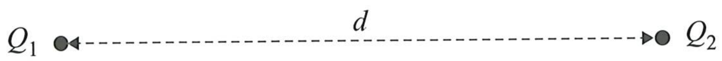
Question 2

The diagram below shows two charges, Q_1 and Q_2, separated by a distance, d.



There is a force, F, acting between the two charges.

Which one of the following is closest to the magnitude of the force acting between the two charges if both d and the charge on Q_1 are halved?

A. $\frac{F}{4}$

B. F

C. $2F$

D. $4F$

Question 3

Space scientists want to place a satellite into a circular orbit where the gravitational field strength of Earth is half of its value at Earth's surface.

Which one of the following expressions best represents the altitude of this orbit above Earth's surface, where R is the radius of Earth?

A. $\frac{\sqrt{2}R}{2} - R$

B. $\sqrt{2}R$

C. $(\sqrt{2}R) - R$

D. $2R - \sqrt{2}R$

$g = G\frac{M}{R^2}$

$g \div 2 \longrightarrow R \times \sqrt{2}$

$h = \sqrt{2}R - R = R(\sqrt{2} - 1)$

Question 2 (7 marks)

Phobos is a small moon in a circular orbit around Mars at an altitude of 6000 km above the surface of Mars. The gravitational field strength of Mars at its surface is 3.72 N kg^{-1}. The radius of Mars is 3390 km.

a. Show that the gravitational field strength 6000 km above the surface of Mars is 0.48 N kg^{-1}. 2 marks

$g_0 = \frac{GM}{r^2}$ $M = \frac{g_0 r^2}{G} = \frac{3.72 \times (3.39 \times 10^6)^2}{6.67 \times 10^{-11}} = 6.41 \times 10^{23}$ kg

$g_1 = \frac{GM}{r^2} = \frac{6.67 \times 10^{-11} \times 6.41 \times 10^{23}}{(9.39 \times 10^6)^2} = 0.48$

or

$\frac{g_1}{g_0} = \left(\frac{r_0}{r_1}\right)^2 = \left(\frac{3390}{9390}\right)^2 = 0.13$

$3.72 \times 0.13 = 0.48$

b. Calculate the orbital period of Phobos. Give your answer in seconds. 3 marks

$T = 2\pi \sqrt{\frac{r^3}{GM}} = 2\pi \sqrt{\frac{(9.39 \times 10^6)^3}{6.67 \times 10^{-11} \times 6.41 \times 10^{23}}} = 27649$

or

$T = 2\pi \sqrt{\frac{r}{g}} = 2\pi \sqrt{\frac{9.39 \times 10^6}{0.48}} = 27790$

27790

$\boxed{27649 \text{ s}}$ 2.8×10^4

c. Phobos is very slowly getting closer to Mars as it orbits.

Will the orbital period of Phobos become shorter, stay the same or become longer as it orbits closer to Mars? Explain your reasoning. 2 marks

$\boxed{\text{Shorter}}$ $\frac{r^3}{T^2}$ - const $r \downarrow$ $T \downarrow$

DO NOT WRITE IN THIS AREA

Question 5 (3 marks)

Figure 5 shows the sun, the moon and Earth.

The mass of the sun is approximately 3.3×10^5 times the mass of Earth.

The distance from the sun to the moon is approximately 390 times the distance from Earth to the moon.

Figure 5

Calculate $\dfrac{\text{magnitude of the sun's gravitational force on the moon}}{\text{magnitude of Earth's gravitational force on the moon}}$.

$r_2 = 390\, r_1 \qquad F = G\dfrac{M\,M}{r^2} \quad \cancel{(1)}$

$F_{sun} = G\dfrac{M_{moon} \times 3.3\times10^5 M_{Earth}}{(390 r_1)^2} \quad (1)$

$F_{Earth} = G\dfrac{M_{moon} M_{Earth}}{r_1^2} \quad (1)$

$\boxed{2.2}$

$\dfrac{F_{sun}}{F_{Earth}} = \dfrac{3.3\times10^5}{390^2} = 2.2 \quad (1)$

DO NOT WRITE IN THIS AREA

Question 2 (9 marks)

There are over 400 geostationary satellites above Earth in circular orbits. The period of orbit is one day (86 400 s). Each geostationary satellite remains stationary in relation to a fixed point on the equator. Figure 2 shows an example of a geostationary satellite that is in orbit relative to a fixed point, X, on the equator.

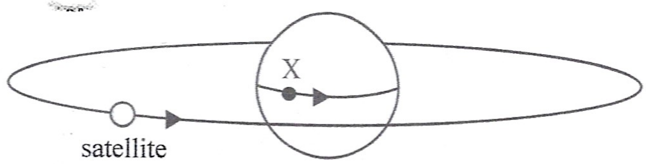


Figure 2

a. Explain why geostationary satellites must be vertically above the equator to remain stationary relative to Earth's surface. 2 marks

Satellites must rotate in the same direction 2%
as Earth with same period. 1m
Satellites orbit the center of mass of Earth or
force of gravity towards centre of Earth. 1m

b. Using $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}, $M_E = 5.98 \times 10^{24}$ kg and $R_E = 6.37 \times 10^6$ m, show that the altitude of a geostationary satellite must be equal to 3.59×10^7 m. 4 marks

56%

$R = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$ 1m

$R = \sqrt[3]{\frac{6.67\times10^{-11} \times 5.98\times10^{24} \times 86400^2}{4\pi^2}}$ 1m

$R = 4.225\times10^7$ 1m

Altitude $= 4.225\times10^7 - \underbrace{6.37\times10^6}_{R_E} =$

$= 3.59\times10^7$ m (1m)

c. Calculate the speed of an orbiting geostationary satellite. 3 marks

54%

$v = \frac{2\pi R}{T}$ 1m

$v = \frac{2\pi \times 4.225\times10^{7}}{86400}$ 1m

$v = 3.07\times10^{3}\ \text{m s}^{-1}$ 1m

3.07×10^{3} m s^{-1}

or

$v = \sqrt{\frac{GM}{R}}$ 1m

$v = \sqrt{\frac{6.67\times10^{-11}\times5.98\times10^{24}}{4.225\times10^{7}}}$ 1m

$v = 3.07\times10^{3}\ \text{m s}^{-1}$ 1m

Question 3

The gravitational field strength at the surface of a uniform spherical planet of radius R is g N kg^{-1}.
At a distance of $3R$ above the planet's surface, the strength of gravity will be closest to

A. 0

B. $\frac{g}{3}$

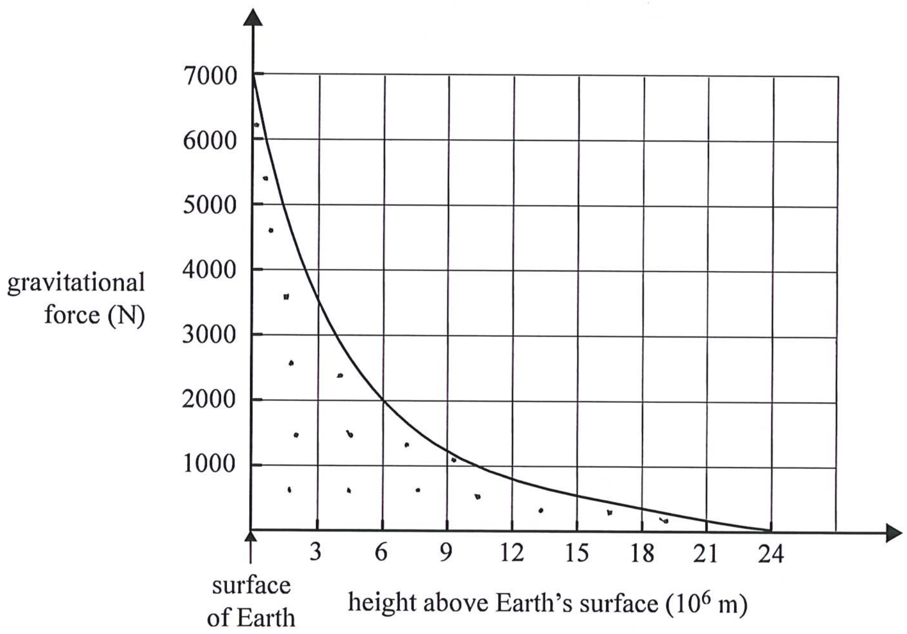
C. $\frac{g}{9}$

D. $\frac{g}{16}$

$g = \frac{GM}{R^2}$ $g_1 = \frac{GM}{(4R)^2}$

Question 4

The Mars *Odyssey* spacecraft was launched from Earth to explore Mars. The graph below shows the gravitational force acting on the 700 kg Mars *Odyssey* spacecraft plotted against its height above Earth's surface.



Which one of the following is closest to the minimum launch energy needed for the Mars *Odyssey* spacecraft to 'escape' Earth's gravitational attraction?

A. 4.0×10^4 J

B. 1.5×10^5 J

C. 4.0×10^{10} J

D. 1.5×10^{11} J

$1 \text{ sq} = 1000 \times 3 \times 10^6 = 3 \times 10^9$ J

$11.5 \text{ sq} = 3.45 \times 10^{10}$

3.45×10^{10}

Question 2 (7 marks)

The speed of a satellite in a circular orbit around a planet is given by $v = \sqrt{\frac{GM}{r}}$, where G is the universal gravitational constant, M is the mass of the planet and r is the orbital radius of the satellite.

Titan is the largest moon of Saturn and has an orbital radius of 1.2×10^9 m. The mass of Saturn is 5.7×10^{26} kg. Assume that Titan's orbit is circular.

a. Calculate Titan's orbital speed. 2 marks

$v = \sqrt{\frac{6.67 \times 10^{-11} \times 5.7 \times 10^{26}}{1.2 \times 10^9}}$

$= 5.6 \times 10^3$

$\boxed{5.6 \times 10^3 \text{ m s}^{-1}}$

Another moon of Saturn is Rhea. Rhea is in a circular orbit of radius 5.3×10^8 m.

b. Does Rhea travel faster than, at the same speed as or slower than Titan? Explain your answer. 2 marks

$\boxed{\text{Faster}}$

$R \downarrow \quad V \uparrow$

c. Titan's period around Saturn is 16 days.

Calculate Rhea's period around Saturn. Show your working. 3 marks

~~Ra~~ $\frac{r_R^3}{r_T^3} = \frac{T_R^2}{T_T^2}$

$T_R = \sqrt{\left(\frac{r_R}{r_T}\right)^3 T_T^2} = \sqrt{\left(\frac{5.3 \times 10^8}{1.2 \times 10^9}\right)^3} \times 16 = 4.7$

$\boxed{4.7 \text{ days}}$

DO NOT WRITE IN THIS AREA

Question 8 (6 marks)

A satellite is moving in a stable circular orbit 25 Earth radii from the centre of Earth, as shown in Figure 5. The period of the satellite is T.

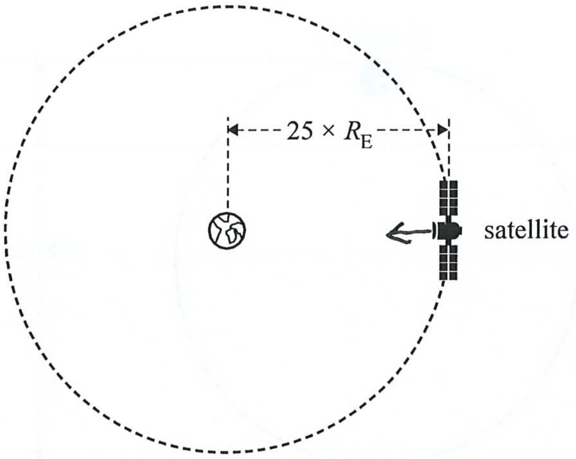


Figure 5

a. Calculate the magnitude of the acceleration of the satellite. Show your working. 2 marks

$g = \frac{GM}{r^2}$ $\frac{g_1}{g} = \frac{r^2}{(25r)^2}$

$g_1 = \frac{1}{25^2} \times 9.8$

$\boxed{1.6 \times 10^{-2} \text{ m s}^{-2}}$

b. Indicate the direction of the acceleration of the satellite by drawing an arrow on the satellite shown in Figure 5. 1 mark

c. Another identical satellite is placed in a stable circular orbit 30 Earth radii from the centre of Earth.

Using the terms 'less than', 'same as' or 'more than', complete the table below to describe the magnitude of the acceleration, the kinetic energy and the period of this satellite compared to those of the satellite that is orbiting at 25 Earth radii. 3 marks

Magnitude of acceleration	Less
Kinetic energy	Less
Period	More

Question 4 44%

The planet Phobetor has a mass four times that of Earth. Acceleration due to gravity on the surface of Phobetor is 18 m s^{-2}.

If Earth has a radius R, which one of the following is closest to the radius of Phobetor?

A. R

B. $1.5R$

C. $2R$

D. $4R$

$g_{Ph} = \frac{GM}{R^2}$ $R = \sqrt{\frac{GM}{g}}$ $R_{Ph} = \sqrt{\frac{G \times 4M_e}{18}}$

$\frac{R_{Ph}}{R_e} = \sqrt{\frac{4 \times 9.8}{18}} = 1.48$ $R_e = \sqrt{\frac{G M_e}{9.8}}$

Question 3 (6 marks)

The motion of Earth's moon can be modelled as a circular orbit around Earth, as shown in Figure 3.

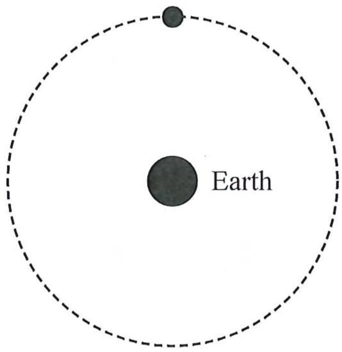


Figure 3

Data

mass of Earth	5.98×10^{24} kg
mass of the moon	7.35×10^{22} kg
radius of the moon's orbit around Earth	3.84×10^{8} m
universal gravitational constant (G)	6.67×10^{-11} N m^2 kg^{-2}

a. Calculate the magnitude of the gravitational force that Earth exerts on the orbiting moon. Give your answer correct to three significant figures. Show your working. 3 marks

$F = \frac{GMm}{r^2}$ $F = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times 7.35 \times 10^{22}}{(3.84 \times 10^{8})^2}$

1.99×10^{20} N

b. The average orbital period of Earth's moon is 27.32 days. The moon is moving slightly further away from Earth at an average rate of 4 cm per year.

Given this information, will the average orbital period of Earth's moon decrease, stay the same or increase? Explain your answer. 3 marks

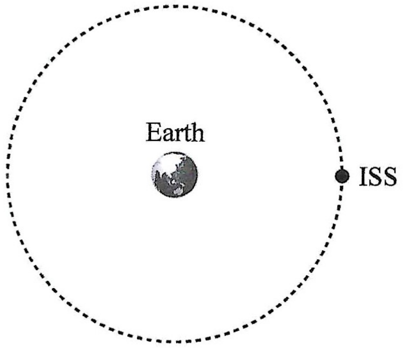
$\frac{R^3}{T^2} = \frac{GM}{4\pi^2}$ Right hand side is constant

so if $R\uparrow$, $T\uparrow$.

Period will increase

Question 11 31%

The International Space Station (ISS) is travelling around Earth in a stable circular orbit, as shown in the diagram below.



Which one of the following statements concerning the momentum and the kinetic energy of the ISS is correct?

A. Both the momentum and the kinetic energy vary along the orbital path.

B. Both the momentum and the kinetic energy are constant along the orbital path.

C. The momentum is constant, but the kinetic energy changes throughout the orbital path.

D. The momentum changes, but the kinetic energy remains constant throughout the orbital path.

Speed constant so E_K = const

Direction of the velocity changes

Question 4 (10 marks)

The Ionospheric Connection Explorer (ICON) space weather satellite, constructed to study Earth's ionosphere, was launched in October 2019. ICON will study the link between space weather and Earth's weather at its orbital altitude of 600 km above Earth's surface. Assume that ICON's orbit is a circular orbit. Use $R_E = 6.37 \times 10^6$ m.

a. Calculate the orbital radius of the ICON satellite. 1 mark

78%

$6.37 \times 10^6 + 6 \times 10^5$

$\boxed{6.97 \times 10^6 \text{ m}}$

b. Calculate the orbital period of the ICON satellite correct to three significant figures. Show your working. 4 marks

38%

$T = \sqrt{\frac{4\pi^2 R^3}{GM}} = \sqrt{\frac{4\pi^2 \times (6.97 \times 10^6)^3}{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}}$

$= 5788$ s

$= 5.79 \times 10^3$ (3 sig. fig.)

$\boxed{5.79 \times 10^3 \text{ s}}$

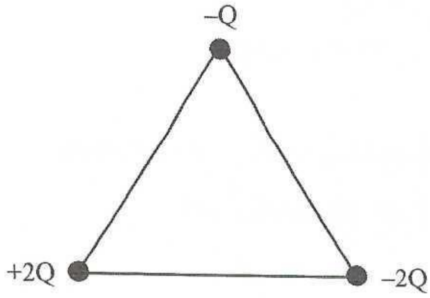
c. Explain how the ICON satellite maintains a stable circular orbit without the use of propulsion engines. 2 marks

9%

There is only one force acting on the satellite – gravitational force towards the Earth. which has constant magnitude and directed perpendicular to the velocity. This is why it maintains a stable circular orbit.

Question 3

Three charges (–Q, +2Q, –2Q) are placed at the vertices of an isosceles triangle, as shown below.



Which one of the following arrows best represents the direction of the net force on the charge –Q?

A. 

B. 

C. 

D. 

Question 4 58 %

The magnitude of the acceleration due to gravity at Earth's surface is g.

Planet Y has twice the mass and half the radius of Earth. Both planets are modelled as uniform spheres.

Which one of the following best gives the magnitude of the acceleration due to gravity on the surface of Planet Y?

A. $\frac{1}{2}g$

B. $1\,g$

C. $4\,g$

D. $8\,g$

$$g = \frac{GM}{r^2}$$

$$g_1 = \frac{G \times 2M}{\left(\frac{r}{2}\right)^2}$$

$$\frac{g_1}{g} = 8$$

Question 4 (5 marks)

Assume that a journey from approximately 2 Earth radii ($2R_E$) down to the centre of Earth is possible. The radius of Earth (R_E) is 6.37×10^6 m. Assume that Earth is a sphere of constant density.

A graph of gravitational field strength versus distance from the centre of Earth is shown in Figure 4.

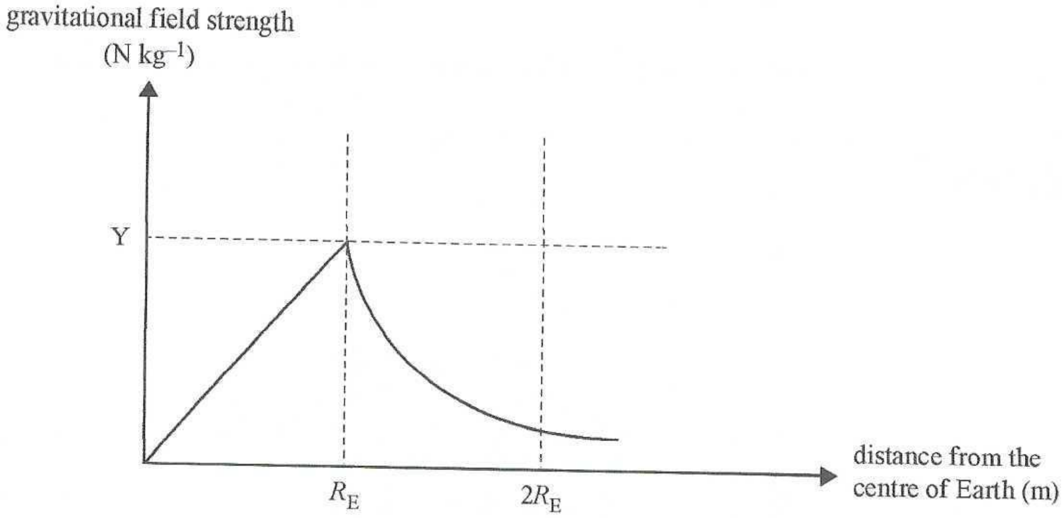


Figure 4

a. What is the numerical value of Y? 1 mark

84%

9.8 N kg^{-1}

b. Explain why gravitational field strength is 0 N kg^{-1} at the centre of Earth. 2 marks

14%

Gravitational attraction will be the same in all directions so net force is 0.

Question 5 (5 marks)

Navigation in vehicles or on mobile phones uses a network of global positioning system (GPS) satellites. The GPS consists of 31 satellites that orbit Earth.

In December 2018, one satellite of mass 2270 kg, from the GPS Block IIIA series, was launched into a circular orbit at an altitude of 20 000 km above Earth's surface.

a. Identify the type(s) of force(s) acting on the satellite and the direction(s) in which the force(s) must act to keep the satellite orbiting Earth. 2 marks

38%

Only one force acting - gravity, directed towards the centre of the Earth.

b. Calculate the period of the satellite to three significant figures. You may use data from the table below in your calculations. Show your working. 3 marks

33%

Data

mass of satellite	2.27×10^3 kg
mass of Earth	5.98×10^{24} kg
radius of Earth	6.37×10^6 m
altitude of satellite above Earth's surface	2.00×10^7 m
gravitational constant	6.67×10^{-11} N m^2 kg^{-2}

$r = 6.37\times10^6 + 2\times10^7$
$= 2.637\times10^7$

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

$$= \sqrt{\frac{4\pi^2 \times (2.637\times10^7)^3}{6.67\times10^{-11} \times 5.98\times10^{24}}}$$

$\boxed{4.26\times10^4 \text{ s}}$

Use the following information to answer Questions 2 and 3.

A powerline carries a current of 1000 A DC in the direction east to west. At the point of measurement, Earth's magnetic field is horizontally north and its strength is 5.0×10^{-5} T.

Question 2

Which one of the following best gives the direction of the electromagnetic force on the powerline?

A. horizontally west

B. horizontally north

C. vertically upwards

D. vertically downwards

Question 3

The magnitude of the force on **each metre** of the powerline is best given by

A. 5.0×10^{3} N

B. 5.0×10^{2} N

C. 5.0×10^{-2} N

D. 5.0×10^{-5} N

Question 4

The gravitational field strength at the surface of Mars is 3.7 N kg^{-1}.

Which one of the following is closest to the change in gravitational potential energy when a 10 kg mass falls from 2.0 m above Mars's surface to Mars's surface?

A. 3.7 J

B. 7.4 J

C. 37 J

D. 74 J

$$\Delta E = mg\Delta h$$
$$= 10 \times 3.7 \times 2$$

Use the following information to answer Questions 5 and 6.

A light globe operates at 12 V_{RMS} AC that is supplied by a 240 V to 12 V transformer connected to a 240 V_{RMS} mains supply.

Question 5

In the transformer, the ratio of turns in the primary (input) to turns in the secondary (output) is

A. 20:1

B. 1:20

C. 28:1

D. 1:28

Question 6

If the light globe is to be operated using a battery instead of the mains supply, what voltage should the battery have for the light globe to operate correctly?

A. 12 V

B. 17 V

C. 8.5 V

D. 6.0 V

Question 10 (6 marks)

A spacecraft with astronauts on board is in orbit around Mars at an altitude of 1.6×10^6 m above the surface of Mars.

The mass of Mars is 6.4×10^{23} kg and its radius is 3.4×10^6 m.

Take the universal gravitational constant, G, to be 6.7×10^{-11} N m^2 kg^{-2}.

The mass of the spacecraft is 2.0×10^4 kg.

a. Calculate the period of orbit of the spacecraft around Mars. Show your working. 4 marks

$r = 3.4 \times 10^6 + 1.6 \times 10^6 = 5.0 \times 10^6$ m

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

$T = \sqrt{\frac{4\pi^2 \times (5 \times 10^6)^3}{6.67 \times 10^{-11} \times 6.4 \times 10^{23}}}$

$\boxed{1.1 \times 10^4 \text{ s}}$

b. The altitude of the spacecraft above the surface of Mars is doubled so that the spacecraft is now in a new stable orbit.

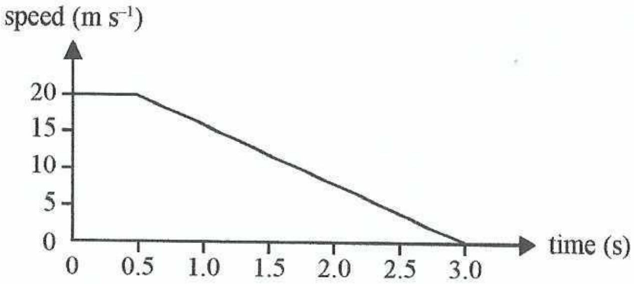
Will the speed of the spacecraft be greater, the same or lower in this new orbit? Explain your reasoning. 2 marks

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

$r \uparrow \rightarrow v \downarrow$

Question 6

Lisa is driving a car of mass 1000 kg at 20 m s^{-1} when she sees a dog in the middle of the road ahead of her. She takes 0.50 s to react and then brakes to a stop with a constant braking force. Her speed is shown in the graph below. Lisa stops before she hits the dog.



Which one of the following is closest to the magnitude of the braking force acting on Lisa's car during her braking time?

A. 6.7 N
B. 6.7 kN
C. 8.0 kN
D. 20.0 kN

✓ **Question 7** 16 %

At one point on Earth's surface at a distance R from the centre of Earth, the gravitational field strength is measured as 9.76 N kg^{-1}.

Which one of the following is closest to Earth's gravitational field strength at a distance $2R$ **above** the surface of Earth at that point?

A. 1.08 N kg^{-1}
B. 2.44 N kg^{-1}
C. 3.25 N kg^{-1}
D. 4.88 N kg^{-1}

$g_1 = \frac{GM}{r_1^2}$

$g_2 = \frac{GM}{r_2^2}$

$\frac{g_2}{g_1} = \frac{r_1^2}{r_2^2}$

$g_2 = \left(\frac{r_1}{r_2}\right)^2 g_1$

$= \frac{9.76}{9}$

$r_1 = R$

$r_2 = R + 2R = 3R$

Question 9 (8 marks)

The spacecraft *Juno* has been put into orbit around Jupiter. The table below contains information about the planet Jupiter and the spacecraft *Juno*. Figure 11 shows gravitational field strength ($N\ kg^{-1}$) as a function of distance from the centre of Jupiter.

Data

mass of Jupiter	1.90×10^{27} kg
radius of Jupiter	7.00×10^{7} m
mass of spacecraft *Juno*	1500 kg

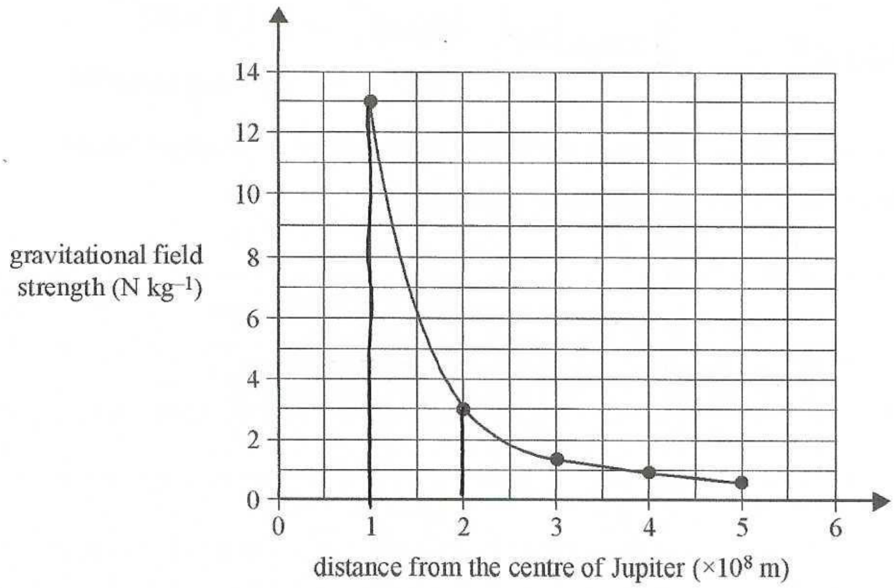


Figure 11

a. Calculate the gravitational force acting on *Juno* by Jupiter when *Juno* is at a distance of 2.0×10^{8} m from the centre of Jupiter. Show your working. 2 marks

From the graph $g = 3\ N kg^{-1}$ 57%

$F = mg = 1500 \times 3$

4500 N

b. Use the graph in Figure 11 to estimate the magnitude of the change in gravitational potential energy of the spacecraft *Juno* as it moves from a distance of 2.0×10^8 m to a distance of 1.0×10^8 m from the centre of Jupiter. Show your working.

3 marks

33%

Area under the graph 14 squares

1 square $1 \times 0.5 \times 10^8 = 5 \times 10^7 \text{ J kg}^{-1}$

$\Delta E_{gp} = M \times \text{Area} = 1500 \times 14 \times 5 \times 10^7$

1.05×10^{12} J

Accepted $9 \times 10^{11} - 1.13 \times 10^{12}$

12 – 15 squares

c. Europa is a moon of Jupiter. It has a circular orbit of radius 6.70×10^8 m around Jupiter.

Calculate the period of Europa's orbit. Show your working.

3 marks

51%

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

$T = \sqrt{\frac{4\pi^2 r^3}{GM}} = \sqrt{\frac{4\pi^2 \times (6.7 \times 10^8)^3}{6.67 \times 10^{-11} \times 1.9 \times 10^{27}}}$

3.06×10^5 s

Question 10 (4 marks)

Members of the public can now pay to take zero gravity flights in specially modified jet aeroplanes that fly at an altitude of 8000 m above Earth's surface. A typical trajectory is shown in Figure 12. At the top of the flight, the trajectory can be modelled as an arc of a circle.

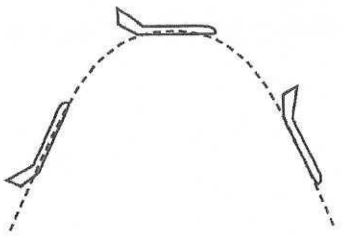


Figure 12

a. Calculate the radius of the arc that would give passengers zero gravity at the top of the flight if the jet is travelling at 180 m s^{-1}. Show your working. 2 marks

63%

$v^2 = gr \quad r = \frac{v^2}{g} = \frac{180^2}{9.8}$

3306 m

3.3×10^3

b. Is the force of gravity on a passenger zero at the top of the flight? Explain what 'zero gravity experience' means. 2 marks

42%

Force of gravity is not zero.
Zero gravity experience means $N = 0$.

SECTION A – Multiple-choice questions

Instructions for Section A

Answer **all** questions in pencil on the answer sheet provided for multiple-choice questions.

Choose the response that is **correct** or that **best answers** the question.

A correct answer scores 1; an incorrect answer scores 0.

Marks will **not** be deducted for incorrect answers.

No marks will be given if more than one answer is completed for any question.

Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Take the value of g to be 9.8 m s^{-2}.

Question 1

Engineers are measuring the force due to Earth's magnetic field on the supply wire of a railway line. The wire runs east–west and carries a current of 2000 A. Earth's magnetic field is horizontal and due north at the place where measurements are taken.

The engineers measure the force on a 10 m length of the wire to be 1.0 N.

Which one of the following best gives the strength of Earth's magnetic field at this point?

A. 2.0×10^{-8} T

B. 5.0×10^{-5} T

C. 5.0×10^{-4} T

D. 200 T

Question 2

Data

mass of Mercury	3.34×10^{23} kg
radius of Mercury	2.44×10^{6} m
universal gravitational constant, G	6.67×10^{-11} N m^2 kg^{-2}

The gravitational field strength at the surface of Mercury is close to

A. 9.00×10^{6} N kg^{-1}

B. 9.81 N kg^{-1}

C. 3.74 N kg^{-1}

D. 3.74×10^{-2} N kg^{-1}

$$g = \frac{GM}{r^2} = \frac{6.67 \times 10^{-11} \times 3.34 \times 10^{23}}{(2.44 \times 10^{6})^2}$$

SECTION B

Instructions for Section B

Answer **all** questions in the spaces provided. Write using blue or black pen.

Where an answer box is provided, write your final answer in the box.

If an answer box has a unit printed in it, give your answer in that unit.

In questions where more than one mark is available, appropriate working **must** be shown.

Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Take the value of g to be 9.8 m s^{-2}.

Question 1 (9 marks)

A 1500 kg weather satellite is in a circular orbit around Earth at an altitude of 850 km. The radius of Earth is 6400 km.

a. Calculate the period of the satellite in seconds. Take the mass of Earth to be 6.0×10^{24} kg and the universal gravitational constant, G, to be 6.7×10^{-11} N m^2 kg^{-2}. Show your working. 3 marks

$\frac{T^2}{r^3} = \frac{4\pi^2}{GM}$ $r = 6400 + 850 = 7250$ km

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

$T = \sqrt{\frac{4\pi^2 \times (7.25 \times 10^6)^3}{6.67 \times 10^{-11} \times 6 \times 10^{24}}}$

6.1×10^3 s

b. The controllers of the satellite use its motors to move the satellite into a higher orbit.

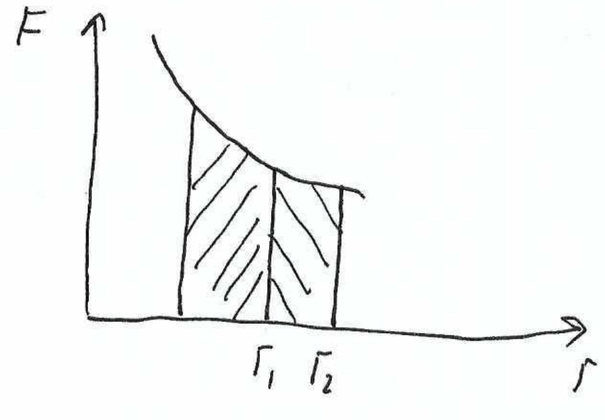
i. Will this increase, decrease or have no effect on the speed of the satellite? Justify your answer. 3 marks

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

As $r \uparrow$ $v \downarrow$

ii. Will this increase, decrease or have no effect on the gravitational potential energy of the satellite? Take the surface of Earth as the zero of gravitational potential energy. Justify your answer. 3 marks

When satellite moves to higher orbit it's gravitational potential energy increases. As it moving from r_1 to r_2 area under the graph increases, so energy does.



Question 4 (9 marks)

Charon, a moon of Pluto, has a circular orbit.

Data

mass of Pluto	1.3×10^{22} kg
radius of Pluto	1.2×10^{6} m
mass of Charon	1.6×10^{21} kg
radius of orbit of Charon	1.8×10^{7} m
universal gravitational constant (G)	6.67×10^{-11} N m^2 kg^{-2}

Assume that Pluto is a uniform sphere.

a. Calculate the gravitational field strength at the surface of Pluto. Show your working and include an appropriate unit. 3 marks

61%

$g = \frac{GM}{r^2} = \frac{6.67 \times 10^{-11} \times 1.3 \times 10^{22}}{(1.2 \times 10^6)^2} = 0.6$

$\boxed{0.6 \text{ N kg}^{-1}}$

b. Calculate the period of orbit of Charon. Show your working. 3 marks

30%

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

$T = \sqrt{\frac{4\pi^2 \times (1.8 \times 10^7)^3}{6.67 \times 10^{-11} \times 1.3 \times 10^{22}}}$

$= 5.2 \times 10^5$

$\boxed{5.2 \times 10^5 \text{ s}}$

c. Scientists wish to place a spacecraft, of mass 1000 kg, in an orbit of the same radius as Charon. Three students, Rick, Melissa and Nam, are discussing the situation and have different opinions.

Rick says as the spacecraft is lighter, it will have to move at a greater speed than Charon to achieve the same orbit.

Melissa says the spacecraft would need to move at the same speed as Charon.

Nam says the spacecraft would need only to move at a lower speed as it is lighter than Charon.

Evaluate these three opinions. Detailed calculations are **not** necessary. 3 marks

23%

Melissa is correct

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

Orbital characteristics of a satelite including speed are independent of the mass of the satelite.

Question 6 (6 marks)

a. Explain the conditions for a satellite to be in a geostationary orbit (that is, stationary over a fixed point on Earth's surface). There is no need to calculate the actual radius of the orbit. 3 marks

Orbit must be over the equator. 2 %

Orbital period = 24 hours

~~Mov~~ Rotates in the same direction as Earth.

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

b. Roger states that there are a number of situations on or near Earth's surface where a person may 'feel weightless'.

Emily states that this is impossible. It is only possible to feel weightless in deep space where there is no, or very little, gravitational force on a person.

Is Emily correct or incorrect? Explain your answer. 3 marks

36 %

Emily is incorrect

Apparent weightlessness can exist where gravitational field $\neq 0$ if normal reaction force = 0. Free fall.

Question 7 (7 marks)

A spacecraft is placed in orbit around Saturn so that it is Saturn-stationary (the Saturn equivalent of geostationary – the spacecraft is always over the same point on Saturn's surface on the equator).

The following information may be needed to answer Question 7:

- mass of Saturn 5.68×10^{26} kg
- mass of spacecraft 2.0×10^{3} kg
- period of rotation of Saturn 10 hours 15 minutes

a. Calculate the period, in seconds, of this spacecraft's orbit. 1 mark

86 %

10 h 15 m = 36 900 s

36 900 s

b. Calculate the radius of the orbit of the spacecraft to achieve the spacecraft orbit in **part a.** Show your working. 3 marks

55%

$r = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$

$= \sqrt[3]{\frac{6.67\times10^{-11} \times 5.8\times10^{26} \times 36900^2}{4\pi^2}}$

$= 1.1\times10^{8}$

1.1×10^{8} m

c. Would an astronaut in this spacecraft feel weightless? Explain your answer. 3 marks

41%

Yes, astronaut will feel weightless.
He will be in the state of apparent weigtlessness as normal reaction force = 0 and he is in a free fall.

Question 5 (6 marks)

A distant star has a planet orbiting it. The period of the planet's circular orbit is 1200 hours. The radius of the planet's orbit is measured to be 7.0×10^{10} m.

a. Use the data above to calculate the mass of the star. Show your working. 4 marks

43%

$$M = \frac{4\pi^2 R^3}{G T^2}$$

$$= \frac{4\pi^2 \times (7\times10^{10})^3}{6.67\times10^{-11} \times (1200\times3600)^2} = 1.1\times10^{31}$$

$\boxed{1.1\times10^{31} \text{ kg}}$

b. Is it possible to determine the mass of this planet from the data above? Give a reason for your answer. 2 marks

16%

No, it is impossible as in

$$\frac{mv^2}{R} = \frac{GmM}{R^2}$$

$$\frac{4\pi^2 R m}{T^2} = \frac{GmM}{R^2}$$

mass of the planet cancels out. Orbital characteristics are independent of the mass of the satelite

Question 7 (6 marks)

A satellite is in a geostationary circular orbit over Earth's equator. It remains vertically above the same point X on the equator, as shown in Figure 9.

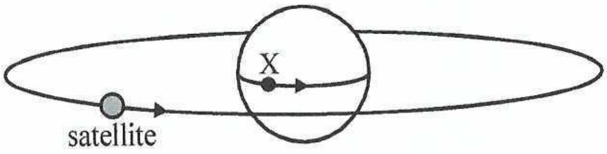


Figure 9

Data

mass of Earth	$M_E = 6.0 \times 10^{24}$ kg
radius of Earth	$R_E = 6.4 \times 10^6$ m
mass of satellite	1000 kg
universal gravitational constant	$G = 6.7 \times 10^{-11}$ N m^2 kg^{-2}

a. Calculate the period of the orbit of the satellite. 1 mark

Same as Earth $24 \times 60 \times 60 = 86400$ 41%

86 400 s

b. Calculate the radius of the orbit of the satellite from the centre of Earth. 2 marks

32%

$r = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$

$= \sqrt[3]{\frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times 86400^2}{4\pi^2}}$

$= 4.2 \times 10^7$

4.2×10^7 m

Question 8

a. Before the spacecraft *Apollo 11* landed on the Moon, it travelled around the Moon in an orbit with a period of 2.0 hours.

Calculate the **height** of *Apollo 11* above the Moon's surface during its orbit of the Moon. Take the orbit to be circular.

Take $G = 6.67 \times 10^{-11}$ m^3 kg^{-1} s^{-2}; $M_{moon} = 7.36 \times 10^{22}$ kg; $R_{moon} = 1.74 \times 10^6$ m.

$$R = \sqrt[3]{\frac{GMT^2}{4\pi^2}} = \sqrt[3]{\frac{6.67\times10^{-11} \times 7.36\times10^{22} \times 7200^2}{4\pi^2}}$$

$$= 1.86\times10^6 \text{ m}$$

$$h = 1.86\times10^6 - 1.74\times10^6 = 1.21\times10^5$$

$\boxed{1.21\times10^5 \text{ m}}$

45%

4 marks

b. Explain the terms 'weightlessness' and 'apparent weightlessness', and identify which term best applies to the astronauts in *Apollo 11* during its orbit of the Moon.

Weightlessness – absence of gravity.
Apparent weightlessness – normal reaction force = 0, object is in a free fall.
Astronauts are in the state of apparent weightlessness.

2 marks

45%

END OF AREA OF STUDY 1

The following information relates to Questions 21–23.

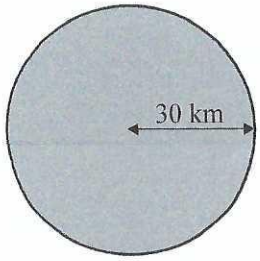


Figure 8

Assume that somewhere in space there is a small spherical planet with a radius of 30 km. By some chance a person living on this planet visits Earth. He finds that he weighs the same on Earth as he did on his home planet, even though Earth is so much larger.

Earth has a radius of 6.37×10^6 m and a mass of 5.98×10^{24} kg.

The acceleration due to gravity (g), or the gravitational field, at the surface of Earth, is approximately 10 N kg^{-1}.

The universal gravitational constant, G, = 6.67×10^{-11} Nm^2 kg^{-2}.

Question 21

What is the value of the gravitational field on the surface of the visitor's planet?

As weight is the same, g is the same

10 N kg^{-1}

74%

1 mark

Question 22

What is the mass of the visitor's planet?

Explain your answer by showing clear working.

$$g = \frac{GM}{r^2} \qquad M = \frac{gr^2}{G}$$

$$= \frac{10 \times (3 \times 10^4)^2}{6.67 \times 10^{-11}}$$

$$= 1.35 \times 10^{20}$$

1.35×10^{20} kg

41%

2 marks

The visitor's home planet is in orbit around its own small star at a radius of orbit of 1.0×10^9 m. The star has a mass of 5.7×10^{25} kg.

Question 23

What would be the period of the orbit of the visitor's planet? Show working.

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

$$T = \sqrt{\frac{4\pi^2 \times (1 \times 10^9)^3}{6.67 \times 10^{-11} \times 5.7 \times 10^{25}}}$$

$$= 3.22 \times 10^6$$

3.22×10^6 s

2 marks

40%

END OF AREA OF STUDY 1

The following information relates to Questions 18–20.

The International Space Station (ISS) is currently under construction in Earth orbit. It is incomplete, with a current mass of 3.04×10^5 kg. The ISS is in a circular orbit of 6.72×10^6 m from the centre of Earth.

In the following questions the data below may be needed.

Mass of ISS	3.04×10^5 kg
Mass of Earth	5.98×10^{24} kg
Radius of Earth	6.37×10^6 m
Radius of ISS orbit	6.72×10^6 m
Gravitational constant	6.67×10^{-11} N m^2 kg^{-2}

Question 18

What is the weight of the ISS in its orbit?

$$F_g = \frac{GMM}{r^2} = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times 3.04 \times 10^5}{(6.72 \times 10^6)^2}$$

$$= 2.69 \times 10^6$$

2.69×10^6 N

53%

2 marks

Question 19

What is the period of orbit of the ISS around Earth?

$$T = \sqrt{\frac{4\pi^2 r^3}{GM}} = \sqrt{\frac{4\pi^2 \times (6.72 \times 10^6)^3}{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}}$$

$$= 5.48 \times 10^3$$

5.48×10^3 s

45%

2 marks

Question 20

When the ISS is completed in 2011, its mass will have increased to 3.70×10^5 kg.

Will the period of orbit of the ISS around Earth then be greater, the same, or less?

Same

Same as period is independent from the mass of the satelite 61%

1 mark

2009

The following information relates to Questions 7–9.

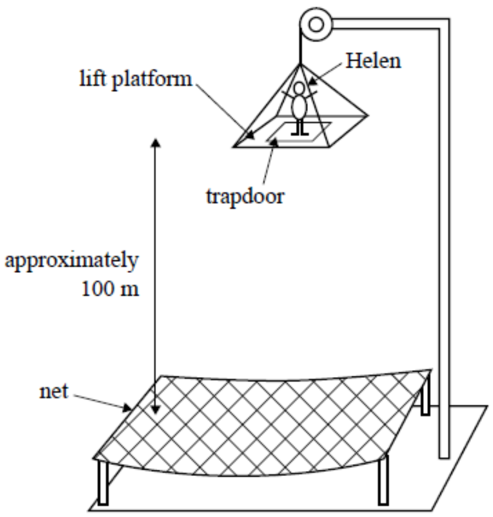


Figure 3

A ride in an amusement park allows a person to free fall without any form of attachment. A person on this ride is carried up on a platform to the top. At the top, a trapdoor in the platform opens and the person free falls. Approximately 100 m below the release point, a net catches the person.
A diagram of the ride is shown in Figure 3.
Helen, who has a mass of 60 kg, decides to take the ride and takes the platform to the top. The platform travels vertically upward at a constant speed of 5.0 m/s.

Question 7 64%

What is Helen's apparent weight as she travels up?
Since Helen was moving up at a constant speed the net force acting on her was zero. Therefore the normal reaction force (apparent weight) equalled the gravity force = mg = 60 x 9.8 = 588 N.

As the platform approaches the top, it slows to a stop at a uniform rate of 2.0 m s^{-2}.

Question 8 43%

What is Helen's apparent weight as the platform slows to a stop?
$mg - N = ma$ $N = m(g - a)$ $N = 60 \times 7.8 = 468\ N$

Helen next drops through the trapdoor and free falls. Ignore air resistance.
During her fall, Helen experiences 'apparent weightlessness'.

Question 9 26%

In the space below explain what is meant by apparent weightlessness. You should make mention of gravitational weight force and normal or reaction force.
Apparent weight is the normal reaction force. Helen was in free fall, accelerating at the value of the gravitational field, so the normal force was zero. Since there was a gravitational field, there was still a weight force acting on Helen. It was common for students to incorrectly state that the normal force equalled the gravitational force, thereby cancelling each other out and creating a feeling of weightlessness. Others referred to Helen reaching terminal velocity and equated this

to apparent weightlessness. Another common approach was to explain apparent weightlessness in terms of an astronaut in orbit in a spaceship; however this did not relate to the question.

The following information relates to Questions 13 and 14.

The **Jason 2** satellite reached its operational circular orbit of radius 1.33 × 10^7 m on 4 July 2008 and then began mapping the Earth's oceans.

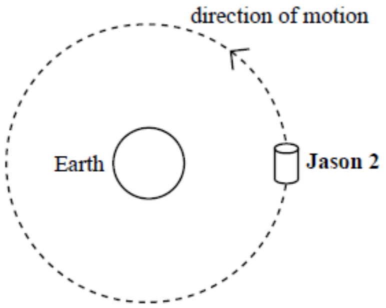
mass of the Earth = 5.98 × 10^24 kg

mass of **Jason 2** = 525 kg

G = 6.67 × 10–11 N m^2 kg^–2

Question 13 26%

On the figure below, draw one or more labelled arrows to show the direction of any force(s) acting on **Jason 2** as it orbits Earth. You can ignore the effect of any astronomical bodies other than the Earth.



*Students were required to draw **and** label arrow(s) to represent any force(s) acting on the satellite orbiting the Earth. The required answer was one arrow from the satellite and pointing towards the Earth, with a label **weight** or **gravitational force** or **mg** or $\boldsymbol{F_g}$. It was not acceptable to label it $\boldsymbol{F_{net}}$ or **centripetal force** or g. Many students incorrectly included an arrow tangential to the path. Others had two arrows pointing towards the Earth. A small number of students did not attempt this question.*

Question 14 51%

What is the period of orbit of the **Jason 2** satellite?

For the orbiting satellite $4\pi^2Rm/T^2 = GMm/R^2$, therefore $T = \sqrt{4\pi^2 R^3 / G M}$

$= \sqrt{4\pi^2(1.33 \times 10^7)^3/(6.67\times10^{-11})(5.98\times10^{24})} = 1.53 \times 10^4$ s.

2008

Figure 8 shows the orbit of a comet around the Sun.

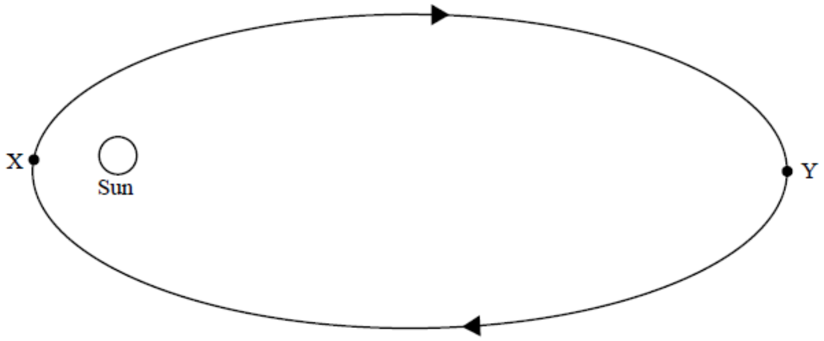


Figure 8

Question 15 **28%**
Describe how the **speed** and **total energy** of the comet vary as it moves around its orbit from X to Y.
The speed decreased from X to Y and the total energy remained constant.

Use the following information to answer Questions 16 and 17.
In March 1999 the Mars Global Surveyor (Figure 9) entered its fi nal circular orbit about Mars, sending information
about Mars back to Earth.
Below is some data that you may find useful when answering Questions 16 and 17.
G = 6.67 × 10^–11 N m^2 kg^–2
Mass of Mars Global Surveyor = 930 kg
Mass of Mars = 6.42 × 10^23 kg
Radius of orbit of Mars Global Surveyor = 3.83 × 10^6 m
Question 16 **58%**
Calculate the gravitational force on the Mars Global Surveyor.
You must show your working.
Applying the formula $F = G\frac{mM}{r^2} =$ *showed that the gravitational force was 2.7 × 10^3 N.*

Question 17 **45%**
Calculate the period of orbit of the Mars Global Surveyor.
You must show your working.

$$From\ \frac{mv^2}{r} = \frac{GmM}{r^2}\ \ and\ \ v = \frac{2\pi r}{T},\ \ T = \sqrt{\frac{4\pi^2 r^3}{GM}} = 7.2 \times 10^3\ s$$

2007

The dwarf planet Pluto was discovered in 1930, and was thought to be the outermost member of our solar system. It can be considered to orbit the Sun in a circle of radius 6 billion kilometres (6.0 × 10^12 m). In 2003 a new dwarf planet, Eris, was discovered. It has approximately the same mass as Pluto, but the average radius of its orbit around the Sun is 10.5 billion kilometres (10.5 × 10^12 m).

Question 12

Which of the choices **(A–D)** below gives the best estimate of the ratio gravitational attraction of the Sun on Eris to gravitational attraction of the Sun on Pluto?

A. 0.33
B. 0.57
C. 1.75
D. 3.06

A

$$\frac{F_E}{F_P} = \frac{r_P^2}{r_E^2} = \frac{6^2}{10.5^2}$$

The period of Pluto around the Sun is 248 Earth-years

Question 13 36%

How many Earth-years does Eris take to orbit the Sun?

$\frac{T_E^2}{T_P^2} = \frac{r_E^3}{r_P^3}$ T=574 years

2006

The planet Mars has a mass of 6.4 × 10^23 kg. The Mars probe that was launched in August 2005 is now orbiting Mars in an orbit with an average radius of 3.00 × 10^7 m

Question 16 30%

What is the period of the orbit in seconds?

$$T = \sqrt{\frac{4\pi^2 r^3}{GM}} = 1.58 \times 10^5\ s$$

2004

A spacecraft of mass 400 kg is placed in a circular orbit of period 2.0 hours about Earth.

Question 1 45%

Show that the spacecraft orbits at a height of 1.70 × 10^6 m above the surface of Earth. M_E = 5.98 × 10^24 kg, R_E = 6.37 × 10^6 m

$$From\ \frac{mv^2}{r} = \frac{GmM}{r^2}\ \ and\ \ v = \frac{2\pi r}{T}\ \ \ r = \sqrt[3]{\frac{GM}{4\pi^2 T^2}}$$

$= 8.06 \times 10^6\ Subtract\ radius\ of\ Earth\ and\ you\ will\ get\ required\ number.$

Pictures of astronauts in the orbiting spacecraft are 'beamed' back to Earth. In these pictures the astronauts appear to be 'floating' around inside the spacecraft.

Question 4 24%

Explain why the astronauts appear to be floating around inside the orbiting spacecraft.

The key to understanding why the astronauts appear to be 'floating' inside the spacecraft involves an understanding of apparent weightlessness. The key point here is that both the astronauts and spacecraft are in free fall; that is, they are both accelerating towards Earth at g. Furthermore, this implies that there will be no normal contact force between the astronaut and the spacecraft in this situation.

2003

The spacecraft, Odyssey, has been in a circular orbit around Mars at an altitude of 400 km.

Question 1 47%

Show that the period of this orbit is approximately 2 hours.

R_{Mars} = 3.4 × 10^6 m, M_{Mars} = 6.4 × 10^23 kg

$$T = \sqrt{\frac{4\pi^2 r^3}{GM}}\ , where\ r = 3.4 \times 10^6 + 4 \times 10^5\ m \quad T = 7.1 \times 10^3\ s$$

Last year astronomers discovered a new body, Quaoar, in our solar system just beyond Pluto. This very large asteroid orbits our Sun in a near perfect circle of radius 6.5 × 10^12 m.

Two enthusiastic astronomy students, Kiera and Darla, were talking about what it would be like to travel and land on Quaoar. Both agreed that they would feel a very small gravitational effect if they were on the surface of Quaoar. However, Darla did not agree with Kiera's reason for the small gravitational effect.

Darla explained that a very small gravitational effect would be felt because Quaoar has such a small mass and that the gravitational force between the asteroid and himself would be very small.

Kiera explained that because Quaoar was in orbit around the Sun they would experience apparent weightlessness because both they and Quaoar would be accelerating towards the Sun at the same rate.

Question 4 15%

Was Kiera correct or incorrect? Explain your answer.

Students needed to address the following key points when considering whether Kiera was correct or incorrect:

• Kiera was in fact incorrect

• at the surface of Quaoar a person would be subject to the combined gravitational force of the sun and that of Quaoar itself

• because both the person and Quaoar were in orbit around the sun then this part of Keira's explanation was correct but she has neglected the gravitational field due to the mass of Quaoar itself

• a person on the surface of Quaoar would feel a contact force between themselves and the surface and hence would not feel weightless.

2002

Currently, the space probe, Cassini, is **between** Jupiter and Saturn (see Figure 2 opposite). Cassini's mission is to deliver a probe to one of Saturn's moons, Titan, and then orbit Saturn collecting data. Below is astronomical data that you may find useful when answering the following questions.

mass of Cassini	2.2×10^3 kg
mass of Jupiter	1.9×10^{27} kg
mass of Saturn	5.7×10^{26} kg
Saturn day	10.7 hours

Question 3 32%

Calculate the magnitude of the total gravitational field experienced by Cassini when it is 4.2 × 10^11 m from Jupiter and 3.9 x 10^11 m from Saturn.

The expected answer for this question involved subtracting the gravitational field due to Saturn from that due to Jupiter according to the equation.

$$g = G\left(\frac{M_J}{r_J^2} - \frac{M_S}{r_S^2}\right) = 4.7 \times 10^{-7}\ N\ kg^{-1}$$

When Cassini arrives in the vicinity of Saturn this year, scientists want it to remain above the same point on Saturn's equator throughout one complete Saturn day. This is called a 'stationary' orbit.

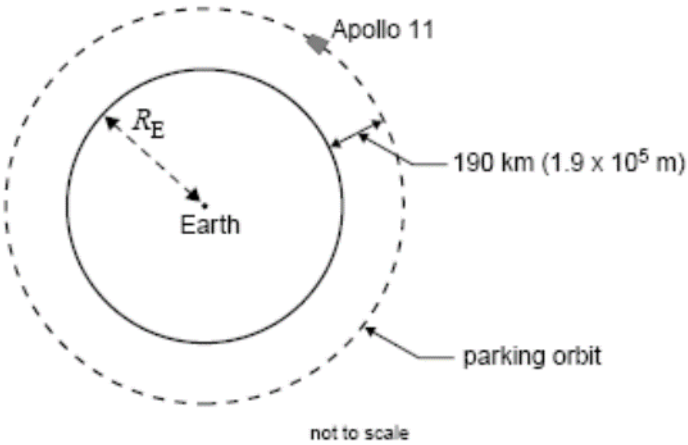
Question 6 31%

Calculate the radius of this 'stationary' orbit.

$$r = \sqrt[3]{\frac{GM}{4\pi^2 T^2}} = 1.1 \times 10^8\ m$$

2000

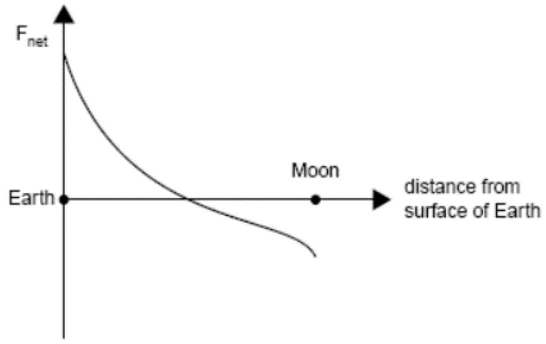
When people went to the Moon in the Apollo 11, the spacecraft was initially placed in a 'parking orbit' 190 km above Earth's surface. This is shown below



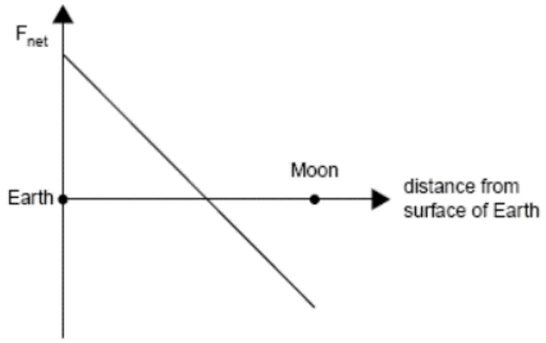
Question 6 58%

Which **one** of the following graphs (**A**–**F**) best represents the **net gravitational force** acting on Apollo 11 as it travels from its parking orbit to the Moon?

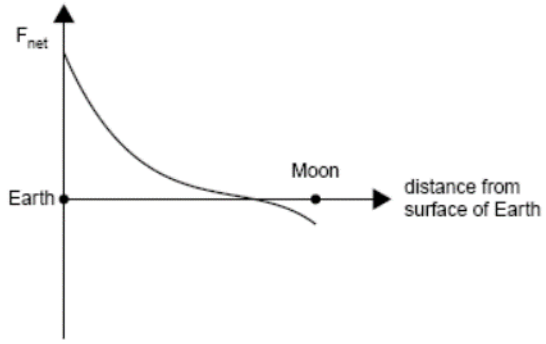
A.



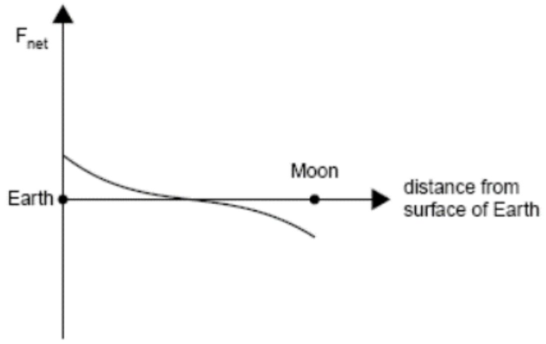
B.



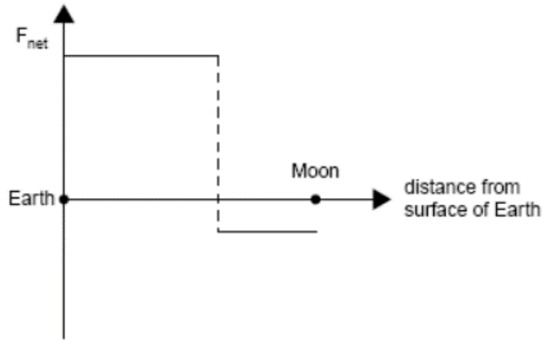
C.



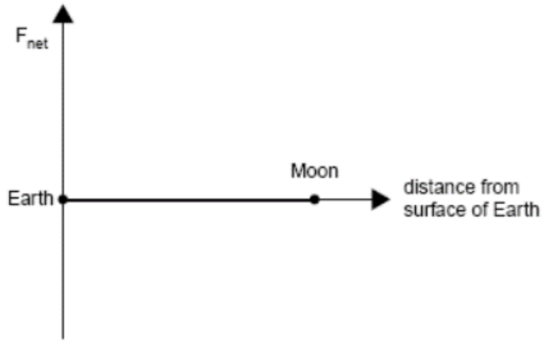
D.



E.



F.

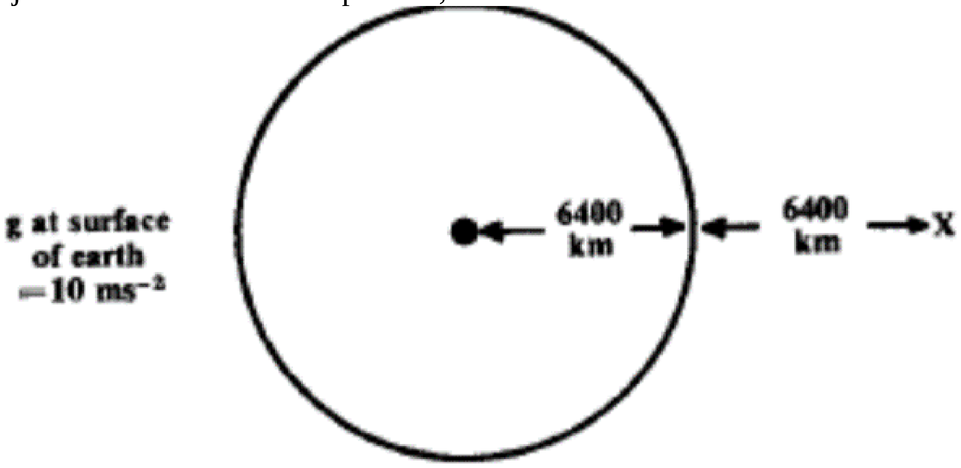


C

The force decreases according to the inverse square law as Apollo 11 travels away from Earth, reaching zero at a point closer to the Moon. The direction of the force now changes as Apollo 11 experiences a net force directed towards the moon. The magnitude of this net force again increases as Apollo 11 approaches the Moon.

1982

An object is let fall from rest at point X, 6400 km above the surface of the earth.



Question 26   28%

How far will it fall in the first second?

Since the object is at 2 x r_e, the acceleration due to gravity will be ¼ of that on the surface of the earth.

Therefore g = 2.45.

We can make the assumption the distance it falls in the first second will be small enough to enable us to consider the field to be constant.

$\therefore x = ut + \frac{1}{2} gt^2$

$\therefore x = 0 + \frac{1}{2} \times 2.45 \times 1^2$

$\therefore x = 1.225$ m