Gravitational Fields

Q1.

In 1990, the Hubble Space Telescope (HST) was launched into a low Earth orbit above the Earth's atmosphere.

HST orbits the Earth in a circular orbit with a speed of 7.59 km s^{-1}.

mass of Earth = 5.97×10^{24} kg
radius of Earth = 6.37×10^{6} m

(i) Show that the height of HST above the surface of the Earth is about 6×10^{5} m.

(3)

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(ii) Calculate the increase in the gravitational potential energy as HST is raised, from its initial position at the Earth's surface, to its orbital height.

mass of HST = 11 600 kg

(2)

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Increase in gravitational potential energy = ...

(iii) A student suggests that giving HST more energy than that required in (ii) would result in the satellite orbiting at a greater height and with a greater speed.

Assess the validity of the student's suggestion.

(4)

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(Total for question = 9 marks)

Q2.

The acceleration of free fall at the surface of the Earth is 9.81 m s^{-2}.
The mass of the Earth is *M* and the diameter of the Earth is *D*.

Which of the following gives the acceleration of free fall, in m s^{-2}, at the surface of a planet with diameter $\frac{D}{2}$ and mass $\frac{M}{9}$?

☐ **A** $\frac{9.81 \times 2}{9}$

☐ **B** $\frac{9.81 \times 4}{9}$

☐ **C** $\frac{9.81 \times 2}{3}$

☐ **D** $\frac{9.81 \times 9}{4}$

(Total for question = 1 mark)

Q3.

Astronomers observing stars at the centre of our galaxy have suggested that many of them are orbiting a supermassive black hole. The mass of this black hole is 9.2×10^{36} kg.

Calculate the orbital period for a star in a circular orbit at a distance of 1.9×10^{14} m from a black hole of this mass.

(3)

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Orbital period = ...

(Total for question = 3 marks)

Q4.

Electric and gravitational fields have a number of similarities and differences.

An electric field is produced by a point charge and a gravitational field is produced by a point mass.

Which of the following statements applies to both of these fields?

☐ **A** The field causes a force on all particles.

☐ **B** The force caused by the field can be attractive or repulsive.

☐ **C** At a distance x from the centre of the field, field strength is proportional to x^2.

☐ **D** At a distance x from the centre of the field, potential is proportional to $1/x$.

(Total for question = 1 mark)

Q5.

Which of the following statements about the fields is **not** correct?

☐ **A** Field strength is a vector.

☐ **B** Potential is always less than 0.

☐ **C** Potential is proportional to $\dfrac{1}{\text{distance from proton}}$

☐ **D** Field strength is proportional to $\dfrac{1}{(\text{distance from proton})^2}$

(Total for question = 1 mark)

Q6.

In 2015 the Messenger spacecraft crashed into the surface of the planet Mercury after four years in orbit observing the surface of Mercury.

Messenger's orbit was highly elliptical, varying between 200 km and 15 000 km above the surface of Mercury. Messenger completed one full orbit every 12 hours.

mass of Messenger spacecraft = 565 kg
mass of planet Mercury = 3.30×10^{23} kg
radius of planet Mercury = 2430 km

It has been suggested that the same orbital period of about 12 hours could have been achieved if Messenger was in a circular orbit 7690 km above the surface of Mercury.

(i) Determine whether this suggestion is correct.

(4)

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(ii) The elliptical orbit chosen had advantages over this circular orbit.

Explain **one** advantage.

(2)

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(Total for question = 6 marks)

Q7.

In 2014 the Rosetta spacecraft reached the comet Churyumov-Gerasimenko.
Rosetta went into orbit around the comet.

The following table gives some data for the comet.

Mass / kg	1.0×10^{13}
Density / kg m^{-3}	470

The comet is irregular in shape but can be modelled as a spherical object.

(a) Show that a sphere with this mass and density has a radius of about 1700 m.

(3)

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(b) Calculate the gravitational field strength at the surface of the comet.

(2)

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Gravitational field strength = ...

(c) A probe was sent from the Rosetta spacecraft to land on the comet.
The probe bounced off the surface of the comet and took 1 hour and 50 minutes to return to the surface again.

Calculate the height above the surface of the comet that the probe would have reached.
Assume that the acceleration of the probe is constant with the magnitude calculated in (b).

(2)

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Height = ...

(d) Explain, using gravitational field theory, how the actual height reached would compare with the value calculated in part (c).

You may assume there are no resistive forces such as air resistance.

(3)

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(Total for question = 10 marks)

Q8.

Which of the following is **not** a similarity between gravitational fields and electric fields?

(1)

☐ **A** For a point charge or point mass, the field follows the inverse square law.

☐ **B** For a point charge or point mass, the field is radial.

☐ **C** Both fields act at a distance.

☐ **D** Both fields act on all particles.

(Total for question = 1 mark)

Q9.

Astronomers observing stars at the centre of our galaxy have suggested that many of them are orbiting a supermassive black hole. The mass of this black hole is 9.2×10^{36} kg.

The star S0-2 is in a highly elliptical orbit around the position of the black hole.

At its point of closest approach, S0-2 is at a distance of 1.8×10^{13} m from the centre of the black hole.

At the most distant point of its orbit, S0-2 is 2.7×10^{14} m from the black hole.

(i) Show that the change in gravitational potential between the closest and most distant points in this orbit is about 3×10^{13} J kg^{-1}.

(2)

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(ii) At its point of closest approach, the star is travelling at a speed of 8.1×10^{6} m s^{-1}.

Calculate the speed of S0-2 at the furthest point in its orbit using the change in gravitational potential.
mass of S0-2 = 2.4×10^{31} kg

(3)

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Speed = ...

(Total for question = 5 marks)

Q10.

In February 2021 the spacecraft Perseverance Rover landed on Mars. When the spacecraft was 11.0 km above the surface of Mars, parachutes opened to slow the descent. The parachutes detached from the spacecraft when it was 2.1 km above the surface of Mars.

Calculate the change in gravitational potential energy of the spacecraft during the parachute section of its descent.

mass of spacecraft = 1030 kg
mass of Mars = 6.39×10^{23} kg
radius of Mars = 3390 km

(3)

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Change in gravitational energy of the spacecraft = ………………………………..

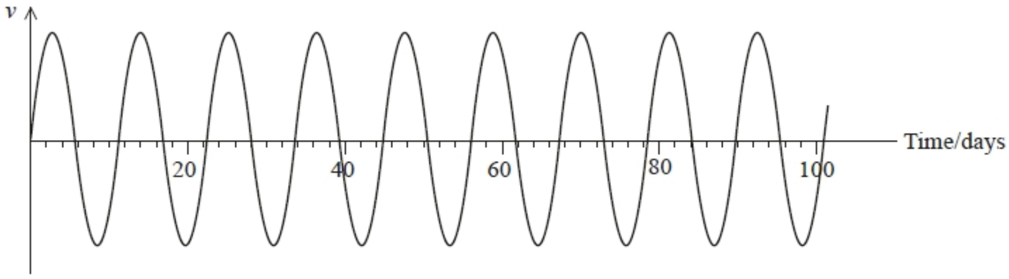
(Total for question = 3 marks)

Q11.

In 2016 astronomers announced the discovery of an Earth-like planet orbiting Proxima Centauri, the closest star to the Sun.

The planet was detected because of the small movement of the star as the planet orbited. The movement was detected using the Doppler shift in the frequency of light travelling to the Earth.

The graph shows how the component of the star's velocity *v* towards the Earth varied over time.



(i) Use the graph to show that the angular velocity of the planet is about 6×10^{-6} radian s^{-1}.

(3)

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(ii) The mass of Proxima Centauri is 0.12 times the mass of the Sun.

Determine the distance of the planet from Proxima Centauri.
mass of Sun = 1.99×10^{30} kg

(3)

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Distance = ...

(Total for question = 6 marks)

Q12.

Astronauts on the 1971 Apollo 14 mission to the Moon brought back many rock samples. It is now believed that one of these contains a piece of rock that originated on Earth about 4 billion years (4×10^9 years) ago.

The piece of rock is believed to have been launched into space when an asteroid struck the Earth.

The gravitational potential between the Earth and the Moon due to the combined effect of their gravitational fields increases to a maximum value of $-1.28\ \text{MJ kg}^{-1}$ at a point between them.

Calculate the minimum speed at which a rock would have to leave the Earth in order to reach the Moon.

In your calculation, you may assume the rock has zero kinetic energy when it has maximum potential energy.

mass of Earth = 5.97×10^{24} kg
radius of Earth = 6370 km

(4)

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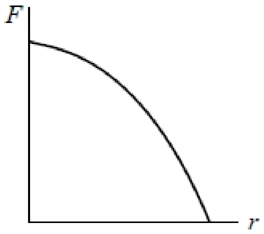
Minimum speed = ...

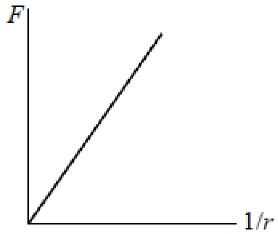
(Total for question = 4 marks)

Q13.

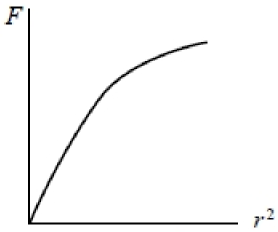
Select the graph that shows correctly the relationship between the gravitational force *F* between two masses and their separation *r*.



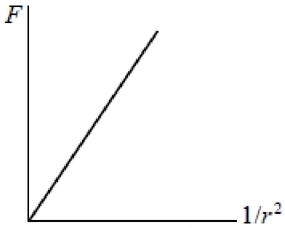
A



B



C



D

☐ **A**

☐ **B**

☐ **C**

☐ **D**

(Total for question = 1 mark)

Q14.

Scientists are developing a space station equipped with large solar panels. The space station would be located in a geostationary orbit. The space station would transfer energy to Earth as microwaves.

(i) A space station in a geostationary orbit is above the equator and has a period of 24 hours.

Explain one advantage of locating the space station in a geostationary orbit.

(2)

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(ii) Calculate the height h of the space station above the equator when it is in a geostationary orbit.

mass of Earth = 6.00×10^{24} kg
24 hours = 8.64×10^{4} s

(4)

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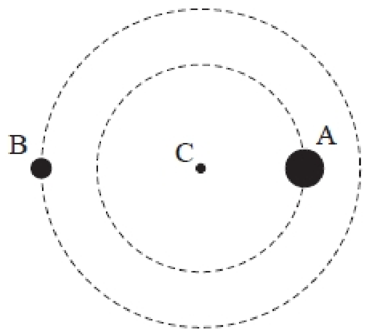
h = ...

(Total for question = 6 marks)

Q15.

The diagram shows two black holes, A and B, orbiting each other.

Assume that the centre of mass C of the system is the centre of a circular orbit for each black hole as shown in the diagram.



Black hole A is in an orbit of radius 2.9×10^{10} m and black hole B is in an orbit of radius 3.6×10^{10} m. Both orbit with the same period, so the total distance between them is

6.5×10^{10} m.

(a) Calculate the force between the black holes.

mass of Sun, $M_\odot = 1.99 \times 10^{30}$ kg
mass of black hole A = $36M_\odot$
mass of black hole B = $29M_\odot$

(2)

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Force = ...

(b) By considering the orbit of one black hole about C, determine the period of the orbit.

(3)

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Period = ...

(Total for question = 5 marks)

Q16.

Astronauts on the 1971 Apollo 14 mission to the Moon brought back many rock samples. It is now believed that one of these contains a piece of rock that originated on Earth about 4 billion years (4×10^9 years) ago.

The piece of rock is believed to have been launched into space when an asteroid struck the Earth.

Four billion years ago, the Moon had a different orbital period, because it was closer to the Earth than it is today.

Calculate the period of the Moon's orbit four billion years ago, when the radius of its orbit was 1.34×10^8 m.

mass of Earth = 5.97×10^{24} kg

(3)

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Period = ...

(Total for question = 3 marks)

Q17.

In 2015 the Messenger spacecraft crashed into the surface of the planet Mercury after four years in orbit observing the surface of Mercury.

Messenger's orbit was highly elliptical, varying between 200 km and 15 000 km above the surface of Mercury. Messenger completed one full orbit every 12 hours.

mass of Messenger spacecraft = 565 kg
mass of planet Mercury = 3.30×10^{23} kg
radius of planet Mercury = 2430 km

Calculate the velocity an object would have as it reached the surface of Mercury if it was released from Messenger's maximum orbital height.
Assume the object is released from rest and that Mercury has no atmosphere.

(4)

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Velocity = ...

(Total for question = 4 marks)

Mark Scheme – Gravitational Fields

Q1.

Question Number	Acceptable Answer		Additional Guidance	Mark
(i)	• Use of $F = \frac{GMm}{r^2}$ with $F = \frac{mv^2}{r}$	(1)	Example of calculation:	
	• Correct substitutions to calculate r	(1)	$\frac{GMm}{r^2} = \frac{mv^2}{r}$	
	• $h = 5.4 \times 10^5$ m	(1)	$r = \frac{GM}{v^2}$	
	OR		$r = \frac{6.67 \times 10^{-11}\,\text{N m}^2\text{kg}^{-2} \times 5.97 \times 10^{24}\,\text{kg}}{(7.59 \times 10^3\,\text{m s}^{-1})^2}$	
	• Use of $g = \frac{GM}{r^2}$ to find value of g at orbit height	(1)	$r = 6.91 \times 10^6$ m	3
	• Use of $a = \frac{v^2}{r}$ with value of g at orbit height	(1)	$\therefore h = (6.91 \times 10^6 - 6.37 \times 10^6)$ m $= 5.42 \times 10^5$ m	
	• $h = 5.4 \times 10^5$ m	(1)		
(ii)	• Use of $GPE = \frac{GMm}{r}$	(1)	Example of calculation:	
	• GPE = 5.7×10^{10} J (ecf from (a)(i))	(1)	$GPE = GMm\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$	2
			$\therefore GPE = 6.67 \times 10^{-11}\,\text{Nm}^2\text{kg}^{-2} \times 5.97 \times 10^{24}\,\text{kg} \times 11600\,\text{kg}\left(\frac{1}{6.37 \times 10^6\,\text{m}} - \frac{1}{6.91 \times 10^6\,\text{m}}\right)$	
			$\therefore GPE = 5.67 \times 10^{10}$ J	

Question Number	Acceptable Answer	Additional Guidance	Mark
(iii)	• This would bring the gravitational potential energy closer to zero (1) • This would mean that the satellite would orbit at a greater height as $GPE \propto \frac{1}{r}$ (1) • To remain in orbit the centripetal acceleration must equal the gravitational field strength at the orbit height **Or** Since gravitational force smaller, $\frac{mv^2}{r}$ would be reduced (1) • (Hence) r is greater so v must be smaller **Or** $v^2 = \frac{GM}{r}$ and satellite would orbit at lower speed (1) **OR** • HST will have more kinetic energy at the original orbit height (1) • The centripetal force will be too small to keep it in this orbit (1) • The satellite would be travelling too fast, so it would move to a higher orbit (1) • (Hence) r is greater so v must be smaller **Or** $v^2 = \frac{GM}{r}$ and satellite would orbit at lower speed (1)		4

Q2.

Question Number	Answer	Mark
	The only correct answer is B because $mg = GMm/r^2$ so acceleration of free fall is proportional to mass / diameter^2 = $g(M/9)/(D/2)^2 = \frac{9.81 \times 4}{9}$	1

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
	Use of $F = mv^2 / r$ with $F = Gm_1 m_2 / r^2$ (1) Use of $v = 2\pi r / T$ (1) $T = 6.64 \times 10^8$ s (= 21 years) (1) **Or** Use of $F = m\omega^2 r$ with $F = Gm_1 m_2 / r^2$ Use of $\omega = 2\pi / T$ $T = 6.64 \times 10^8$ s (= 21 years)	<u>Example of calculation</u> $F = Gm_1 m_2 / r^2 = m_2 v^2 / r = (2\pi r)^2 m_2 / rT^2$ $T^2 = 4\pi^2 r^3 / G m_1$ $= 4\pi^2 \times (1.9 \times 10^{14}\ \text{m})^3 / (6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 9.2 \times 10^{36}\ \text{kg})$ $T = 6.64 \times 10^8$ s (= 21 years)	3

Q4.

Question Number	Acceptable answer	Additional guidance	Mark
	D	The only correct answer is D: potential is proportional to $1/x$ A is not correct because electric fields do not cause a force on uncharged particles B is not correct because the force caused by gravitational field has only ever been shown to be attractive C is not correct because field strength is inversely proportional to x^2	1

Q5.

Question Number	Acceptable answer	Additional guidance	Mark
	B	The only correct answer is B because the electric field is always positive except at infinity, when it is zero A is not the correct choice because the statement is correct C is not the correct choice because the statement is correct D is not the correct choice because the statement is correct	1

Q6.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• use of $F = Gm_1m_2/r^2$ **and** use of $F = mr\omega^2$ **Or** use of $F = Gm_1m_2/r^2$ **and** use of $F = mv^2/r$ • use of $T = 2\pi/\omega$ **Or** use of $T = 2\pi r/v$ • T = 12 hours **Or** F = 120 N by gravitational approach and centripetal force approach **Or** $\omega = 1.45 \times 10^{-4}$ radians s^{-1} by gravitational approach and circular motion approach **Or** height of orbit = 7700 km • Comparative statement consistent with their value(s)	(1) (1) (1) (1)	MP3 and 4 - for force and angular velocity, both approaches required Example of calculation $T^2 = 4\pi^2r^3 / Gm_1$ $T^2 = 4\pi^2 \times (2\,430\,000 \text{ m} + 7\,690\,000 \text{ m})^3 / 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 3.30 \times 10^{23} \text{ kg}$ T = 43115 s = 11.98 hours	4
(ii)	**Max 2** • Allows satellite to get (much) closer to surface • So more detailed photographs/scans possible **OR** • Allows satellite to spend time further from the surface • So prevents exposure to prolonged heat from planet damaging probe **OR** • Satellite varies distance from surface • So it can take wide-angle and close-up pictures of the planet	 (1) (1) (1) (1) (1) (1)	For each, the second marking point is dependent on the first. Award second marking point for other sensible advantages	2

Q7.

Question Number	Acceptable answers		Additional guidance	Mark
(a)	• use of density = mass / volume • use of $V = 4/3\ \pi r^3$ • $r =$ 1720 m	(1) (1) (1)	<u>Example of calculation:</u> $V = 1.0 \times 10^{13}$ kg ÷ 470 kg m^{-3} $= 2.13 \times 10^{10}$ m^3 $= 4/3\ \pi r^3$ $r = {}^3\sqrt{}(2.13 \times 10^{10}$ m$^3 \times 3) \div 4\pi$ = 1720 m	**(3)**

Question Number	Acceptable answers		Additional guidance	Mark
(b)	• use of $g = GM/r^2$ • $g = 2.3 \times 10^{-4}$ N kg^{-1}	(1) (1)	<u>Example of calculation:</u> $g = 6.67 \times 10^{-11}$ N m^2 kg^{-2} × 1.0 × 10^{13} kg / (1720 m)^2 $g = 2.25 \times 10^{-4}$ N kg^{-1}	**(2)**

Question Number	Acceptable answers		Additional guidance	Mark
(c)	• use of $s = ½\ gt^2$ • $s = 1.2 \times 10^3$ m	(1) (1)	<u>Example of calculation:</u> $s = 0.5 \times 2.25 \times 10^{-4}$ m s^{-2} × (3300 s)^2 $= 1.2 \times 10^3$ m	**(2)**

Question Number	Acceptable answers		Additional guidance	Mark
(d)	An explanation that makes reference to the following: • the calculated height is comparable with the radius (of asteroid) • the field should be considered as radial rather than parallel, so the gravitational field strength is decreasing significantly for the probe <u>OR</u> $g = GM/r^2$ the change in r is comparable with the radius, so there will be a significant change in g • acceleration is less, so the actual height would be less	 (1) (1) (1) (1)		**(3)**

Q8.

Question Number	Answer	Mark
	D Both fields act on all particles.	**1**
	Incorrect Answers: A – this is a similarity B – this is a similarity C – this is a similarity	

Q9.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Use of $V = -Gm/r$ (1) • Change in $V = 3.18 \times 10^{13}$ (J kg^{-1}) (1)	Example of calculation $\Delta V = -Gm\,(1/r_2 - 1/r_1)$ $= -6.67 \times 10^{-11}$ N m^2 kg^{-2} $\times 9.2 \times 10^{36}$ kg $\times$ $((1/2.7 \times 10^{14}$ m $- 1/1.8 \times 10^{13}$ m) $= 3.18 \times 10^{13}$ J kg^{-1}	2
(ii)	• Equate change in gravitational potential energy to change in kinetic energy Or use of $E_p = mV$ (1) • Use of $E_k = ½\,mv^2$ (1) • $v = 1.4 \times 10^6$ m s^{-1} (1)	Example of calculation $m \times 3.18 \times 10^{13}$ J kg^{-1} $= (0.5 \times m \times (8.10 \times 10^6$ m s$^{-1})^2) - (0.5 \times m\,v_2^2)$ $v_2 = 1.4 \times 10^6$ m s^{-1}	3

Q10.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $V_{grav} = -\frac{GM}{r}$ (1) • Recognises that $\Delta E_{grav} = m \times \Delta V_{grav}$ (1) • $\Delta E_{grav} = (-)\ 3.4 \times 10^7$ J (1) **OR** • Use of $g_{Mars} = -\frac{GM}{r^2}$ with justification that change in g is minimal • Use of $\Delta E_{grav} = m \times g \times \Delta h$ • $\Delta E_{grav} = (-)\ 3.4 \times 10^7$ J	Example of calculation $\Delta V_{grav} = -\frac{GM}{r_2} + \frac{GM}{r_1}$ $\Delta V_{grav} = GM\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$ $\Delta V_{grav} = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2} \times 6.39 \times 10^{23}\ \text{kg}\left(\frac{1}{(3.39 \times 10^6 + 11.0 \times 10^3)\text{m}} - \frac{1}{(3.39 \times 10^6 + 2.1 \times 10^3)\text{m}}\right)$ $\therefore \Delta V_{grav} = -3.29 \times 10^4\ \text{J kg}^{-1}$ $\therefore \Delta E_{grav} = -3.29 \times 10^4\ \text{J kg}^{-2} \times 1030\ \text{kg} = -3.39 \times 10^7\ \text{J}$	3

Q11.

Question Number	Acceptable answers		Additional guidance	Mark
i	• Use of $\omega = 2\pi/T$ • For at least 2 full cycles • $\omega = 6.5 \times 10^{-6}$ (radian s^{-1})	(1) (1) (1)	For MP3, accept correctly rounded answers in range 6.5×10^{-6} radian s^{-1} to 6.6×10^{-6} radian s^{-1} Example of calculation $\omega = 5 \times 2\pi / (56 \times 24 \times 60 \times 60)$ s $= 6.49 \times 10^{-6}$ radian s^{-1}	3
ii	• Equates $F = Gm_1m_2/r^2$ and $F = m\omega^2 r$ Or $F = Gm_1m_2/r^2$ and $F = mv^2/r$ with $v = 2\pi r/T$ • Correct rearrangement and substitution (e.g. in $r^3 = Gm_1/\omega^2$) • $r = 7.2 \times 10^9$ m (ecf from (b)(i))	(1) (1) (1)	Example of calculation $r^3 = 6.67 \times 10^{-11}$ N m^2 kg^{-2} $\times 0.12 \times 1.99 \times 10^{30}$ kg / $(6.5 \times 10^{-6}$ radian $s^{-1})^2$ $r = 7.2 \times 10^9$ m ($r = 7.6 \times 10^9$ m for 'show that' value)	3

Q12.

Question Number	Acceptable answers		Additional guidance	Mark
	• Use of $V_{grav} = -GM/R$ • Calculate $\Delta V_{grav} = V_{grav\ Moon} - V_{grav\ Earth}$ • Use of $m\,\Delta V_{grav} = E_k = \frac{1}{2} mv^2$ • $v = 11\ 000$ m s^{-1}	(1) (1) (1) (1)	Example of calculation $V_{grav} = -6.67 \times 10^{-11}$ N m^2 kg^{-1} $\times 5.97 \times 10^{24}$ kg / 6 370 000 m $= -62.5$ MJ kg^{-1} $\Delta V_{grav} = -62.5$ MJ kg^{-1} $- -1.28$ MJ kg^{-1} $= -61.2$ MJ kg^{-1} $\frac{1}{2} v^2 = 61.2$ MJ kg^{-1} $v = 11\ 100$ m s^{-1}	4

Q13.

Question Number	Acceptable answers	Additional guidance	Mark
	D		1

Q14.

Question Number	Acceptable Answer		Additional Guidance	Mark
(i)	• Satellite would always be above the same point on the Earth's surface • So that contact/communication with the space station would be maintained at all times	(1) (1)		2
(ii)	Use of $F = \frac{GMm}{r^2}$ with $F = m\omega^2 r$ Use of $\omega = 2\pi/T$ $r = 4.23 \times 10^7$ m $h = 3.6 \times 10^7$ m **OR** Use of $F = \frac{GMm}{r^2}$ with $F = \frac{mv^2}{r}$ Use of $v = 2\pi r/T$ $r = 4.23 \times 10^7$ m $h = 3.6 \times 10^7$ m	(1) (1) (1) (1) (1) (1) (1) (1)	<u>Example of calculation:</u> $m\omega^2 r = \frac{GMm}{r^2}$ $\therefore \left(\frac{2\pi}{T}\right)^2 = \frac{GM}{r^3}$ $\therefore r = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$ $r = \sqrt[3]{\frac{6.67\times10^{11}\text{N m}^2\text{ kg}^2\times6.00\times10^{24}\text{kg}\times(8.64\times10^4\text{s})^2}{4\pi^2}}$ $r = 4.23 \times 10^7$ m $h = r - R_E = 4.23 \times 10^7 - 6.4 \times 10^6$ m $= 3.59 \times 10^7$ m	4

Q15.

Question Number	Acceptable answers		Additional guidance	Mark
(a)	• use of $F = Gm_1m_2/r^2$ • force = 6.5×10^{31} N	(1) (1)	<u>Example of calculation</u> $F = 6.67 \times 10^{-11}$ N m² kg⁻² $\times 29 \times 1.99 \times 10^{30}$ kg $\times 36 \times 1.99 \times 10^{30}$ kg / $(6.5 \times 10^{10}$ m$)^2$ force = 6.5×10^{31} N	2

Question Number	Acceptable answers		Additional guidance	Mark
(b)	**Either** • use of $F = mv^2/r$ ecf from (a) • use of $v = 2\pi r/T$ • $T = 1.1 \times 10^6$ s **Or** • use of $F = m\omega^2 r$ ecf from (a) • use of $\omega = 2\pi/T$ • $T = 1.1 \times 10^6$ s	 (1) (1) (1) (1) (1) (1)	<u>Example of calculation</u> $F = mv^2/r = m(2\pi r/T)^2/r$ $T^2 = 4\pi^2 mr/F$ $= 4\pi^2 \times 29 \times 1.99 \times 10^{30}$ kg $\times 3.6 \times 10^{10}$ m / 6.5×10^{31} N $= 1.21 \times 10^{12}$ s² $T = 1.12 \times 10^6$ s = 18700 min = 312 hours = 13 days	3

Q16.

Question Number	Acceptable answers		Additional guidance	Mark
	• Use of $F = Gm_1m_2/r^2$ and $F = mv^2/r$	(1)	'Use of' can be with any mass m for the orbiting body, or by algebraic combination with no m	
	• Use of $v = 2\pi r/T$	(1)	Example of calculation $F = GMm/r^2 = mv^2/r$ $GM/r^2 = v^2/r$ $v = 2\pi r/T$ $T^2 = 4\pi^2r^3 / GM$ $= 4\pi^2 (1.34 \times 10^8 \text{ m})^3 / 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-1} \times 5.97 \times 10^{24} \text{ kg} = 2.39 \times 10^{11} \text{ s}^2$ $T = 488\,000$ s = 5.7 days	
	• $T = 488\,000$ s = 5.7 days	(1)		
	OR			
	• Use of $F = Gm_1m_2/r^2$ and $F = m\omega^2r$			
	• Use of $\omega = 2\pi/T$			
	• $T = 488\,000$ s = 5.7 days			3

Q17.

Question Number	Acceptable Answers		Additional Guidance	Mark
	• Use of $V_{grav} = - GM/r$ **Or** Use of $E_P = - GMm/r$ with an assumed mass	(1)	Example of calculation $\Delta V = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 3.30 \times 10^{23} \text{ kg } (1/2.43 \times 10^6 \text{ m} - 1/1.743 \times 10^7 \text{ m}) = 7.795 \times 10^6 \text{ J kg}^{-1}$ $\frac{1}{2} mv^2 = 7.795 \times 10^6 \text{ J kg}^{-1} \times m$ Assume 1 kg $v = 3948 \text{ m s}^{-1}$	4
	• Subtraction of potential at surface from potential at orbital height **Or** Subtraction of potential energy at surface from potential energy at orbital height	(1)		
	• Use of difference in potential = $E_K/m = \frac{1}{2} v^2$ **Or** Use of difference in potential energy = $E_K = \frac{1}{2} mv^2$	(1)		
	• $v = 3948 \text{ m s}^{-1}$	(1)		