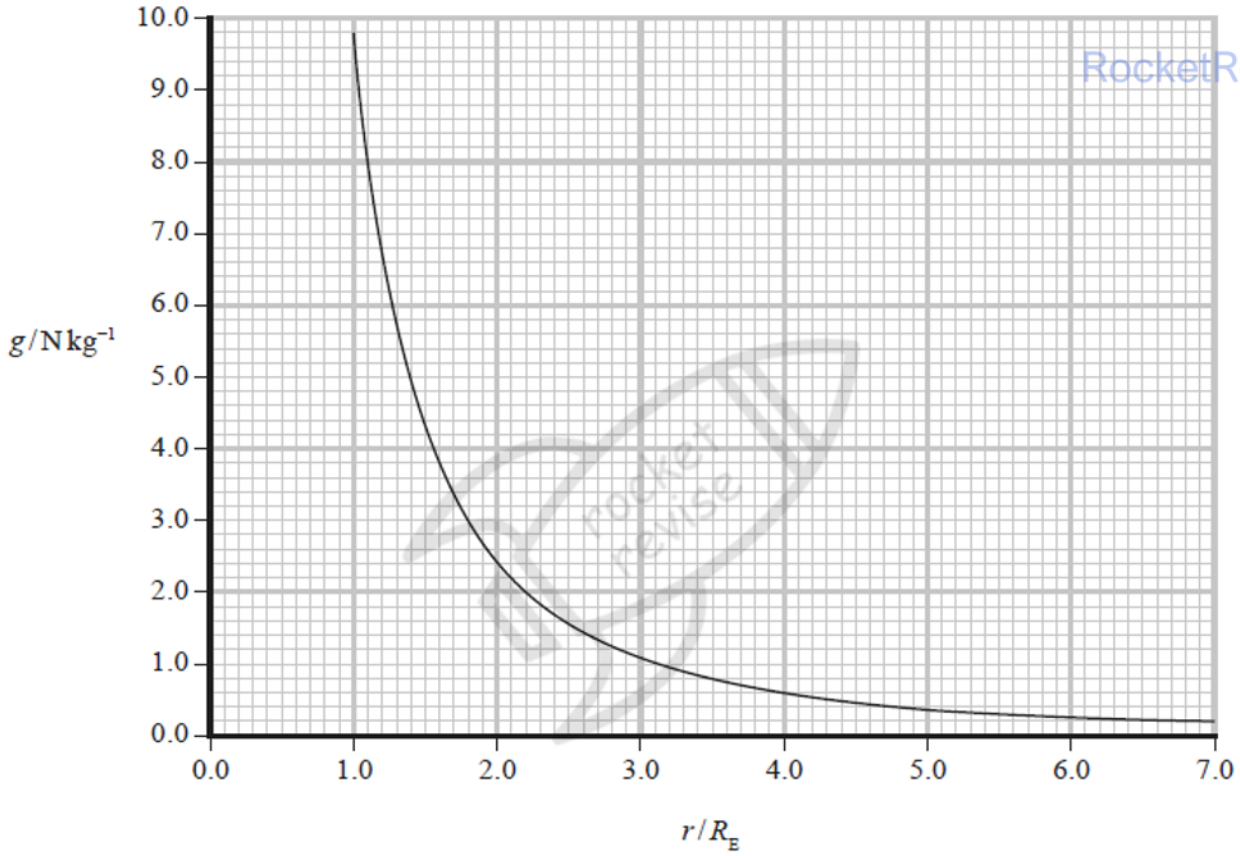
Questions

Q1.

The graph shows how the gravitational field strength g of the Earth varies with distance r from the centre of the Earth.

r is given in multiples of the radius R_E of the Earth.



(a) Show that g obeys an inverse square law.

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(b) A satellite is launched from the surface of the Earth into an orbit a height $5R_E$ above the surface of the Earth.

(i) The change in gravitational potential energy ΔE_{grav} of a mass m when it experiences a vertical displacement Δh can be calculated using the expression

$$\Delta E_{grav} = mg\Delta h$$

State why this expression cannot be used to calculate the change in the gravitational potential energy of the satellite.

(1)

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(ii) Calculate the change in gravitational potential energy of the satellite.

mass of the Earth = 6.0×10^{24} kg
$R_E = 6.4 \times 10^{6}$ m
mass of satellite = 3.5×10^{3} kg

(3)

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Change in gravitational potential energy = ...

(Total for question = 7 marks)

Q2.

Electrostatic forces and gravitational forces can both be modelled by the idea of a field.
Give one similarity and one difference between electric fields and gravitational fields.

Similarity

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Difference

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(Total for question = 2 marks)

Q3.

Salyut 1 was the first Earth-orbiting space station. It was built by the Soviet Union and launched into a low Earth orbit fifty years ago.

(a) Salyut 1 orbited at an average height above the surface of the Earth of 211 km.

mass of Salyut 1 = 18 400 kg

mass of Earth = 5.98×10^{24} kg

radius of Earth = 6.37×10^{6} m

(i) A textbook claims that for astronauts in Salyut 1, there would be a sunrise 16 times every day.

Assess the validity of this claim.

1 day = 8.64×10^{4} s

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(ii) Salyut 1 made almost three thousand orbits before falling back to Earth.

Calculate the change in gravitational potential energy of Salyut 1 as it fell back to Earth.

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Change in gravitational potential energy = ...

(b) Salyut 1 burned up over the Pacific Ocean as it re-entered the Earth's atmosphere.

Explain why Salyut 1 burned up.

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(Total for question = 9 marks)

Q4.

The Earth is 9.3 times more massive than Mars. The gravitational field strength at the surface of

the Earth is 2.6 times greater than at the surface of Mars.

Calculate the mean radius of Mars.

mean radius of Earth = 6.37×10^6 m

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Mean radius of Mars = ...

(Total for question = 2 marks)

Q5.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

A helium nucleus approaches a gold nucleus. An electric force and a gravitational force act on each nucleus.

Which statement about these forces is **not** correct?

☒ **A** The electric force between the nuclei is repulsive.

☒ **B** The electric force is always smaller than the gravitational force.

☒ **C** Both forces increase as the nuclei approach.

☒ **D** The gravitational force between the nuclei is attractive.

(Total for question = 1 mark)

Q6.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The gravitational field strength on the surface of Mercury is g_M.
Callisto, a moon of Jupiter, has the same radius as Mercury but only one third of its density.

What is the gravitational field strength on the surface of Callisto?

☒ **A** $\frac{g_M}{9}$

☒ **B** $\frac{g_M}{3}$

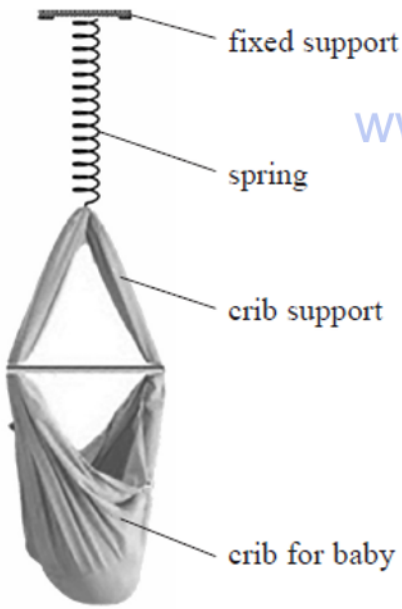
☒ **C** $3g_M$

☒ **D** $9g_M$

(Total for question = 1 mark)

Q7.

A website advertises a baby crib that can be hung from a spring. The crib can be set into vertical oscillation.



The instructions for the crib state that the crib can support a maximum mass of 15.0 kg.

(a) (i) When the crib supports a mass of 15.0 kg the spring extends by 42.5 cm.

Show that the stiffness of the spring is about 350 N m^{-1}.

(2)

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(ii) A baby is placed in the crib and the spring extends to bring the system to equilibrium. The crib is displaced through a small vertical displacement and released.

State why the crib will oscillate with simple harmonic motion.

(2)

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(iii) The baby has a mass of 7.25 kg.

Calculate the period of oscillation of the crib.

mass of crib = 2.55 kg
stiffness of spring = 350 N m^{-1}

(2)

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Period of oscillation of crib = ...

(b) The maximum mass that the spring can support before being damaged is 25.0 kg.

Explain why the instructions state that the maximum mass is only 15.0 kg.

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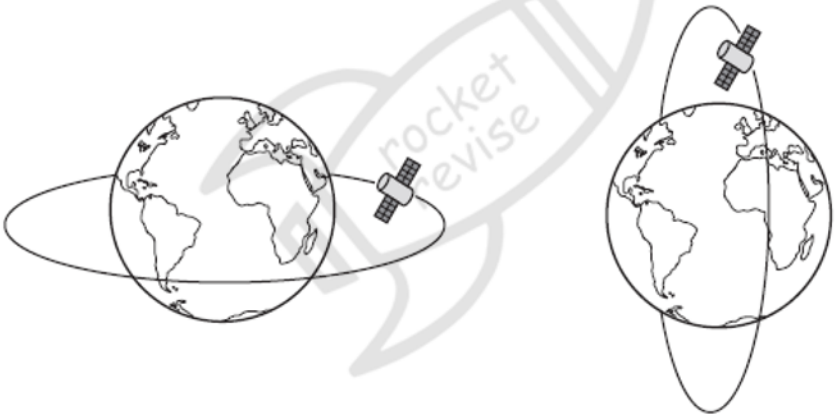
(Total for question = 8 marks)

Q8.

Weather satellites may be in an equatorial orbit or a polar orbit, as shown.



equatorial orbit polar orbit

(a) A weather satellite in a polar orbit circles the Earth at a height of 8.50×10^5 m above the surface of the Earth.

(i) Show that the gravitational potential at this height is about -5.5×10^7 J kg^{-1}.

mass of Earth = 5.98×10^{24} kg
radius of Earth = 6360 km

(2)

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(ii) Hence calculate the increase in gravitational potential energy when the satellite is placed in orbit.

satellite mass = 4990 kg
gravitational potential at the Earth's surface = -6.27×10^7 J kg^{-1}

(2)

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Increase in gravitational potential energy = ...

(b) It is claimed that a satellite in orbit at a height of 8.50×10^5 m would make 15 orbits of the Earth every 24 hours.

Assess the validity of this claim.

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(c) It is suggested that the satellite could be placed in an equatorial orbit at a radius of 42 200 km. With this radius the satellite would have an orbital period equal to 24 hours.

Give one advantage and one disadvantage of placing a weather satellite in a polar orbit rather than in the suggested equatorial orbit.

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(Total for question = 11 marks)

Q9.

A small satellite of mass 245 kg is orbiting the Earth. The radius of the orbit is equal to twice the radius of the Earth.

The weight of the satellite in its orbit is about

☒ **A** zero.

☒ **B** 600 N.

☒ **C** 1200 N.

☒ **D** 2400 N.

(Total for question = 1 mark)

Q10.

In 2015, the company SpaceX stated its plan to launch about 4,000 "Starlink" satellites into a low Earth orbit. These satellites would provide a low-cost internet service to people around the world.

By the start of 2020 almost 200 Starlink satellites had been launched into an orbit 550 km above the Earth's surface.

mass of Earth = 6.0×10^{24} kg
radius of Earth = 6.4×10^{6} m

(a) Calculate the orbital time of a Starlink satellite.

(3)

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Orbital time of satellite = ...

(b) Explain why satellites in low Earth orbits have a smaller orbital time than satellites in higher Earth orbits.

(3)

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(c) The satellites were launched into orbit using rockets able to make multiple space flights.

Calculate the minimum kinetic energy required to raise the satellite to its lower orbit height.

mass of a Starlink satellite = 227 kg.

(3)

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Minimum kinetic energy = ...

(Total for question = 9 marks)

Q11.

In the 17th century, Kepler proposed his 'law of harmonies' for planetary motion. This law suggested that the ratio of the square of the orbital period T to the cube of the mean radius R has the same value for all the planets that orbit the Sun.

Mathematically his 'law of harmonies' can be written

$$T^2 = KR^3$$

where K is a constant.

(a) The table shows data for Earth and Mars.

Planet	T / s	R / m
Earth	3.16×10^7	1.50×10^{11}
Mars	5.93×10^7	2.28×10^{11}

Show that, for Earth and for Mars, K has a value of about $3.0 \times\times 10^{-19}$ s^2 m^{-3}.

(3)

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(b) Kepler's law of harmonies was derived later by Newton. Newton applied his law of gravitation to a planet moving in an approximately circular orbit around the Sun.

Determine a value for K by applying Newton's law of gravitation to a planet of mass m moving in a circular orbit about the Sun.

mass of Sun = 1.99×10^{30} kg

(3)

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K = ... $s^2\ m^{-3}$

(c) Jupiter is the most massive planet in the solar system and has many moons. Kepler's law of harmonies applies to the orbiting moons. However, the value of K for the moons is not the same as the value that applies to planets orbiting the Sun.

Ganymede is Jupiter's largest moon. Ganymede has an orbital radius of 1.07×10^9 m and an orbital period of 172 hours.

Another moon, Io, has an orbital radius of 4.22×10^8 m.

Calculate the orbital period T_I of Io about Jupiter.

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T_I = ...

(Total for question = 8 marks)

Q12.

The planets orbit the Sun in approximately circular orbits. The orbital time T of a planet is related to the average distance r of the planet from the Sun.

(a)(i) Show that T is related to r by the expression:

$T^2 \propto r^3$

(3)

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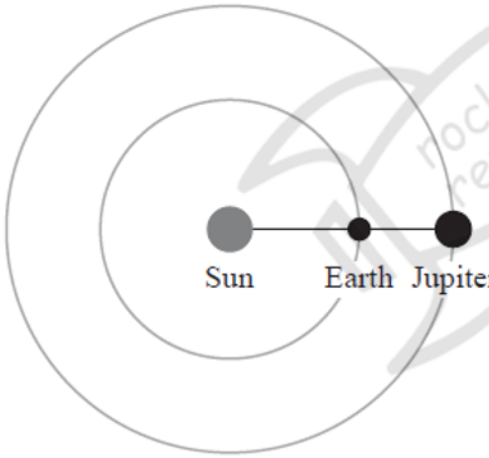
(ii) When planets align as they orbit the Sun they are said to be 'in opposition'.

The diagram shows the Earth and Jupiter in opposition.



NOT TO SCALE

A website states that the Earth and Jupiter are in opposition every 13 months.

Deduce whether this statement is correct.

mean distance from Earth to Sun = 1.5×10^{11} m
mean distance from Jupiter to Sun = 7.8×10^{11} m
T_{Earth} = 12 months

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(b) The distance of Jupiter from the Sun varies from 7.4×10^{11} m to 8.2×10^{11} m.

Calculate the change in gravitational potential energy of Jupiter as it moves from its closest distance to its furthest distance from the Sun.

mass of Sun = 2.0×10^{30} kg
mass of Jupiter = 1.9×10^{27} kg

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Change in gravitational potential energy = ...

(Total for question = 11 marks)

Q13.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

A space shuttle of mass *m* is returning to Earth of mass *M*. The space shuttle falls from a height *R* above the Earth, where *R* is equal to the radius of the Earth.

Which of the following gives the change in gravitational potential energy, ΔE_{grav}, of the space shuttle?

☒ **A** $\Delta E_{grav} = GMm\left(\frac{1}{2R} - \frac{1}{R}\right)$

☒ **B** $\Delta E_{grav} = GMm\left(\frac{1}{R} - \frac{1}{2R}\right)$

☒ **C** $\Delta E_{grav} = \frac{GMm}{R}$

☒ **D** $\Delta E_{grav} = \frac{GMm}{2R}$

(Total for question = 1 mark)

Q14.

The dwarf planet Ceres is the largest object in the asteroid belt.

Ceres has a mass of 9.38×10^{20} kg. Ceres has a circular orbit of radius 4.14×10^{11} m around the Sun.

(a) (i) Show that the gravitational force exerted on Ceres by the Sun is about 7×10^{17} N.

mass of Sun = 1.99×10^{30} kg

(2)

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(ii) Determine the time *T*, in years, for Ceres to make one complete orbit about the Sun.

1 year = 3.15×10^{7} s

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T = ... years

(b) Mercury is the smallest planet in our solar system. The gravitational field strength g_m at the surface of Mercury is 3.7 N kg^{-1}.

It is claimed that the gravitational field strength at the surface of Ceres is less than 5% of g_m.

Evaluate whether this claim is accurate.

radius of Ceres = 470 km

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(Total for question = 9 marks)

Q15.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The gravitational field strength at the surface of the Earth is g.

Another planet has the same density as the Earth, but twice the radius of the Earth.

What is the gravitational field strength at the surface of this planet?

☒ **A** $4g$

☒ **B** $2g$

☒ **C** $\frac{g}{2}$

☒ **D** $\frac{g}{4}$

(Total for question = 1 mark)

Q16.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

A communications satellite has a mass of 935 kg. The satellite has an orbital radius four times the radius of the Earth.

☒ **A** 0 N

☒ **B** 570 N

☒ **C** 2300 N

☒ **D** 9200 N

(Total for question = 1 mark)

Q17.

In the 18th century, Cavendish carried out the first experiment to determine the gravitational constant *G*. The experiment used two lead spheres.

(a) A physicist planned to investigate the gravitational force using lead spheres identical to the ones used in Cavendish's original experiment.

One of the spheres had a diameter of 30.5 cm and a mass of 158 kg.

The second sphere had a diameter of 2.5 cm and a mass of 0.73 kg.

The minimum force that could be measured by the physicist was 50 μN.

Deduce whether the physicist would be able to measure the gravitational force between the two spheres.

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(b) Experiments to determine *G* have usually been carried out using large masses.

In 2021 physicists at the University of Vienna carried out an experiment to determine *G* using gold spheres with masses of less than 100 mg.

They obtained a value for *G* equal to 6.04×10^{-11} m^3 kg^{-1} s^{-2}.

(i) Show that m^3 kg^{-1} s^{-2} is a correct unit for *G*.

(2)

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(ii) The physicists concluded that their value for *G* was within reasonable agreement with the standard value of *G*.

Evaluate the validity of their conclusion.

$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

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(Total for question = 8 marks)

Q18.

The 'escape velocity' is the minimum speed needed for an object to escape from the gravitational field of a planet.

An object travelling at the escape velocity has a kinetic energy equal to the magnitude of its gravitational potential energy at the surface of the planet.

(a) Show that the escape velocity v for a planet of mass M and radius r is given by the expression

$$v = \sqrt{\frac{2GM}{r}}$$

(2)

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(b) (i) Show that the escape velocity for a mass at the Earth's surface is about 1.1×10^4 m s^{-1}.

mass of Earth = 5.98×10^{24} kg
radius of Earth = 6.36×10^6 m

(2)

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(ii) When the Earth formed, a large proportion of the gas in the Earth's atmosphere was hydrogen.

Explain why hydrogen gas is no longer a large proportion of the gas in the Earth's atmosphere. No further calculation is necessary.

at 20 °C, $\sqrt{\langle c^2 \rangle}$ = 1900 m s^{-1} for hydrogen

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(Total for question = 6 marks)

Q19.

In January 2023, the asteroid 2023 BU came close to the Earth. The closest distance of the asteroid from the surface of the Earth was 3590 km.

(a) Calculate the force between the asteroid and the Earth at the closest distance. You may assume the asteroid is a sphere.

asteroid diameter = 5.65 m
asteroid density = 1950 kg m^{-3}
mass of Earth = 5.98 × 10^{24} kg
radius of Earth = 6380 km

(4)

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Force between asteroid and Earth = ...

(b) Calculate the change in gravitational potential energy of the asteroid if it had fallen to the surface of the Earth from a height of 3590 km.

Assume that the mass of the asteroid remains constant.

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Change in gravitational potential energy = ...

(c) Explain why the mass of the asteroid would **not** remain constant as the asteroid fell to the surface of the Earth.

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(Total for question = 9 marks)

Q20.

Makemake is a dwarf planet in the solar system. Makemake has a mass of 3.1×10^{21} kg and a radius of 715 km.

(a) Calculate the gravitational field strength at the surface of Makemake.

(2)

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Gravitational field strength at surface = ...

(b) The average distance of Makemake from the Sun is similar to the average distance of the dwarf planet Pluto from the Sun.

A website states:

"The time taken by Makemake to complete one orbit of the Sun is 20% greater than the time taken by Pluto to complete one orbit of the Sun."

Assess the accuracy of the website statement.

mass of Sun = 1.99×10^{30} kg
orbit radius of Makemake = 6.80×10^{12} m
orbit time of Pluto = 248 years
1 year = 3.15×10^{7} s

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(Total for question = 8 marks)

Q21.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The Moon is gradually moving away from the Earth.

The gravitational potential at the Earth due to the Moon, and the gravitational force between the Earth and the Moon, are both changing.

Which row of the table is correct?

	Gravitational potential	Gravitational force
☒ **A**	decreases	decreases
☒ **B**	increases	decreases
☒ **C**	decreases	increases
☒ **D**	increases	increases

(Total for question = 1 mark)

Q22.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Mars has approximately 8 times the mass of the Moon.

Mars has twice the diameter of the Moon.

The value of g on the surface of the Moon is 1.6 N kg^{-1}.

What is the value of g on the surface of Mars?

☒ **A** 0.8 N kg^{-1}

☒ **B** 1.6 N kg^{-1}

☒ **C** 3.2 N kg^{-1}

☒ **D** 6.4 N kg^{-1}

(Total for question = 1 mark)

Q23.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

A satellite of mass m is on the Earth's surface.

The satellite is moved into a circular orbit of height h above the Earth.

The mass of the Earth is M and the radius of the Earth is R.

Which of the following gives the change in gravitational potential energy of the satellite?

☒ **A** $\frac{GM}{(R+h)} - \frac{GM}{R}$

☒ **B** $\frac{GMm}{R} - \frac{GMm}{(R+h)}$

☒ **C** $\frac{GM}{(R+h)^2} - \frac{GM}{R^2}$

☒ **D** $\frac{GMm}{R^2} - \frac{GMm}{(R+h)^2}$

(Total for question = 1 mark)

Q24.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

A small satellite of mass 122 kg is orbiting the Earth. The satellite is orbiting at a height above the surface of the Earth equal to the radius of the Earth.

Which of the following is the approximate weight of the satellite in its orbit?

☐ **A** zero

☐ **B** 300 N

☐ **C** 600 N

☐ **D** 1200 N

(Total for question = 1 mark)