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) $½mv^2 = m\Delta\varphi$ 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) $M_2 = \{(R_1 + R_2)^2 \times R_1 \times \omega^2\} / G$ (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	
			$= 2\pi/(3.2 \times 10^7)$		
			$= 1.96 \times 10^{-7}$ rad s^{-1}	A1	[2]
		(ii)	force = $mr\omega^2$ <u>or</u> force = mv^2/r and $v = r\omega$	C1	
			$= 6.0 \times 10^{24} \times 1.5 \times 10^{11} \times (1.96 \times 10^{-7})^2$		
			$= 3.46 \times 10^{22}$ N	A1	[2]
	(b)	(i)	gravitation/gravity/gravitational field (strength)	B1	[1]
		(ii)	$F = GMm/x^2$ <u>or</u> $GM = r^3\omega^2$	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 (= $\frac{1}{2}mv^2$) = $GMm / 2r$	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 <u>mass</u> 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)	$E_K = \frac{1}{2}m\,(7600^2 - 7320^2)$	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 <u>atmosphere/air</u>		
			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 $5.95 \rightarrow 6.14$)	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 $6.3 \rightarrow 6.6$)	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 <u>force</u> 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
$v = 5.0 \times 10^3\,\mathrm{m\,s^{-1}}$ A1 [3]
(Use of diameter instead of radius to give $v = 3.6 \times 10^3\,\mathrm{m\,s^{-1}}$ scores 2 marks)

Q11.

1	(a)	force proportional to product of masses and inversely <u>proportional to</u> 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 × 24 × 3600) or 2π / (2.36 x 10^6)	M1	
		= 2.66 × 10^{-6} rad s^{-1}	A0	[1]
	(ii)	$GM = r^3\omega^2$ or $GM = v^2r$	C1	
		M = (3.84 × 10^5 × 10^3)^3 × (2.66 × 10^{-6})^2 / (6.67 × 10^{-11})	M1	
		= 6.0 × 10^{24} kg	A0	[2]
		(special case: uses $g = GM/r^2$ with g = 9.81, r = 6.4 × 10^6 scores max 1 mark)		
	(c) (i)	grav. force = (6.0 × 10^{24}) × (7.4 × 10^{22}) × (6.67 × 10^{-11})/(3.84 × 10^8)^2	C1	
		= 2.0 × 10^{20} N (*allow 1 SF*)	A1	[2]
	(ii)	*either* $\Delta E_P = Fx$ because F constant as x ! radius of orbit	B1	
		ΔE_P = 2.0 × 10^{20} × 4.0 × 10^{-2}	C1	
		= 8.0 × 10^{18} J (*allow 1 SF*)	A1	[3]
		or $\Delta E_P = GMm/r_1 - GMm/r_2$	C1	
		Correct substitution	B1	
		8.0 × 10^{18} 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 × 10^8)^2 / (1.5 × 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	
		$M = 4\pi^2R^3 / GT^2$	A0	[3]
		(allow working to be given in terms of acceleration)		
	(ii)	M = {$4\pi^2$ × (1.5 × 10^{11})^3} / {6.67 × 10^{-11} × (3.16 × 10^7)^2}	C1	
		= 2.0 × 10^{30} 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	
			$½m\ \{v_1^2 - v_2^2\}$	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 becomes smaller as object approaches a pole / is zero at pole	 B1 B1	 [2]
	(ii)	1. acceleration = $6.4 \times 10^6 \times (2\pi / \{8.6 \times 10^4\})^2$ = 0.034 m s^{-2} 2. acceleration = 0	C1 A1 A1	 [2] [1]
	(c)	e.g. 'radius' of planet varies density of planet not constant 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	M1	
			swept out by radius	A1	[2]
		(ii)	$\omega \times T = 2\pi$	B1	[1]
	(b)		centripetal force is provided by the gravitational force	B1	
			either $mr(2\pi/T)^2 = GMm/r^2$ *or* $mr\omega^2 = GMm/r^2$	M1	
			$r^3 \times 4\pi^2 = GM \times T^2$	A1	
			$GM/4\pi^2$ is a constant (c)	A1	
			$T^2 = cr^3$	A0	[4]
	(c)	(i)	*either* $T^2 = (45/1.08)^3 \times 0.615^2$ *or* $T^2 = 0.30 \times 45^3$	C1	
			T = 165 years	A1	[2]
		(ii)	speed = $(2\pi \times 1.08 \times 10^8) / (0.615 \times 365 \times 24 \times 3600)$	C1	
			= 35 km s^{-1}	A1	[2]

Q24.

1	(a)			gravitational force provides the centripetal force	B1	
				$GMm/r^2 = mr\omega^2$ (*must be in terms of* ω)	B1	
				$r^3\omega^2 = GM$ <u>and</u> GM is a constant	B1	[3]
	(b)	(i)	1.	for Phobos, $\omega = 2\pi/(7.65 \times 3600)$	C1	
				$= 2.28 \times 10^{-4}$ rad s^{-1}		
				$(9.39 \times 10^6)^3 \times (2.28 \times 10^{-4})^2 = 6.67 \times 10^{-11} \times M$	C1	
				$M = 6.46 \times 10^{23}$ kg	A1	[3]
			2.	$(9.39 \times 10^6)^3 \times (2.28 \times 10^{-4})^2 = (1.99 \times 10^7)^3 \times \omega^2$	C1	
				$\omega = 7.30 \times 10^{-5}$ rad s^{-1}	C1	
				$T = 2\pi/\omega = 2\pi/(7.30 \times 10^{-5})$		
				$= 8.6 \times 10^4$ s		
				= 23.6 hours	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	
$= -1.77 \times 10^7$ 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 $= 1.27 \times 10^7$ J	A0	[1]
(ii) <u>change in</u> grav. potential energy = <u>change in</u> 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	M1	
from infinity (to the point)	A1	[2]
(b) $E_P = -m\phi$	B1	[1]
(c) $\phi \propto 1/x$	C1	
either at 6*R* from centre, potential is $(6.3 \times 10^7)/6$ (= 1.05×10^7 J kg^{-1})		
<u>and</u> at 5*R* from centre, potential is $(6.3 \times 10^7)/5$ (= 1.26×10^7 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		
		$½mV_0^2 = GMm / x$	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) <u>greater than v</u> (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 <u>energy</u> = $(-)GMm / x$	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]