Access Tuition

A-Level Physics

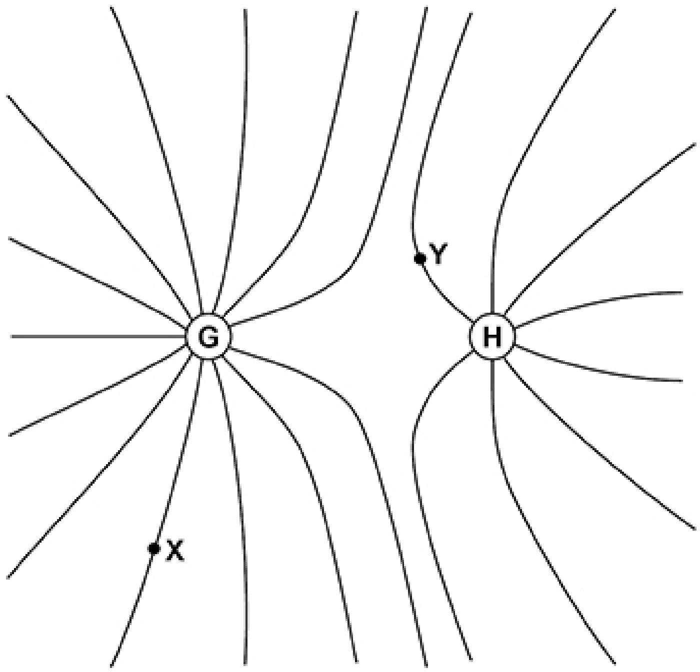
Gravitational Fields

Question Paper

Time available: 77 minutes
Marks available: 61 marks

1. The lines in **Figure 1** show the shape of the gravitational field around two stars **G** and **H**.

Figure 1



(a) Compare, with reference to **Figure 1**, the masses of **G** and **H**.

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(2)

(b) **X** and **Y** are two points in the field.

Annotate **Figure 1** to show the field direction at **X** and the field direction at **Y**.

(1)

(c) A spherical asteroid **P** has a mass of 2.0×10^{20} kg.

The gravitational field strength at its surface is 0.40 N kg^{-1}.

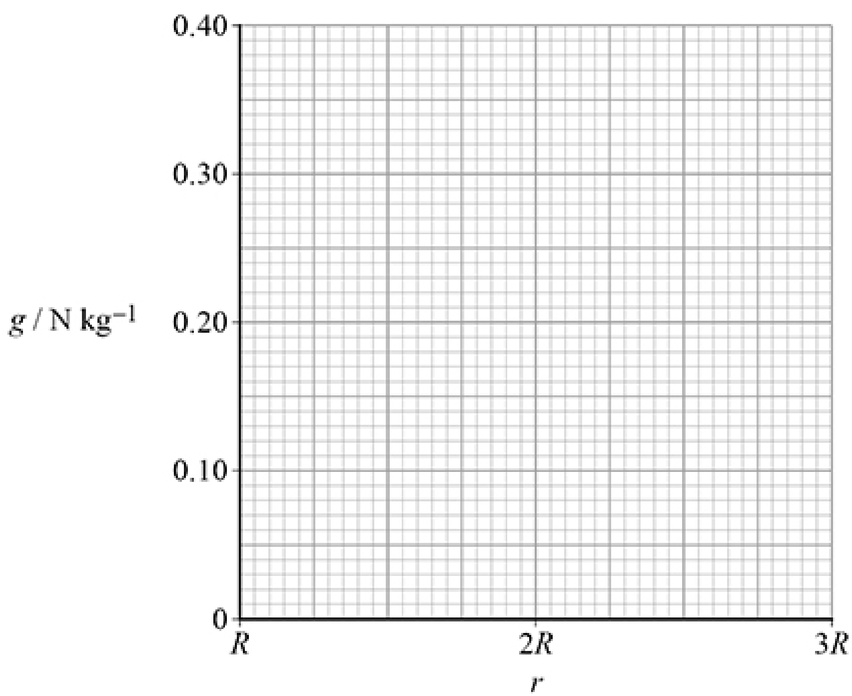
Calculate the radius R of **P**.

R = ______________ m

(1)

(d) Sketch, on **Figure 2**, the variation of the gravitational field strength g with distance r. The distance r is measured from the centre of **P**.

Figure 2



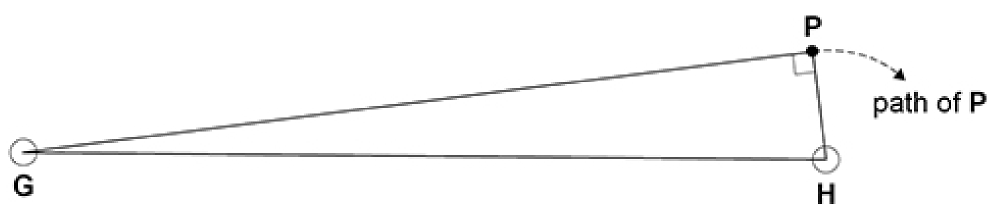
(1)

(e) Explain what is represented by the area under the graph between $r = R$ and $r = 2R$ on **Figure 2**.

(2)

Asteroid **P** approaches the two stars **G** and **H**.
Figure 3 shows one position of **P** close to **H**.

Figure 3



(f) The gravitational force on **P** from **G** is 6.38×10^{12} N.
The mass of **H** is 3.00×10^{25} kg and the mass of **P** is 2.00×10^{20} kg.
The distance **HP** is 1.50×10^{11} m.

Calculate the magnitude of the acceleration of **P**.

magnitude of acceleration = ________________ $m\ s^{-2}$

(4)

(g) Explain why **P** cannot have a circular orbit around **H**.

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(1)
(Total 12 marks)

2. (a) Derive an expression to show that for satellites in a circular orbit

$$T^2 \propto r^3$$

where T is the period of orbit and r is the radius of the orbit.

(2)

(b) Pluto is a dwarf planet. The mean orbital radius of Pluto around the Sun is 5.91×10^9 km compared to a mean orbital radius of 1.50×10^8 km for the Earth.

Calculate in years the orbital period of Pluto.

orbital period of Pluto = ____________________ yr

(2)

(c) A small mass released from rest just above the surface of Pluto has an acceleration of 0.617 m s^{-2}.

Assume Pluto has no atmosphere that could provide any resistance to motion.

Calculate the mass of Pluto.

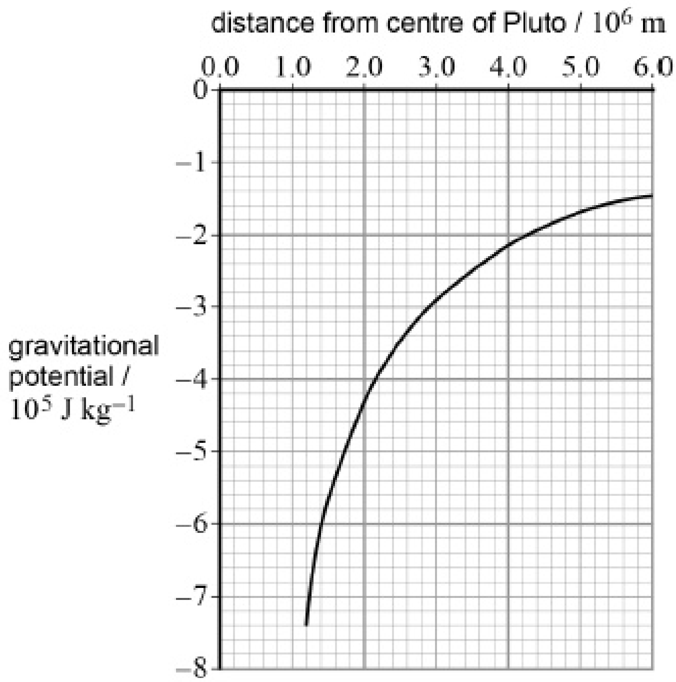
Give your answer to an appropriate number of significant figures.

radius of Pluto = 1.19×10^6 m

mass of Pluto = ____________________ kg

(3)

(d) The graph shows the variation in gravitational potential with distance from the centre of Pluto for points at and above its surface.



A meteorite hits Pluto and ejects a lump of ice from the surface that travels vertically at an initial speed of 1400 m s^{-1}.

Determine whether this lump of ice can escape from Pluto.

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(3)
(Total 10 marks)

3. (a) Define the gravitational potential at a point.

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(2)

(b) Explain why gravitational potential is always negative.

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(2)

(c) Show that the magnitude of the gravitational potential at the Earth's surface due to the mass of the Earth is about 6.3×10^7 J kg^{-1}.

(2)

(d) A satellite is launched into a geostationary orbit.

Describe and explain **two** features of a geostationary orbit.

1. ____

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2. ____

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(2)

(e) The satellite has a mass of 1200 kg and the radius of its orbit is 4.23×10^7 m.

Calculate the gain in gravitational potential energy of the satellite when it is placed into orbit from the Earth's surface.

gain in potential energy = ________________________ J

(3)

(f) Impulse engines are used to place the satellite into an orbit with a longer period.

Discuss any changes this makes to the orbital motion of the satellite.

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(4)

(Total 15 marks)

4. (a) Explain why astronauts in an orbiting space vehicle experience the sensation of weightlessness.

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(2)

(b) A space vehicle has a mass of 16 800 kg and is in orbit 900 km above the surface of the Earth.

mass of the Earth = 5.97×10^{24} kg
radius of the Earth = 6.38×10^{6} m

(i) Show that the orbital speed of the vehicle is approximately 7400 m s^{-1}.

(4)

(ii) The space vehicle moves from the orbit 900 km above the Earth's surface to an orbit 400 km above the Earth's surface where the orbital speed is 7700 m s^{-1}.

Calculate the total change that occurs in the energy of the space vehicle.
Assume that the vehicle remains outside the atmosphere after the change of orbit.
Use the value of 7400 m s^{-1} for the speed in the initial orbit.

change in energy ____________________ J

(4)

(Total 10 marks)

5. **Figure 1** shows (not to scale) three students, each of mass 50.0 kg, standing at different points on the Earth's surface. Student **A** is standing at the North Pole and student **B** is standing at the equator.

Figure 1

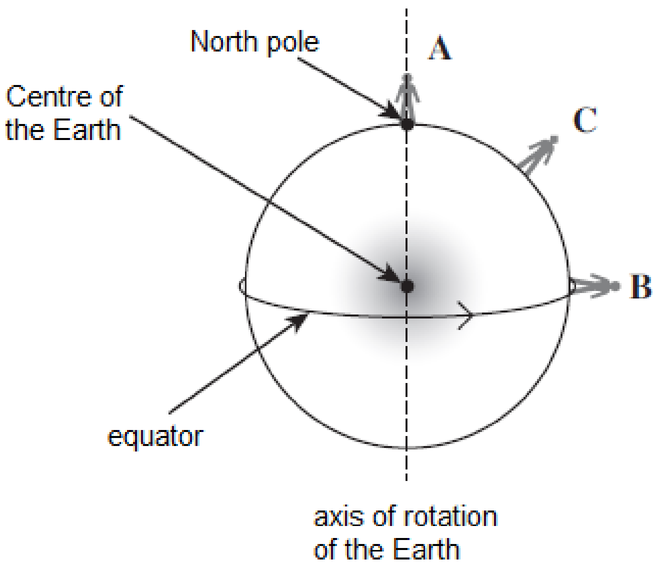
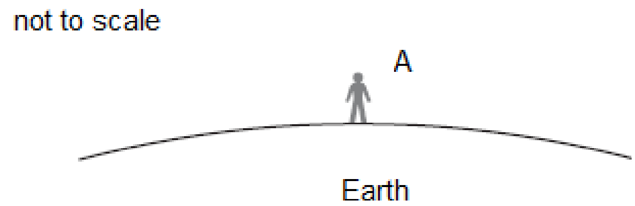


Figure 2



The radius of the Earth is 6370 km.
The mass of the Earth is 5.98×10^{24} kg.

In this question assume that the Earth is a perfect sphere.

(a) (i) Use Newton's gravitational law to calculate the gravitational force exerted by the Earth on a student.

force ____________________ N

(3)

(ii) **Figure 2** shows a closer view of student **A**.
Draw, on **Figure 2**, vector arrows that represent the forces acting on student **A**.

(2)

(b) (i) Show that the linear speed of student **B** due to the rotation of the Earth is about 460 m s^{-1}.

(3)

(ii) Calculate the magnitude of the centripetal force required so that student **B** moves with the Earth at the rotational speed of 460 m s^{-1}.

magnitude of the force ____________________ N

(2)

(iii) Show, on **Figure 1**, an arrow showing the direction of the centripetal force acting on student **C**.

(1)

(c) Student **B** stands on a bathroom scale calibrated to measure weight in newton (N). If the Earth were not rotating, the weight recorded would be equal to the force calculated in part (a)(i).

State and explain how the rotation of the Earth affects the reading on the bathroom scale for student **B**.

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(3)

(Total 14 marks)