6.2 Newton's Law of Gravitation

Question Paper

Course	DP IB Physics
Section	6. Circular Motion & Gravitation
Topic	6.2 Newton's Law of Gravitation
Difficulty	Hard

Time allowed: 80

Score: /62

Percentage: /100

Question 1a

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

(a)

(i)
Calculate the mass of the moon

[2]

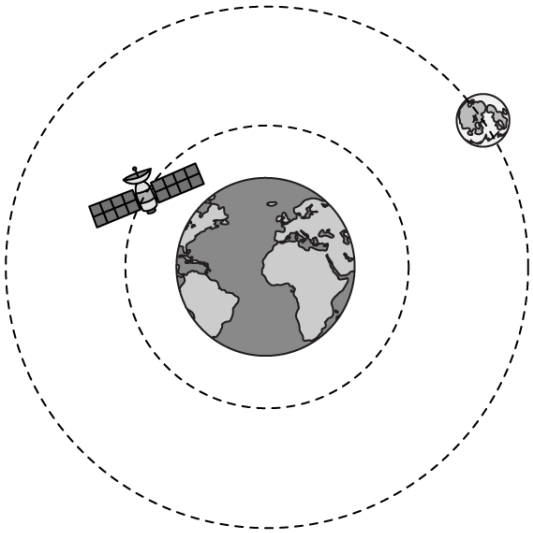
(ii)
State the assumption necessary for part (i)

[1]

[3 marks]

Question 1b

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

(b)
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]

[4 marks]

Question 1c

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

[3]

[3 marks]

Question 1d

Two planets X and Y have the same mass. Planet X has a radius R and the gravitational field strength on its surface is g. The radius of planet Y is twice that of planet X and the gravitational field strength at the surface of planet Y is one fifth of the value of the gravitational field strength on X.

(d)
Use the equation you derived in part (c) to show that the volume of planet Y is 10 times larger than the volume of planet X.

[3]

[3 marks]

Question 2a

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.

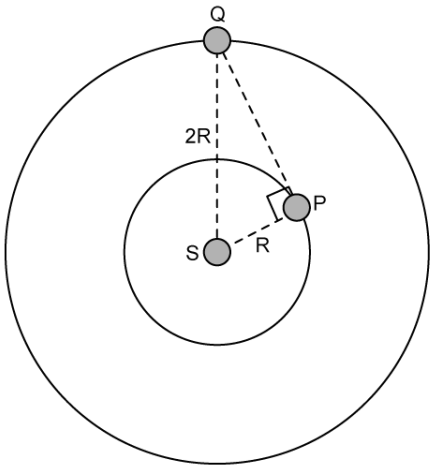
(a)
Calculate the gravitational field strength at the surface of the planet.

[3]

[3 marks]

Question 2b

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.

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

[3]

[3 marks]

Question 2c

Planet P is twice the mass of planet Q.

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

Label the approximate position of the neutral point.

[2]

[2 marks]

Question 3a

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.

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

[3]

[3 marks]

Question 3b

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}.

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

[3]

[3 marks]

Question 3c

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.

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

[6]

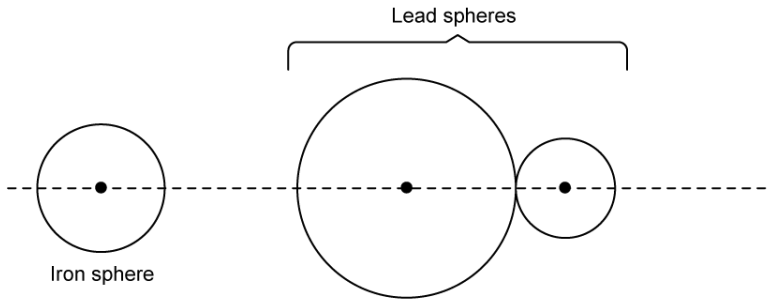
[6 marks]

Question 4a

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.



(a)
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.

[3]

[3 marks]

Question 4b

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

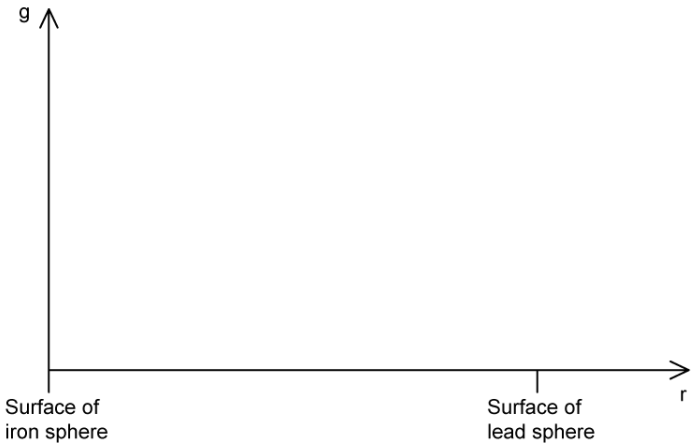
[3]

[3 marks]

Question 4c

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

(c)
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.

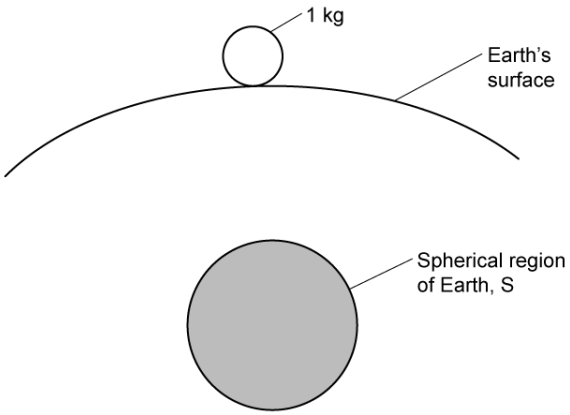


[3]

[3 marks]

Question 5a

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}.



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

[3]

[3 marks]

Question 5b

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.

(b)

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

[1]

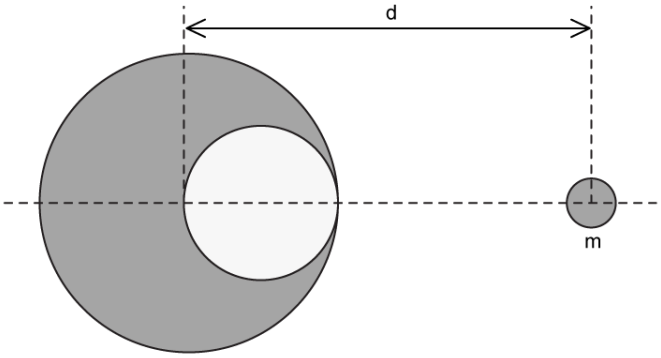
(ii)
Determine the uncertainty within which the acceleration of free fall needs to be measured if the meters are to detect such a quantity of oil.

[2]

[3 marks]

Question 5c

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*.



(c)

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]

Question 6a

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

(a)

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.

[2]

[2 marks]

Question 6b

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.

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

[6]

[6 marks]

Question 6c

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

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

[2]

[2 marks]