Name:

Date:

GRAVITATIONAL FIELDS
TEST 1

A2-Level

Mark

Grade

PHYSICS

For this paper you must have:

- Ruler
- Pencil and Rubber
- Scientific calculator, which you are expected to use when appropriate

Instructions

- Answer all questions
- Answer questions in the space provided
- All working must be shown

Information

- The marks for the questions are shown in brackets

1 The Rosetta space mission placed a robotic probe on Comet 67P in 2014.

(a) The total mass of the Rosetta spacecraft was 3050 kg. This included the robotic probe of mass 108 kg and 1720 kg of propellant. The propellant was used for changing velocity while travelling in deep space where the gravitational field strength is negligible.

Calculate the change in gravitational potential energy of the Rosetta spacecraft from launch until it was in deep space.
Give your answer to an appropriate number of significant figures.

Mass of the Earth = 6.0×10^{24} kg
Radius of the Earth = 6400 km

change in gravitational potential energy ____________________ J

(4)

(b) As it approached the comet, the speed of the Rosetta spacecraft was reduced to match that of the comet. This was done in stages using four 'thrusters'. These were fired simultaneously in the same direction.

Explain how the propellant produces the thrust.

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(3)

(c) Each thruster provided a constant thrust of 11 N.

Calculate the deceleration of the Rosetta spacecraft produced by the four thrusters when its mass was 1400 kg.

deceleration ____________________ m s^{-2}

(1)

(d) Calculate the maximum change in speed that could be produced using the 1720 kg of propellants.

Assume that the speed of the exhaust gases produced by the propellant was 1200 m s^{-1}

maximum change in speed ____________________ m s^{-1}

(3)

(e) When the robotic probe landed, it had to be anchored to the comet due to the low gravitational force. Comet 67P has a mass of about 1.1×10^{13} kg. A possible landing site was about 2.0 km from the centre of mass.

(i) Calculate the gravitational force acting on the robotic probe when at a distance of 2.0 km from the centre of mass of the comet.

gravitational force ____________________ N

(3)

(ii) Calculate the escape velocity for an object 2.0 km from the centre of mass of the comet.

escape velocity ____________________ $m\ s^{-1}$

(3)

(iii) A scientist suggests using a drill to make a vertical hole in a rock on the surface of the comet. The anchoring would be removed from the robotic probe before the drill was used. The drill would exert a force of 25 N for 4.8 s.

Explain, with the aid of a calculation, whether this process would cause the robotic probe to escape from the comet.

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(3)

(Total 20 marks)

2 (a) (i) State what is meant by the term **escape velocity**.

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(1)

(ii) Show that the escape velocity, v, at the Earth's surface is given by $v = \sqrt{\frac{2GM}{R}}$

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

(2)

(iii) The escape velocity at the Moon's surface is 2.37×10^{3} m s^{-1} and the radius of the Moon is 1.74×10^{6} m.

Determine the mean density of the Moon.

mean density ____________________ kg m^{-3}

(2)

(b) State **two** reasons why rockets launched from the Earth's surface do **not** need to achieve escape velocity to reach their orbit.

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(2)

(Total 7 marks)

3 (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)

4 (a) (i) Define gravitational field strength and state whether it is a scalar or vector quantity.

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(2)

(ii) A mass m is at a height h above the surface of a planet of mass M and radius R. The gravitational field strength at height h is g. By considering the gravitational force acting on mass m, derive an equation from Newton's law of gravitation to express g in terms of M, R, h and the gravitational constant G.

(2)

(b) (i) A satellite of mass 2520 kg is at a height of 1.39×10^7 m above the surface of the Earth. Calculate the gravitational force of the Earth attracting the satellite.
Give your answer to an appropriate number of significant figures.

force attracting satellite ____________________ N

(3)

(ii) The satellite in part (i) is in a circular polar orbit. Show that the satellite would travel around the Earth three times every 24 hours.

(5)

(c) State and explain **one** possible use for the satellite travelling in the orbit in part (ii).

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(2)

(Total 14 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

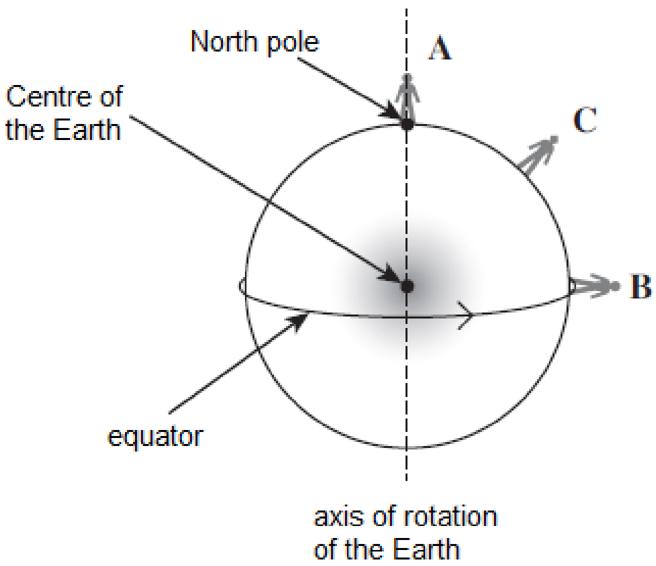
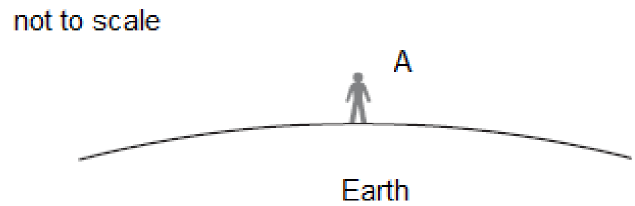


Figure 2



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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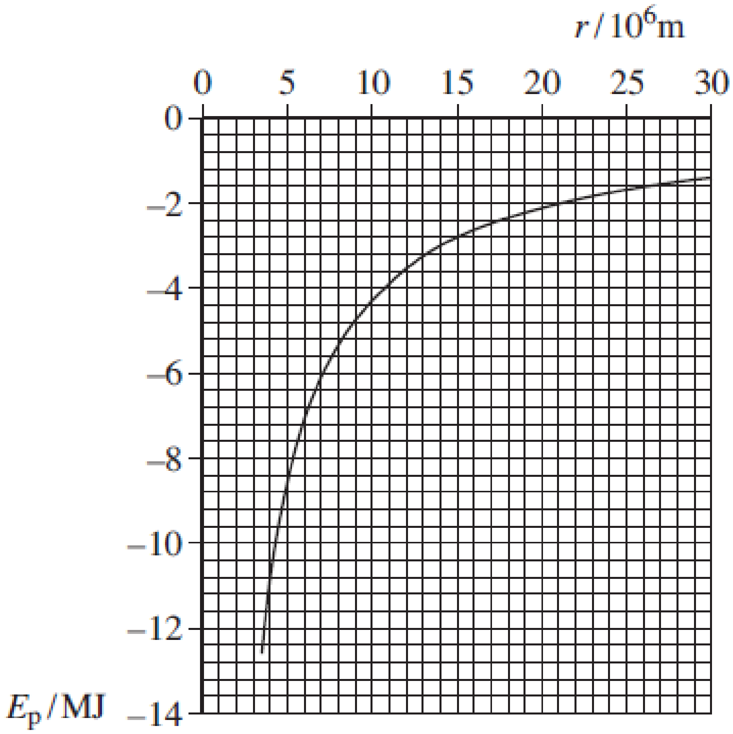
(3)

(Total 14 marks)

6 The graph below shows how the gravitational potential energy, E_p, of a 1.0 kg mass varies with distance, r, from the centre of Mars. The graph is plotted for positions above the surface of Mars.



(a) Explain why the values of E_p are negative.

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(2)

(b) Use data from the graph to determine the mass of Mars.

mass of Mars ____________________ kg

(3)

(c) Calculate the escape velocity for an object on the surface of Mars.

escape velocity ____________________ m s^{-1}

(3)

(d) Show that the graph data agree with $E_p \propto \frac{1}{r}$

(3)

(Total 11 marks)

7 A spacecraft of mass 1.0×10^6 kg is in orbit around the Sun at a radius of 1.1×10^{11} m
The spacecraft moves into a new orbit of radius 2.5×10^{11} m around the Sun.

What is the total change in gravitational potential energy of the spacecraft?

A -6.76×10^{14} J ○

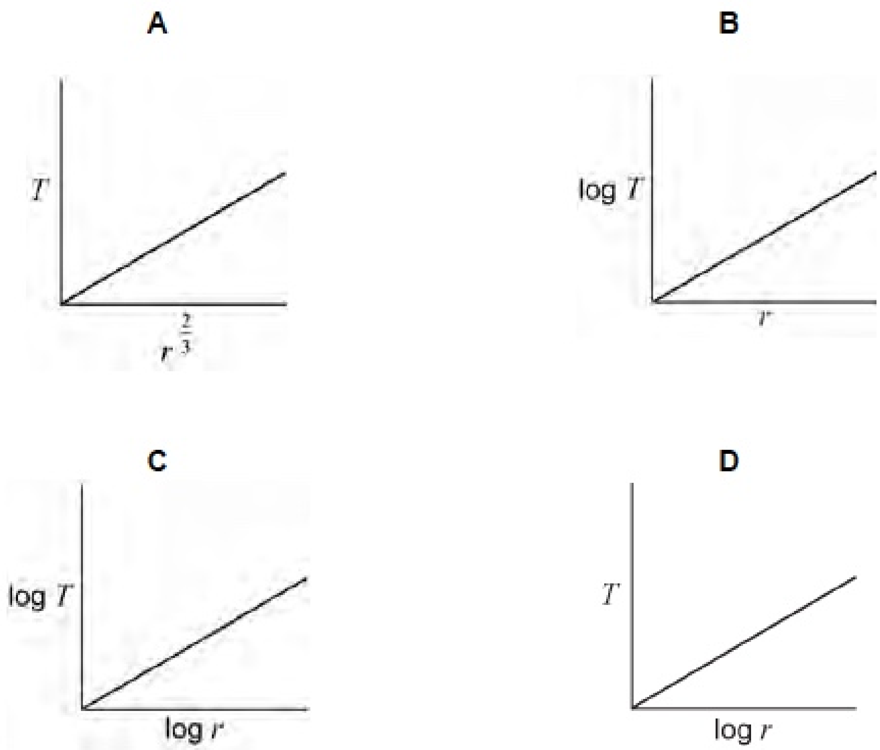
B -3.38×10^{14} J ○

C 3.38×10^{14} J ○

D 6.76×10^{14} J ○

(Total 1 mark)

8 Which graph shows the relationship between the time period T and the orbital radius r of a planet in orbit around the Sun?



A ⬭

B ⬭

C ⬭

D ⬭

(Total 1 mark)

9 The Earth can be assumed to be a uniform sphere of radius R.

What is the mean density of the Earth?

A $\frac{3g}{4\pi RG}$ ⬭

B $\frac{3RG}{4\pi g}$ ⬭

C $\frac{3G}{4\pi Rg}$ ⬭

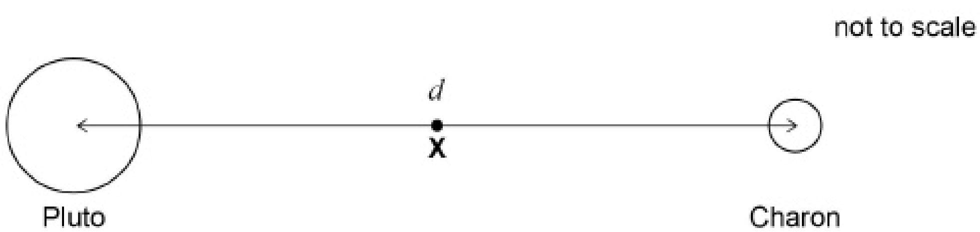
D $\frac{3Rg}{4\pi G}$ ⬭

(Total 1 mark)

10 Charon is a moon of Pluto that has a mass equal to $\frac{1}{9}$ that of Pluto.

The distance between the centre of Pluto and the centre of Charon is *d*.

X is the point at which the resultant gravitational field due to Pluto and Charon is zero.



What is the distance of **X** from the centre of Pluto?

A $\frac{2}{9}d$ ⬭

B $\frac{2}{3}d$ ⬭

C $\frac{3}{4}d$ ⬭

D $\frac{8}{9}d$ ⬭

(Total 1 mark)