2]

Q9.

1 (a) region (of space) where a particle / body experiences a force — B1 [1]

(b) similarity: e.g. force $\propto 1 / r^2$
potential $\propto 1 / r$ — B1 [1]

difference: e.g. gravitation force (always) attractive — B1
electric force attractive or repulsive — B1 [2]

(c) *either* ratio is $Q_1Q_2 / 4\pi\varepsilon_0 m_1 m_2 G$ — C1
$= (1.6 \times 10^{-19})^2 / 4\pi \times 8.85 \times 10^{-12} \times (1.67 \times 10^{-27})^2 \times 6.67 \times 10^{-11}$ — C1
$= 1.2 \times 10^{36}$ — A1 [3]

or $F_E = 2.30 \times 10^{-28} \times R^{-2}$ (C1)
$F_G = 1.86 \times 10^{-64} \times R^{-2}$ (C1)
$F_E / F_G = 1.2 \times 10^{36}$ (A1)

Q10.

1 (a) work done in bringing unit mass from infinity (to the point) — B1 [1]

(b) gravitational force is (always) attractive — B1
either as r decreases, object/mass/body does work
or work is done by masses as they come together — B1 [2]

(c) *either* force on mass = mg (where g is the acceleration of free fall /gravitational field strength) — B1
$g = GM/r^2$ — B1
if r @ h, g is constant — B1
ΔE_P = force × distance moved — M1
$= mgh$ — A0

or $\Delta E_P = m\Delta\phi$ — (C1)
$= GMm(1/r_1 - 1/r_2) = GMm(r_2 - r_1)/r_1r_2$ — (B1)
if $r_2 \approx r_1$, then $(r_2 - r_1) = h$ and $r_1r_2 = r^2$ — (B1)
$g = GM/r^2$ — (B1)
$\Delta E_P = mgh$ — (A0) [4]

(d) $\frac{1}{2}mv^2 = m\Delta\phi$
$v^2 = 2 \times GM/r$ — C1
$= (2 \times 4.3 \times 10^{13}) / (3.4 \times 10^6)$ — C1
$v = 5.0 \times 10^3\ \text{m s}^{-1}$ — A1 [3]
(Use of diameter instead of radius to give $v = 3.6 \times 10^3\ \text{m s}^{-1}$ scores 2 marks)

Q11.

1 (a) force proportional to product of masses and inversely proportional to square of separation (*do not allow square of distance/radius*) M1
either point masses *or* separation @ size of masses A1 [2]

(b) (i) $\omega = 2\pi / (27.3 \times 24 \times 3600)$ or $2\pi / (2.36 \times 10^6)$ M1
$= 2.66 \times 10^{-6}\,\text{rad s}^{-1}$ A0 [1]

(ii) $GM = r^3\omega^2$ or $GM = v^2 r$ C1
$M = (3.84 \times 10^5 \times 10^3)^3 \times (2.66 \times 10^{-6})^2 / (6.67 \times 10^{-11})$ M1
$= 6.0 \times 10^{24}\,\text{kg}$ A0 [2]
(special case: uses $g = GM/r^2$ with $g = 9.81$, $r = 6.4 \times 10^6$ scores max 1 mark)

(c) (i) grav. force $= (6.0 \times 10^{24}) \times (7.4 \times 10^{22}) \times (6.67 \times 10^{-11})/(3.84 \times 10^8)^2$ C1
$= 2.0 \times 10^{20}\,\text{N}$ (*allow 1 SF*) A1 [2]

(ii) *either* $\Delta E_P = Fx$ because F constant as x ! radius of orbit B1
$\Delta E_P = 2.0 \times 10^{20} \times 4.0 \times 10^{-2}$ C1
$= 8.0 \times 10^{18}\,\text{J}$ (*allow 1 SF*) A1 [3]

or $\Delta E_P = GMm/r_1 - GMm/r_2$ C1
Correct substitution B1
$8.0 \times 10^{18}\,\text{J}$ A1
($\Delta E_P = GMm/r_1 + GMm/r_2$ is incorrect physics so 0/3)

Q12.

1 (a) region of space area / volume B1
where a mass experiences a force B1 [2]

(b) (i) force proportional to product of two masses M1
force inversely proportional to the square of their separation M1
either reference to point masses *or* separation >> 'size' of masses A1 [3]

(ii) field strength $= GM / x^2$ **or** field strength $\propto 1 / x^2$ C1
ratio $= (7.78 \times 10^8)^2 / (1.5 \times 10^8)^2$ C1
$= 27$ A1 [3]

(c) (i) *either* centripetal force $= mR\omega^2$ and $\omega = 2\pi / T$
or centripetal force $= mv^2 / R$ and $v = 2\pi R / T$ B1
gravitational force provides the centripetal force B1
either $GMm / R^2 = mR\omega^2$ *or* $GMm / R^2 = mv^2 / R$ M1
$M = 4\pi^2 R^3 / GT^2$ A0 [3]
(allow working to be given in terms of acceleration)

(ii) $M = \{4\pi^2 \times (1.5 \times 10^{11})^3\} / \{6.67 \times 10^{-11} \times (3.16 \times 10^7)^2\}$ C1
$= 2.0 \times 10^{30}\,\text{kg}$ A1 [2]

Q13.

1 (a) equatorial orbit / above equator B1
satellite moves from west to east / same direction as Earth spins B1
period is 24 hours / same period as spinning of Earth B1 [3]
(allow 1 mark for 'appears to be stationary/overhead' if none of above marks scored)

(b) gravitational force provides/is the centripetal force B1
$GMm/R^2 = mR\omega^2$ or $GMm/R^2 = mv^2/R$ M1
$\omega = 2\pi / T$ or $v = 2\pi R / T$ or clear substitution M1
clear working to give $R^3 = (GMT^2 / 4\pi^2)$ A1 [4]

(c) $R^3 = 6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times (24 \times 3600)^2 / 4\pi^2$ C1
$= 7.57 \times 10^{22}$ C1
$R = 4.2 \times 10^7$ m A1 [3]
(missing out 3600 gives 1.8×10^5 m and scores 2/3 marks)

Q14.

4 (a) (i) $\frac{1}{2}mv^2 = GMm / R$ B1
$v^2 = 2GM / R$ A0
(ii) $g = GM/R^2$ M1
clear algebra giving $v^2 = 2gR$ ..... A1 [3]

(b) $\frac{1}{2}mv^2 = 3/2kT$
$v^2 = 3kT / m$ C1
$3kT / m = 2gR$ C1
$T = (2 \times 6.6 \times 10^{-27} \times 9.81 \times 6.4 \times 10^6) / (1.38 \times 10^{-23} \times 3)$ C1
$T = 2.0 \times 10^4$ K ..... A1 [4]

Q15.

1 (a) (i) radial lines B1
pointing inwards B1

(ii) no difference OR lines closer near surface of smaller sphere ..... B1 [3]

(b) (i) $F_G = GMm/R^2$ C1
$= (6.67 \times 10^{-11} \times 5.98 \times 10^{24})/(6380 \times 10^3)^2$
$= 9.80$ N A1

(ii) $F_C = mR\omega^2$ C1
$\omega = 2\pi/T$ C1
$F_C = (4\pi^2 \times 6380 \times 10^3)/8.64 \times 10^4)^2$
$= 0.0337$ N A1

(iii) $F_G - F_C = 9.77$ N ..... A1 [6]

(c) because acceleration (of free fall) is (resultant) force per unit mass B1
acceleration = 9.77 m s^{-2} ..... B1 [2]

Q16.

1	(a)	$GM / R^2 = R\omega^2$	C1	
		$\omega = 2\pi / (24 \times 3600)$	C1	
		$6.67 \times 10^{-11} \times 6.0 \times 10^{24} = R^3 \times \omega^2$		
		$R^3 = 7.57 \times 10^{22}$	M1	
		$R = 4.23 \times 10^7$ m	A0	**[3]**
	(b)(i)	$\Delta\Phi = GM/R_e - GM/R_o$	C1	
		$= (6.67 \times 10^{-11} \times 6.0 \times 10^{24}) (1 / 6.4 \times 10^6 - 1 / 4.2 \times 10^7)$		
		$= 5.31 \times 10^7$ J kg^{-1}	C1	
		$\Delta E_P = 5.31 \times 10^7 \times 650$	C1	
		$= 3.45 \times 10^{10}$ J	A1	**[4]**
	(c)	e.g. satellite will already have some speed in the correct direction ...	B1	**[1]**

Q17.

1	(a)	*either* ratio of work done to mass/charge *or* work done moving unit mass/charge from infinity *or* both have zero potential at infinity	B1	[1]
	(b)	gravitational forces are (always attractive)	B1	
		electric forces can be attractive or repulsive	B1	
		for gravitational, work got out as masses come together /mass moves from infinity	B1	
		for electric, work done on charges if same sign, work got out if opposite sign as charges come together	B1	[4]

Q18.

4	(a)	(i) $GMm \{(R + h_1)^{-1} - (R + h_2)^{-1}\}$	B1	
		$\frac{1}{2}m \{v_1^2 - v_2^2\}$	B1	[2]
	(b)	$2M \times 6.67 \times 10^{-11} \{(26.28 \times 10^6)^{-1} - (29.08 \times 10^6)^{-1}\} = 5370^2 - 5090^2$	B1	
		$M \times 4.888 \times 10^{-19} = 2.929 \times 10^6$	C1	
		$M = 6.00 \times 10^{24}$ kg	A1	[3]
		(If equation in **(a)** *is dimensionally unsound, then 0/3 marks in* **(b)***, if dimensionally sound but incorrect, treat as e.c.f.)*		

Q19.

1 (a) (i) $F = GMm / R^2$ B1 [1]

(ii) $F = mR\omega^2$ B1 [1]

(iii) reaction force = $GMm / R^2 - mR\omega^2$ (*allow e.c.f.*) B1 [1]

(b) (i) *either* value of R in expression $R\omega^2$ varies
or $mR\omega^2$ no longer parallel to GMm / R^2 / normal to surface B1
becomes smaller as object approaches a pole / is zero at pole B1 [2]

(ii) **1.** acceleration = $6.4 \times 10^6 \times (2\pi / \{8.6 \times 10^4\})^2$ C1
$= 0.034$ m s^{-2} A1 [2]
2. acceleration = 0 A1 [1]

(c) e.g. 'radius' of planet <u>varies</u>
density of planet <u>not constant</u>
planet spinning
nearby planets / stars
(*any sensible comments, 1 mark each, maximum 2)* B2 [2]

Q20.

1 (a) $F \propto Mm / R^2$ ……(*words or explained symbols*) M1
either M and m are point masses
or R >> diameter of masses …(*do not allow 'size'*) .....A1 [2]

(b) (i) equatorial orbit B1
period 24 hours / same angular speed B1
from west to east / same direction of rotation .....B1 [3]
(*allow one of the last two marks for 'always overhead' if 2nd or 3rd marks not scored*)

(ii) gravitational force provides centripetal force
/ gives rise to centripetal acceleration ….(*in 'words'*) B1
$GM / x^2 = x\omega^2$ M1
$g = GM / R^2$ M1
to give $gR^2 = x^3\omega^2$ .....A0 [3]

(iii) $\omega = 2\pi / (24 \times 3600) = 7.27 \times 10^{-5}$ rad s^{-1} C1
$9.81 \times (6.4 \times 10^6)^2 = x^3 \times (7.27 \times 10^{-5})^2$ C1
$x^3 = 7.6 \times 10^{22}$
$x = 4.2 \times 10^7$ m .....A1 [3]
(*use of g = 10 m s^{-2}, loses 1 mark but once only in the Paper*)

[Total: 11]

Q21.

1 (a) (i) force per (unit) mass ……(*ratio idea essential*) ..... B1 [1]

(ii) $g = GM / R^2$ C1
$9.81 = (6.67 \times 10^{-11} \times M) / (6.38 \times 10^6)^2$ ……(*all 3 s.f*) M1
$M = 5.99 \times 10^{24}$ kg ..... A0 [2]

(b) (i) *either* $GM = \omega^2 r^3$ *or* $gR^2 = \omega^2 r^3$ C1
either $6.67 \times 10^{-11} \times 5.99 \times 10^{24} = \omega^2 \times (2.86 \times 10^7)^3$
or $9.81 \times (6.38 \times 10^6)^2 = \omega^2 \times (2.86 \times 10^7)^3$ C1
$\omega = 1.3 \times 10^{-4}$ rad s^{-1} ..... A1 [3]
(*use of* $r = 2.22 \times 10^7$ *m scores max 2 marks*)

(ii) period of orbit = $2\pi / \omega$ C1
$= 4.8 \times 10^4$ s (= 13.4 hours) A1
period for geostationary satellite is 24 hours (= 8.6×10^4 s) A1
so no ..... A0 [3]

(c) satellite can then provide cover at Poles ..... B1 [1]

[Total: 10]

Q22.

1 (a) force per unit mass (*ratio idea essential*) B1 [1]

(b) graph: correct curvature M1
from (R,1.0 g_S) & at least one other correct point A1 [2]

(c) (i) fields of Earth and Moon are in opposite directions M1
either resultant field found by subtraction of the field strength
or any other sensible comment A1
so there is a point where it is zero A0 [2]
(*allow* $F_E = -F_M$ *for 2 marks*)

(ii) $GM_E / x^2 = GM_M / (D - x)^2$ C1
$(6.0 \times 10^{24}) / (7.4 \times 10^{22}) = x^2 / (60R_E - x)^2$ C1
$x = 54 R_E$ A1 [3]

(iii) graph: $g = 0$ at least ⅔ distance to Moon B1
g_E and g_M in opposite directions M1
correct curvature (by eye) and $g_E > g_M$ at surface A1 [3]

Q23.

1	(a)	(i)	rate of change of angle / angular displacement swept out by radius	M1 A1	[2]
		(ii)	$\omega \times T = 2\pi$	B1	[1]
	(b)		centripetal force is provided by the gravitational force *either* $mr(2\pi/T)^2 = GMm/r^2$ *or* $mr\omega^2 = GMm/r^2$ $r^3 \times 4\pi^2 = GM \times T^2$ $GM/4\pi^2$ is a constant (c) $T^2 = cr^3$	B1 M1 A1 A1 A0	[4]
	(c)	(i)	*either* $T^2 = (45/1.08)^3 \times 0.615^2$ *or* $T^2 = 0.30 \times 45^3$ $T = 165$ years	C1 A1	[2]
		(ii)	speed $= (2\pi \times 1.08 \times 10^8) / (0.615 \times 365 \times 24 \times 3600)$ $= 35$ km s^{-1}	C1 A1	[2]

Q24.

1	(a)		gravitational force provides the centripetal force $GMm/r^2 = mr\omega^2$ (*must be in terms of* ω) $r^3\omega^2 = GM$ and GM is a constant	B1 B1 B1	[3]
	(b)	(i)	**1.** for Phobos, $\omega = 2\pi/(7.65 \times 3600)$ $= 2.28 \times 10^{-4}$ rad s^{-1} $(9.39 \times 10^6)^3 \times (2.28 \times 10^{-4})^2 = 6.67 \times 10^{-11} \times M$ $M = 6.46 \times 10^{23}$ kg	C1 C1 A1	[3]
			2. $(9.39 \times 10^6)^3 \times (2.28 \times 10^{-4})^2 = (1.99 \times 10^7)^3 \times \omega^2$ $\omega = 7.30 \times 10^{-5}$ rad s^{-1} $T = 2\pi/\omega = 2\pi/(7.30 \times 10^{-5})$ $= 8.6 \times 10^4$ s $= 23.6$ hours	C1 C1 A1	[3]
		(ii)	*either* almost 'geostationary' *or* satellite would take a long time to cross the sky	B1	[1]

Q25.

1 (a) (i) weight = GMm/r^2 C1
= $(6.67 \times 10^{-11} \times 6.42 \times 10^{23} \times 1.40)/(½ \times 6.79 \times 10^6)^2$ C1
= 5.20 N A1 [3]

(ii) potential energy = $-GMm/r$ C1
= $-(6.67 \times 10^{-11} \times 6.42 \times 10^{23} \times 1.40)/(½ \times 6.79 \times 10^6)$ M1
= -1.77×10^7 J A0 [2]

(b) *either* $½mv^2 = 1.77 \times 10^7$ C1
$v^2 = (1.77 \times 10^7 \times 2)/1.40$ C1
$v = 5.03 \times 10^3$ m s^{-1} A1
or $½mv^2 = GMm/r$ (C1)
$v^2 = (2 \times 6.67 \times 10^{-11} \times 6.42 \times 10^{23})/(6.79 \times 10^6/2)$ (C1)
$v = 5.02 \times 10^3$ m s^{-1} (A1) [3]

Q26.

1 (a) force is proportional to the product of the masses and
inversely proportional to the square of the separation M1
either point masses *or* separation >> size of masses A1 [2]

(b) (i) gravitational force provides the centripetal force B1
$mv^2/r = GMm/r^2$ and $E_K = ½mv^2$ M1
hence $E_K = GMm/2r$ A0 [2]

(ii) 1. $\Delta E_K = ½ \times 4.00 \times 10^{14} \times 620 \times (\{7.30 \times 10^6\}^{-1} - \{7.34 \times 10^6\}^{-1})$ C1
$= 9.26 \times 10^7$ J (*ignore any sign in answer*) A1 [2]
(*allow* 1.0×10^8 J *if evidence that* E_K *evaluated separately for each r*)

2. $\Delta E_P = 4.00 \times 10^{14} \times 620 \times (\{7.30 \times 10^6\}^{-1} - \{7.34 \times 10^6\}^{-1})$ C1
$= 1.85 \times 10^8$ J (*ignore any sign in answer*) A1 [2]
(*allow* 1.8 or 1.9×10^8 J)

(iii) *either* $(7.30 \times 10^6)^{-1} - (7.34 \times 10^6)^{-1}$ *or* ΔE_K is positive / E_K increased M1
speed has increased A1 [2]

Q27.

1 (a) work done in moving unit mass M1
from infinity (to the point) A1 [2]

(b) (i) gravitational potential energy = GMm / x
energy = $(6.67 \times 10^{-11} \times 7.35 \times 10^{22} \times 4.5) / (1.74 \times 10^6)$ M1
energy = 1.27×10^7 J A0 [1]

(ii) change in grav. potential energy = change in kinetic energy B1
$½ \times 4.5 \times v^2 = 1.27 \times 10^7$
$v = 2.4 \times 10^3$ m s^{-1} A1 [2]

(c) Earth would attract the rock / potential at Earth('s surface) not zero / <0
/ at Earth, potential due to Moon not zero M1
escape speed would be lower A1 [2]

Q28.

1 (a) force proportional to product of the two masses and inversely proportional to the square of their separation — M1
either reference to point masses *or* separation >> 'size' of masses — A1 [2]

(b) gravitational force provides the centripetal force — B1
$GMm/R^2 = mR\omega^2$ — M1
where *m is* the mass of the planet — A1
$GM = R^3\omega^2$ — A0 [3]

(c) $\omega = 2\pi / T$ — C1
either $M_{star} / M_{Sun} = (R_{star} / R_{Sun})^3 \times (T_{Sun} / T_{star})^2$
$M_{star} = 4^3 \times (½)^2 \times 2.0 \times 10^{30}$ — C1
$= 3.2 \times 10^{31}$ kg — A1 [3]
or $M_{star} = (2\pi)^2 R_{star}^3 / GT^2$ — (C1)
$= \{(2\pi)^2 \times (6.0 \times 10^{11})^3\} / \{6.67 \times 10^{-11} \times (2 \times 365 \times 24 \times 3600)^2\}$ — (C1)
$= 3.2 \times 10^{31}$ kg — (A1)

Q29.

1 (a) work done bringing unit mass from infinity (to the point) — M1 A1 [2]

(b) $E_P = -m\phi$ — B1 [1]

(c) $\phi \propto 1/x$ — C1

either at 6*R* from centre, potential is $(6.3 \times 10^7)/6$ $(= 1.05 \times 10^7$ J kg$^{-1})$
and at 5*R* from centre, potential is $(6.3 \times 10^7)/5$ $(= 1.26 \times 10^7$ J kg$^{-1})$ — C1
change in energy $= (1.26 - 1.05) \times 10^7 \times 1.3$ — C1
$= 2.7 \times 10^6$ J — A1

or change in potential $= (1/5 - 1/6) \times (6.3 \times 10^7)$ — (C1)
change in energy $= (1/5 - 1/6) \times (6.3 \times 10^7) \times 1.3$ — (C1)
$= 2.7 \times 10^6$ J — (A1) [4]

Q30.

1 (a) gravitational force provides/is the centripetal force — B1
$GMm/r^2 = mv^2/r$ — M1
$v = \sqrt{(GM/r)}$ — A0 [2]

allow gravitational field strength provides/is the centripetal acceleration — (B1)
$GM/r^2 = v^2/r$ — (M1)

(b) (i) kinetic energy increase/change = loss/change in (gravitational) potential energy — B1
$\frac{1}{2}mV_0^2 = GMm/x$ — C1
$V_0^2 = 2GM/x$
$V_0 = \sqrt{(2GM/x)}$ — A1 [3]

(max. 2 for use of r not x)

(ii) V_0 is (always) greater than v (for $x = r$) — M1
so stone could not enter into orbit — A1 [2]

(*expressions in* ***(a)*** *and* ***(b)(i)*** *must be dimensionally correct)*

Q31.

1 (a) $g = GM/R^2$ — C1
$= (6.67 \times 10^{-11} \times 6.4 \times 10^{23})/(3.4 \times 10^6)^2 = 3.7\,\text{N kg}^{-1}$ — A1 [2]

(b) $\Delta E_P = mg\Delta h$
because $\Delta h \ll R$ (or $1800\,\text{m} \ll 3.4 \times 10^6\,\text{m}$) g is constant — B1
$\Delta E_P = 2.4 \times 3.7 \times 1800$ — C1
$= 1.6 \times 10^4\,\text{J}$ — A1 [3]
(*use of* $g = 9.8\,\text{m s}^{-2}$ *max. 1 for explanation*)

(c) gravitational potential energy = $(-)GMm/x$ — C1
$v^2 = 2GM/x$ — C1
$x = 4D = 4 \times 6.8 \times 10^6$ — C1

$v^2 = (2 \times 6.67 \times 10^{-11} \times 6.4 \times 10^{23})/(4 \times 6.8 \times 10^6)$
$= 3.14 \times 10^6$
$v = 1.8 \times 10^3\,\text{m s}^{-1}$ — A1 [4]
(*use of* $3.5D$ *giving* $1.9 \times 10^3\,\text{m s}^{-1}$, *allow max. 3*)

Q32.

2 (a) smooth curve with decreasing gradient, not starting at $x = 0$ — M1
end of line not at $g = 0$ or horizontal — A1 [2]

(b) straight line with positive gradient — M1
line starts at origin — A1 [2]

(c) sinusoidal shape — B1
only positive values and peak/trough height constant — B1
4 'loops' — B1 [3]