IB · SL · Physics

3 hours   15 questions

Structured Questions

Gravitational Fields

Newton's Law of Gravitation / Gravitational Field Strength / Gravitational Field Lines / Kepler's Laws of Planetary Motion

Easy (4 questions)	/46
Medium (3 questions)	/29
Hard (8 questions)	/78
Total Marks	**/153**

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Easy Questions

1 (a) State Newton's Law of Gravitation.

(2 marks)

(b) Newton's Law of Gravitation can also be written in equation form:

$$F = G\frac{Mm}{r^2}$$

Match the terms in the equation with the correct definition and unit:

Term
F
G
M and m
r

Definition
Gravitational constant
Mass
Force
Radius

Unit
kg
N
m
$N\ m^2\ kg^{-2}$

(4 marks)

(c) Newton's Law of Gravitation applies to point masses. Although planets are not point masses, the law also applies to planets orbiting the sun.

State why Newton's Law of Gravitation can apply to planets.

....

(1 mark)

(d) The mass of the Earth is 6.0×10^{24} kg. A satellite of mass 5000 kg is orbiting at a height of 8500 km above the centre of the Earth.

Calculate the gravitational force between the Earth and the satellite.

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(4 marks)

2 (a) Complete the definition of Kepler's third law using words or phrases from the selection below:

For planets or satellites in a .... about the same central body, the .... of the time period is .... to the .... of the radius of the orbit.

circular orbit **linear velocity** **square** **cube** **time**

length **mass** **proportional**

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(4 marks)

(b) Kepler's third law can also be represented by the equation:

$$T^2 = \frac{4\pi^2 r^3}{GM}$$

Define each of the terms in the equation above and give the unit:

(i) *T*

[1]

(ii) *G*

[1]

(iii) *M*

[1]

(iv) *r*

[1]

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(4 marks)

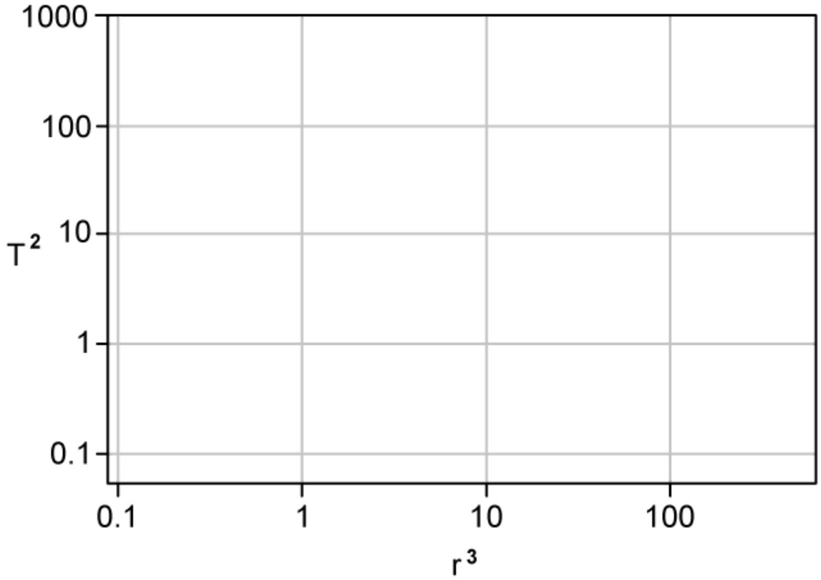
(c) Venus has an orbital period, *T* of 0.61 years and its orbital radius, *r* is 0.72 AU from the Sun.

Using these numbers, show that Kepler's Third Law, $T^2 \propto r^3$ is true for Venus. No unit conversions are necessary.

(3 marks)

(d) Kepler's Third Law $T^2 \propto r^3$ can be represented graphically on log paper.

On the axes below, sketch a graph of $T^2 \propto r^3$ for our solar system, marking on the position of the Earth.



(3 marks)

3 (a) Define the following terms:

(i) Gravitational field

[2]

(ii) Gravitational field strength

[2]

(4 marks)

(b) Gravitational field strength can be written in equation form as:

$$g = \frac{F}{m}$$

Define each of the terms in the equation above and give the unit:

(i) g

[1]

(ii) F

[1]

(iii) m

[1]

(3 marks)

(c) An astronaut of mass 80 kg stands on the Moon which has a gravitational field strength of 1.6 N kg^{-1}.

Calculate the weight of the astronaut on the Moon.

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(3 marks)

(d) The mass of the Earth is 5.972×10^{24} kg and sea level on the surface of the Earth is 6371 km.

Show that the gravitational field strength, *g*, is about 9.86 N kg^{-1} at sea level.

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(3 marks)

4 **(a)** Define the term gravitational field.

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(2 marks)

(b) An equation to describe field strength is:

$$field\ strength = \frac{X}{Y}$$

Define X and Y in terms of a gravitational field.

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(2 marks)

(c) Based on your answer to part (b), define the terms in the following equation:

$$g = \frac{F}{m}$$

....

(1 mark)

(d) The following text is about uniform gravitational fields.

Complete the following sentences by circling the correct words:

A gravitational field is a region of space in which objects with **mass / charge** will experience a force.

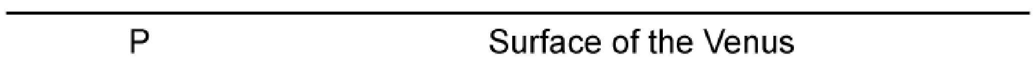
The direction of the gravitational field is always directed **away from / towards** the centre of the mass.

Gravitational forces are always **attractive / repulsive** and cannot be **attractive / repulsive**.

(3 marks)

Medium Questions

1 (a) A small horizontal region on the surface of Venus is shown. P is a point underneath the surface which contains material of higher density than the material surrounding it.



Draw the gravitational field lines on the surface of Venus.

(3 marks)

(b) By considering the gravitational force acting on a mass, *m*, at the surface of Venus, write an equation for the mass, *M*, of Venus in terms of the radius of Venus, *R*, the gravitational field strength, *g*, and the gravitational constant, *G*.

(2 marks)

(c) Calculate the mass of Venus and express its mass as a percentage of the mass of Mercury.

The following information is available:

- Radius of Venus = 6.05×10^6 m
- Radius of Mercurcy = 2.40×10^6 m
- Gravitational field strength at Venus's surface = 8.80 N kg^{-1}
- Gravitational field strength at Mercury's surface = 3.70 N kg^{-1}

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(3 marks)

(d) NASA's spacecraft, Messenger, orbited Mercury for 4 years studying the magnetic field and chemical composition of the planet. Its orbit was highly elliptical, ranging from an altitude of 200 km to over 9000 km above the surface of Mercury.

Calculate the gravitational field strength of Mercury at an altitude of 270 km.

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(3 marks)

2 (a) Explain how the force(s) on an object on the surface of a planet result in the object rotating in circular motion.

(3 marks)

(b) A rock of mass 60 kg is at rest on the surface of Mars. The gravitational force on the rock is 240 N.

Calculate the gravitational field strength of Mars.

(2 marks)

(c) Mars has a mass of 6.4×10^{23} kg.

Determine the radius of Mars to three significant figures.

(3 marks)

(d) Calculate the orbital velocity of Mars to three significant figures.

(3 marks)

3 (a) The distance from the Earth to the Sun is 1.5×10^{11} m. The mass of the Earth is 6×10^{24} kg and the mass of the Sun is 3.3×10^{5} times the mass of the Earth.

Estimate the gravitational force between the Sun and the Earth.

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(2 marks)

(b) Mars is 1.5 times further away from the Sun than the Earth and is 10 times lighter than Earth.

Predict the gravitational force between Mars and the Sun.

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(3 marks)

(c) Determine the acceleration of free fall on a planet 20 times as massive as the Earth and with a radius 10 times larger.

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(2 marks)

Hard Questions

1 (a) The gravitational field strength on the moon's surface is 1.63 N kg^{-1}. It has a diameter of 3480 km.

(i) Calculate the mass of the moon

[2]

(ii) State the assumption necessary for part (i)

[1]

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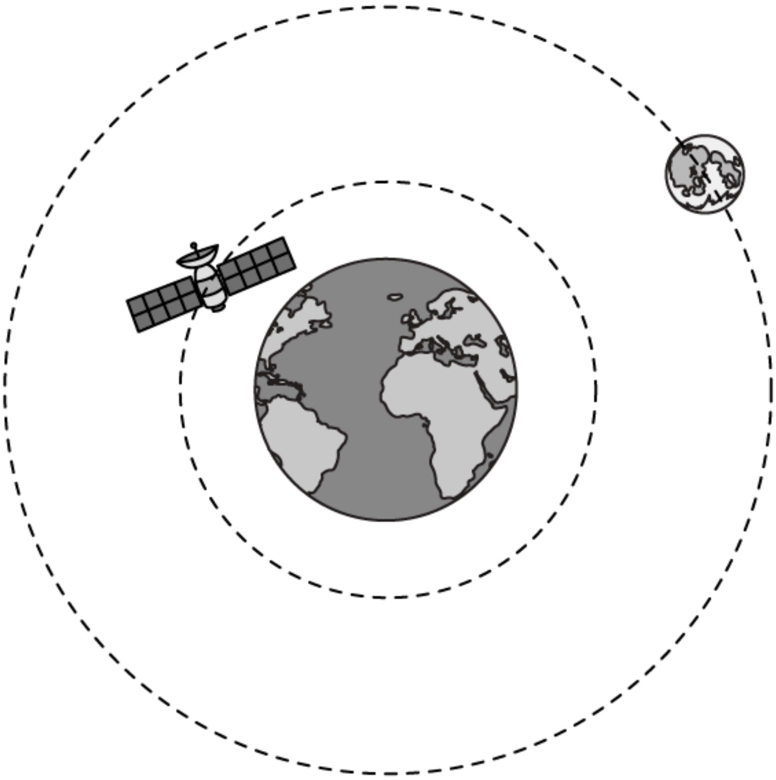
(3 marks)

(b) The ISS orbits the Earth at an average distance of 408 km from the surface of the Earth.



The following data are available:

- Average distance between the centre of the Earth and the centre of the Moon = 3.80 × 10^8 m
- Mass of the Earth = 5.97 × 10^{24} kg
- Radius of the Earth = 6.37 × 10^6 m

Calculate the maximum gravitational field strength experienced by the ISS. You may assume that both the Moon and the ISS can be positioned at any point on their orbital path.

(4 marks)

(c) Show that the gravitational field strength g is proportional to the radius of a planet r and its density ρ.

(3 marks)

(d) Two planets X and Y are being compared by a group of astronomers. They have different masses.

Planet X has a density ρ and the gravitational field strength on its surface is g. The density of planet Y is three times that of planet X and the gravitational field strength on its surface is 9 times that of planet X.

Use the equation you derived in part (c) to show that the mass of planet Y is roughly 80 times larger than the mass of planet X.

(4 marks)

2 (a) The gravitational field strength on the surface of a particular moon is 2.5 N kg^{-1}. The moon orbits a planet of similar density, but the diameter of the planet is 50 times greater than the moon.

Calculate the gravitational field strength at the surface of the planet.

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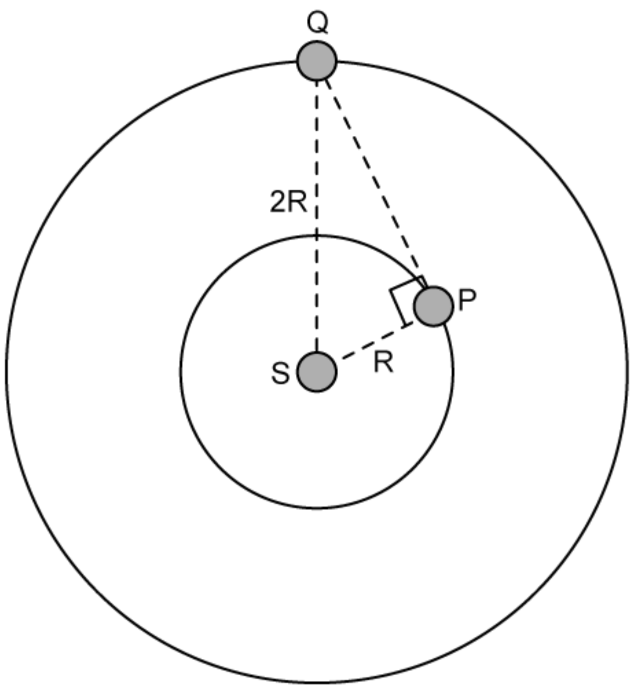
(3 marks)

(b) Two planets P and Q are in concentric circular orbits about a star S.



The radius of P's orbit is *R* and the radius of Q's orbit is 2*R*. The gravitational force between P and Q is *F* when angle SPQ is 90° as shown.

Deduce an equation for the gravitational force between P and Q, in terms of *F*, when they are nearest to each other.

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(3 marks)

(c) Planet P is twice the mass of planet Q.

Sketch the gravitational field lines between the two planets on the image below.

Label the approximate position of the neutral point.

(2 marks)

3 (a) The distance between the Sun and Mercury varies from 4.60×10^{10} m to 6.98×10^{10} m. The gravitational attraction between them is *F* when they are closest together.

Show that the minimum gravitational force between the Sun and Mercury is about 43% of *F.*

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(3 marks)

(b) Mercury has a mass of 3.30×10^{23} kg and a mean diameter of 4880 km. A rock is projected from its surface vertically upwards with a velocity of 6.0 m s^{-1}.

Calculate how long it will take for the rock to return to Mercury's surface.

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(3 marks)

(c) Venus is approximately 5.00×10^{10} m from Mercury and has a mass of 4.87×10^{24} kg. A satellite of mass 1.50×10^{4} kg is momentarily at point P, which is 1.75×10^{10} from Mercury, which itself has a mass of 3.30×10^{23} kg.

Calculate the magnitude of the resultant gravitational force exerted on the satellite when it is momentarily at point P.

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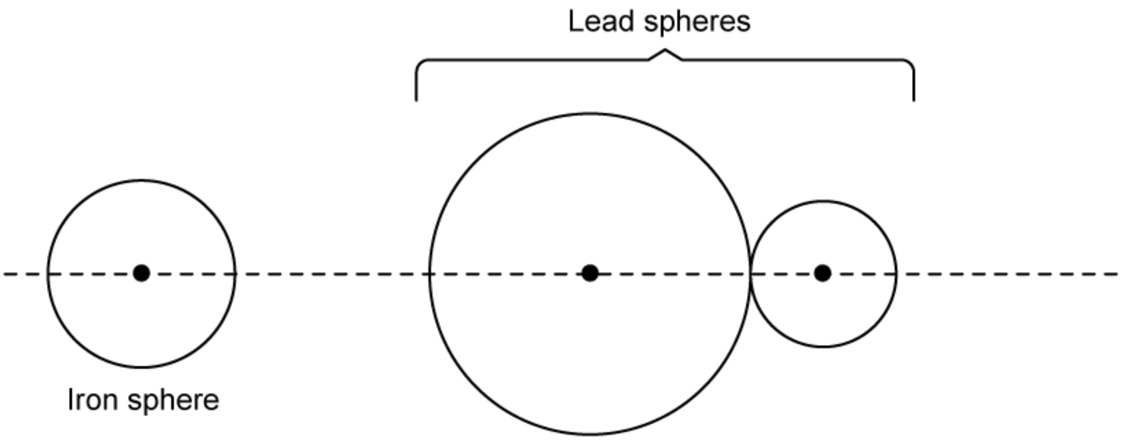
(6 marks)

4 (a) A student has two unequal, uniform lead spheres.

Lead has a density of 11.3×10^3 kg m^{-3}. The larger sphere has a radius of 200 mm and a mass of 170 kg. The smaller sphere has a radius of 55 mm.

The surfaces of two lead spheres are in contact with each other, and a third, iron sphere of mass 20 kg and radius 70 mm is positioned such that the centre of mass of all three spheres lie on the same straight line.



Calculate the distance between the surface of the iron sphere and the surface of the larger lead sphere which would result in no gravitational force being exerted on the larger sphere.

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(3 marks)

(b) Calculate the resultant gravitational field strength on the surface of the iron sphere.

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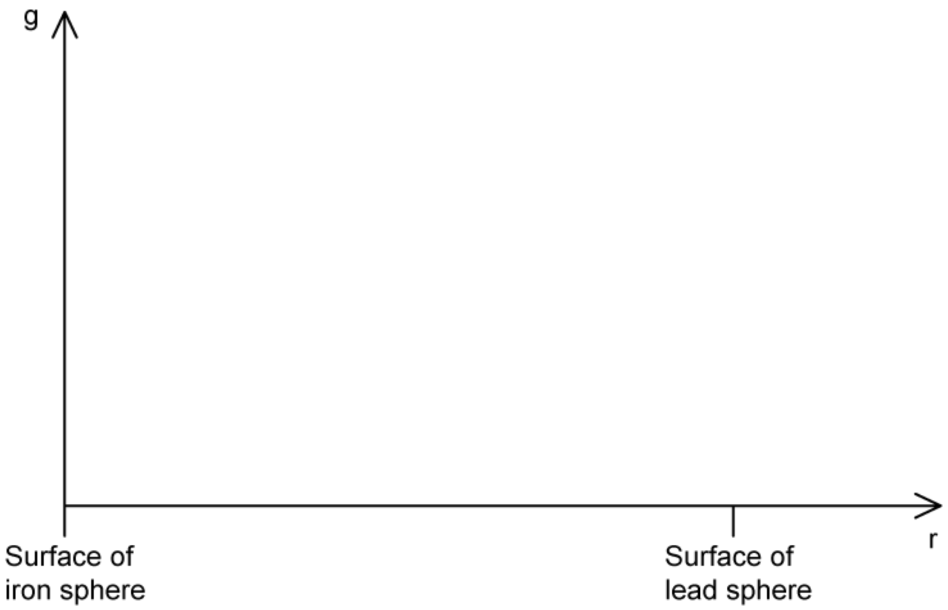
(3 marks)

(c) The smaller lead sphere is removed. The separation distance between the surface of the iron sphere and the large lead sphere is *r*.

Sketch a graph on the axes provided showing the variation of gravitational field strength *g* between the surface of the iron sphere and the surface of the lead sphere.



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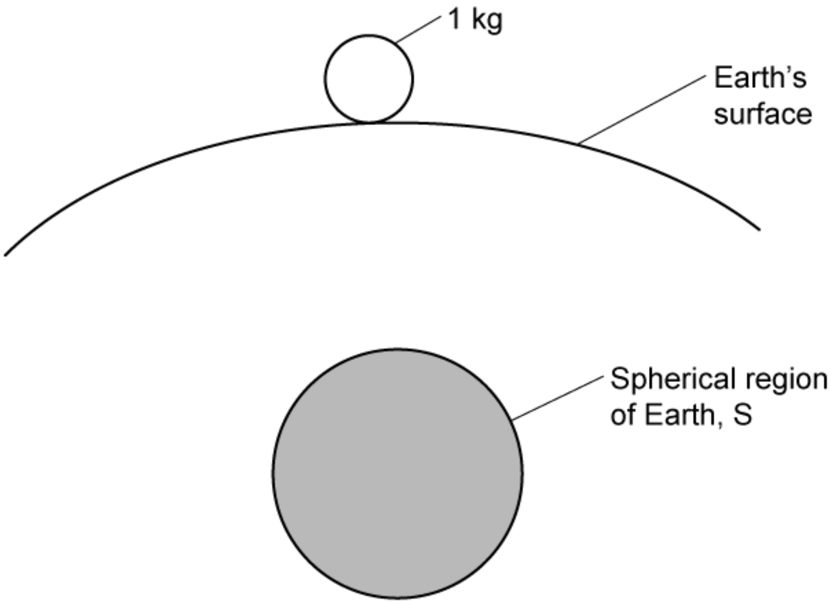
(3 marks)

5 (a) A kilogram mass rests on the surface of the Earth. A spherical region S, whose centre of mass is underneath the Earth's surface at a distance of 3.5 km, has a radius of 2 km. The density of rock in this region is 2500 kg m^{-3}.



Determine the size of the force exerted on the kilogram mass by the matter enclosed in S, justifying any approximations.

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(3 marks)

(b) If the region S consisted of oil of density 900 kg m^{-3} instead of rock, the force recorded on the kilogram mass would reduce by approximately 2.9×10^{-4} N.

(i) Suggest how gravity meters may be used in oil prospecting.

[1]

(ii) Determine the uncertainty within which the acceleration of free fall needs to be measured if the meters are to detect such a quantity of oil.

[2]

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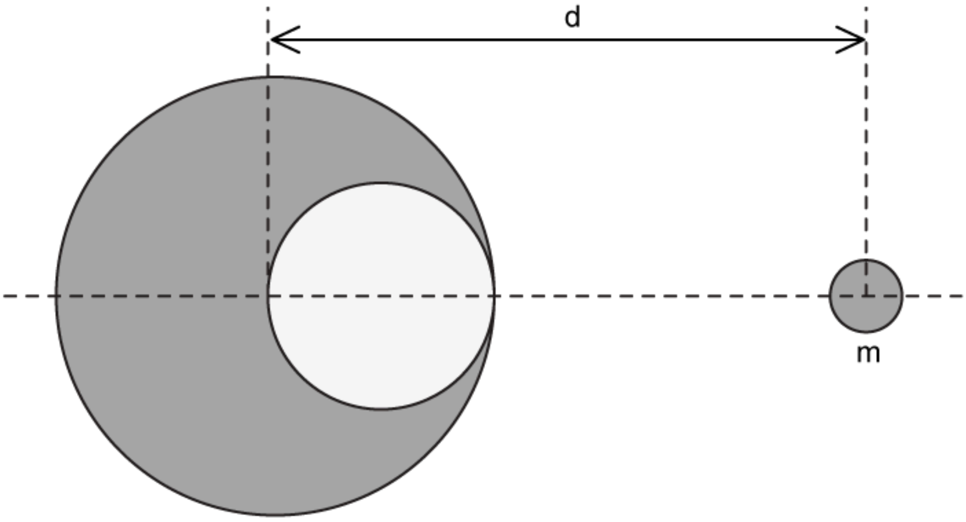
(3 marks)

(c) A spherical hollow is made in a lead sphere of radius *R*, such that its surface touches the outside surface of the lead sphere on one side and passes through its centre on the opposite side. The mass of the sphere before it was made hollow is *M*.



Show that the magnitude of the force *F* exerted by the spherical hollow on a small mass *m*, placed at a distance *d* from its centre, is given by:

$$F = \frac{GMm}{d^2}\left(1 - \frac{1}{8}\left(\frac{2d}{2d - R}\right)^2\right)$$

[4]

(4 marks)

6 (a) Scientists want to put a satellite in orbit around planet Venus.

Justify how Newton's law of gravitation can be applied to a satellite orbiting Venus, when neither the satellite, nor the planet are point masses.

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(2 marks)

(b) The satellite's orbital time, T, and its orbital radius, R, are linked by the equation:

$$T^2 = kR^3$$

Venus has a mass of 4.9×10^{24} kg.

Determine the value of the constant k, and give the units in SI base units.

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(6 marks)

(c) One day on Venus is equal to 116 Earth days and 18 Earth hours.

Determine the orbital speed of the satellite in m s^{-1}.

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(2 marks)

7 (a) An object has a weight of 100 N at a distance of 200 km above the centre of a small planet.

Sketch a labelled graph to show the relationship between the gravitational force, *F*, between two masses and the distance, *r*, between them. Mark at least three points on the graph using the information provided in the question.

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(3 marks)

(b) The distance along the Earth's surface from the North Pole to the Equator is 1×10^7 m.

Calculate the mass of the Earth.

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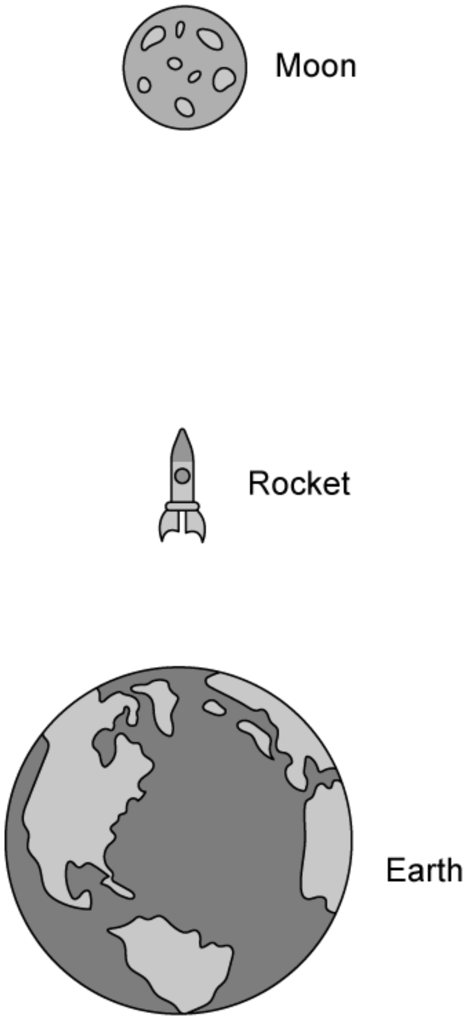
(2 marks)

(c) A rocket is sent from the Earth to the moon. The moon has a radius of 1.74×10^6 m and the gravitational field strength on its surface is 1.62 N kg^{-1}. The radius of the Earth is 6370 km.



The distance between the centre of the Earth and the centre of the moon is 385 000 km.

Calculate the distance above the Earth's surface where there is no resultant gravitational field strength acting on the rocket.

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(4 marks)

8 (a) The orbits of the Earth and Jupiter are very nearly circular, with radii of 150×10^9 m and 778×10^9 m respectively. It takes Jupiter 11.8 years to complete a full orbit of the Sun.

Show that the values in this question are consistent with Kepler's third law.

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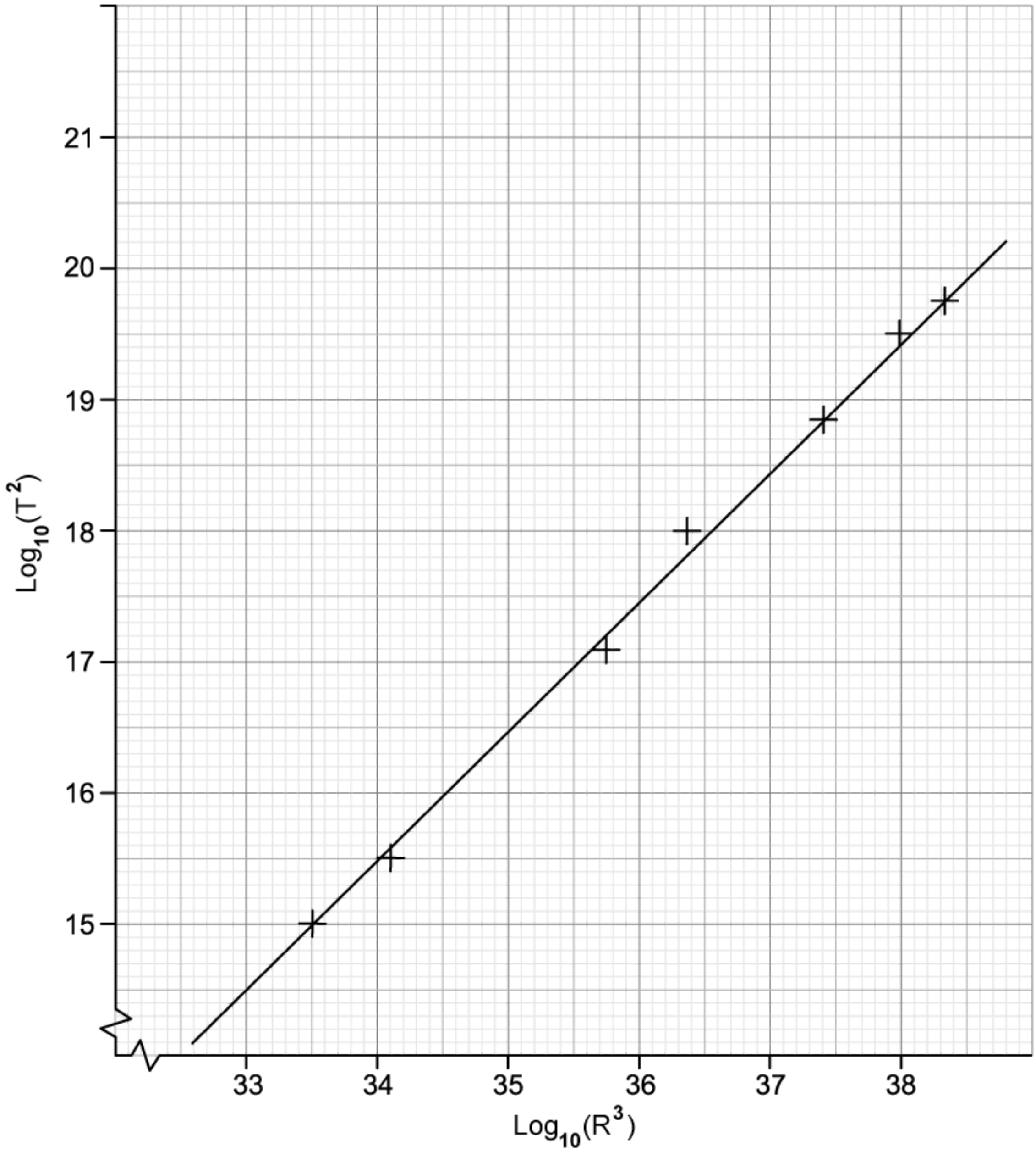
(2 marks)

(b) Data from the orbits of different planets around our Sun is plotted in a graph of $\log(T^2)$ against $\log(R^3)$ as shown in the graph below, where *T* is the orbital period and *R* is the radius of the planet's orbit.

The values of *T* and *R* have been squared and cubed respectively due to Kepler's Third Law stating that:

$$T^2 = \frac{4\pi^2 r^3}{GM}$$



Calculate the percentage error for the mass of the Sun obtained from the graph.

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(4 marks)