PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



EXAM QUESTION PACK

TOPIC 12: GRAVITATIONAL FIELDS

SCORE	PERCENTAGE
/155	%

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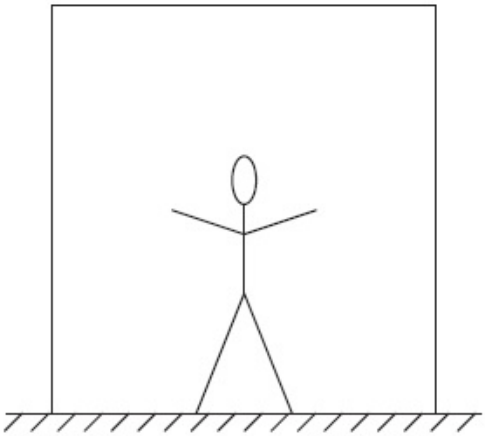
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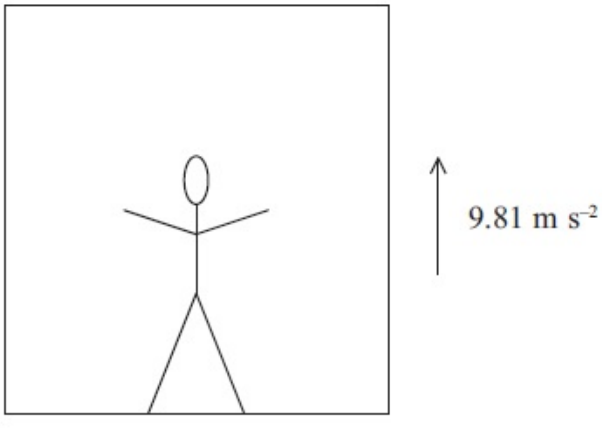
Q1.

* Einstein imagined a person in a large box without windows. He suggested that, with no way to see outside, the person could not tell whether they were:

- experiencing gravity on Earth
- in deep space far away from any effects of gravity but being accelerated at a rate of 9.81 m s^{-2}.



Stationary on Earth



Accelerating in deep space

Account for Einstein's suggestion by explaining in each case what a person standing in the box would feel through their feet. It may help to assume the person has mass *m*.

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(Total for question = 6 marks)

Q2.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The acceleration of free fall at the surface of the Earth is 9.81 m s^{-2}.
The mass of the Earth is M and the diameter of the Earth is D.

Which of the following gives the acceleration of free fall, in m s^{-2}, at the surface of a planet with diameter $\frac{D}{2}$ and mass $\frac{M}{9}$?

☐ **A** $\frac{9.81 \times 2}{9}$

☐ **B** $\frac{9.81 \times 4}{9}$

☐ **C** $\frac{9.81 \times 2}{3}$

☐ **D** $\frac{9.81 \times 9}{4}$

(Total for question = 1 mark)

Q3.

The Shanghai Maglev Train is the first commercially operated high-speed magnetic levitation train in the world, connecting the airport and central Shanghai.



The total distance travelled is 29.9 km and the total journey time is 440 s. The train starts from rest and reaches a speed of 97 m s^{-1} in 120 s.

(i) Calculate the average acceleration of the train during the first 120 s.

(2)

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Average acceleration of train = ...

(ii) Calculate the average speed of the train for the period following the 120 s acceleration.

(3)

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Average speed of train = ...

(Total for question = 5 marks)

Q4.

Astronomers observing stars at the centre of our galaxy have suggested that many of them are orbiting a supermassive black hole. The mass of this black hole is 9.2×10^{36} kg.

Calculate the orbital period for a star in a circular orbit at a distance of 1.9×10^{14} m from a black hole of this mass.

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Orbital period = ...

(Total for question = 3 marks)

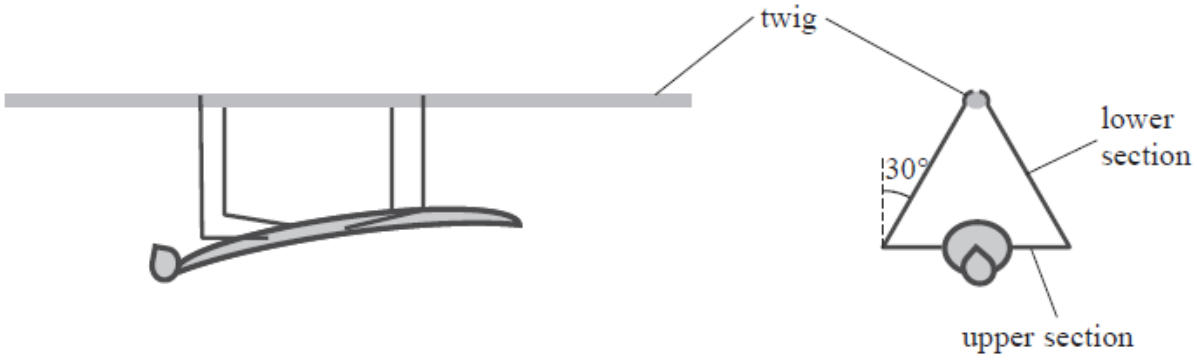
Q5.

The photograph shows a praying mantis hanging from a thin twig. Four of the praying mantis's six legs are in contact with the twig. The tension in the legs balances the weight to keep the praying mantis stationary.



© Robert Clamp

(a) The diagrams show a simplified model of the situation. For each leg in contact with the twig, the upper section is horizontal and the lower section is at an angle of 30° to the vertical.



Side view End view

(i) Calculate the tension in the lower section of each leg in contact with the twig assuming that

these tensions are all equal.

mass of praying mantis = 5.4×10^{-4} kg

(4)

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Tension = ...

(ii) A student suggests that the tension in each leg in contact with the twig is 25% of the weight of the praying mantis. State why this is **not** correct.

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(b) The praying mantis moves around the twig so that it is now standing upright and on top of the twig.

State the difference between the stress in the legs when the praying mantis is beneath the twig and when it is on top of the twig.

(1)

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(Total for question = 6 marks)

Q6.

In 1990, the Hubble Space Telescope (HST) was launched into a low Earth orbit above the Earth's atmosphere.

HST orbits the Earth in a circular orbit with a speed of 7.59 km s^{-1}.

mass of Earth = 5.97×10^{24} kg
radius of Earth = 6.37×10^{6} m

(i) Show that the height of HST above the surface of the Earth is about 6×10^{5} m.

(3)

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(ii) Calculate the increase in the gravitational potential energy as HST is raised, from its initial position at the Earth's surface, to its orbital height.

mass of HST = 11 600 kg

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Increase in gravitational potential energy = ...

(iii) A student suggests that giving HST more energy than that required in (ii) would result in the satellite orbiting at a greater height and with a greater speed.

Assess the validity of the student's suggestion.

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(Total for question = 9 marks)

Q7.

Communication satellites were first proposed in 1945 by the science fiction author Athur C. Clarke. In an article published in the magazine Wireless World he asked whether rocket stations could give worldwide radio coverage.

In the article Clarke states:

"There are an infinite number of possible stable orbits, circular and elpitical, in which a rocket would remain if the initial conditions were correct. A velocity of 8 km s^{-1} applies only to the closest possible orbit, one just outside the atmosphere, and the period of revolution would be about 90 minutes. As the radius of the orbit increases the velocity decreases, since gravity is diminishing and less centrifugal force is needed to balance it."

with permission of Electronics World www.electronicsworld.co.uk

(a) State what is meant in the article by the phrase "gravity is diminishing", and criticise the statement that "less centrifugal force is needed to balance (the satellite)".

(3)

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(b) (i) By deriving an appropriate equation, show that the orbital speed of a satellite decreases as the radius of orbit increases.

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(ii) By deriving an appropriate equation, show that the orbital period of a satellite increases as the orbital speed decreases.

(2)

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(c) The period T of a satellite in a circular orbit is given by the equation

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

Where r is the radius of orbit and M is the mass of the Earth

Calculate the period of a satellite in an orbit 4.0×10^5 m above the surface of the Earth.

mass of the Earth = 5.98×10^{24} kg

radius of the Earth = 6.36×10^6 m

(2)

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Period of satellite = ...

(d) After a time the radius of a satellite's orbit will start to decrease due to the resisitive forces acting on the satellite from the atmosphere. As this happens the satellite speeds up.

Describe the energy changes occurring as the radius of the orbit decreases.

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(Total for question = 12 marks)

Q8.

* Describe the similarities and differences between electric and gravitational fields.

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(Total for question = 6 marks)

Q9.

Electric and gravitational fields have a number of similarities and differences.

An electric field is produced by a point charge and a gravitational field is produced by a point mass.

Which of the following statements applies to both of these fields?

☒ **A** The field causes a force on all particles.

☒ **B** The force caused by the field can be attractive or repulsive.

☒ **C** At a distance x from the centre of the field, field strength is proportional to x^2.

☒ **D** At a distance x from the centre of the field, potential is proportional to $1/x$.

(Total for question = 1 mark)

Q10.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Which of the following statements about the fields is **not** correct?

☒ **A** Field strength is a vector.

☒ **B** Potential is always less than 0.

☒ **C** Potential is proportional to $\frac{1}{\text{distance from proton}}$

☒ **D** Field strength is proportional to $\frac{1}{(\text{distance from proton})^2}$

(Total for question = 1 mark)

Q11.

In 2015 the Messenger spacecraft crashed into the surface of the planet Mercury after four years in orbit observing the surface of Mercury.

Messenger's orbit was highly elliptical, varying between 200 km and 15 000 km above the surface of Mercury. Messenger completed one full orbit every 12 hours.

mass of Messenger spacecraft = 565 kg
mass of planet Mercury = 3.30×10^{23} kg
radius of planet Mercury = 2430 km

It has been suggested that the same orbital period of about 12 hours could have been achieved if Messenger was in a circular orbit 7690 km above the surface of Mercury.

(i) Determine whether this suggestion is correct.

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(ii) The elliptical orbit chosen had advantages over this circular orbit.

Explain **one** advantage.

(2)

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(Total for question = 6 marks)

Q12.

The gravitational field strength at the surface of the Earth is 9.8 N kg^{-1}. A satellite is orbiting at a height above the ground equal to the radius of the Earth.

The gravitational field strength, in N kg^{-1}, at this height is

- **A** 0.0
- **B** 2.5
- **C** 4.9
- **D** 9.8

(Total for Question = 1 mark)

Q13.

The first satellite weather picture was taken in 1960. Today more than 200 weather satellites are in use. Some of these satellites are in a geostationary orbit around the Earth, so that they remain at the same point above the Earth's surface all the time.

(a) (i) Show that the magnitude of the gravitational field strength g at a point outside of the Earth is given by

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

where r is the distance of the point from the centre of the Earth and M is the mass of the Earth.

(2)

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(ii) Use this expression together with an expression for the centripetal acceleration to show that the radius of a satellite's orbit is given by

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

where T is the time for one orbit of the satellite.

(3)

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(iii) Hence calculate a value for the radius of the geostationary orbit.

$$M = 6.0 \times 10^{24} \text{ kg}$$

(3)

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Radius = ...

(b) State why all geostationary satellites are in an orbit above the Earth's equator.

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(Total for question = 9 marks)

Q14.

Exoplanets are planets orbiting stars other than our own Sun. Most exoplanets discovered so far are giant planets similar to the planet Jupiter. The exoplanet Kepler-7b has a mass about 0.43 times the mass of Jupiter, and a radius about 1.6 times the radius of Jupiter.

Take the gravitational field strength at the surface of Kepler-7b to be g_K, and the gravitational field strength at the surface of Jupiter to be g_J.

The ratio $\frac{g_K}{g_J}$ is

- **A** 0.17
- **B** 0.27
- **C** 0.69
- **D** 1.1

(Total for question = 1 mark)

Q15.

In 2014 the Rosetta spacecraft reached the comet Churyumov-Gerasimenko.
Rosetta went into orbit around the comet.

The following table gives some data for the comet.

Mass / kg	1.0×10^{13}
Density / kg m^{-3}	470

The comet is irregular in shape but can be modelled as a spherical object.

(a) Show that a sphere with this mass and density has a radius of about 1700 m.

(3)

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(b) Calculate the gravitational field strength at the surface of the comet.

(2)

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Gravitational field strength = ...

(c) A probe was sent from the Rosetta spacecraft to land on the comet.
The probe bounced off the surface of the comet and took 1 hour and 50 minutes to return to the surface again.

Calculate the height above the surface of the comet that the probe would have reached. Assume that the acceleration of the probe is constant with the magnitude calculated in (b).

(2)

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Height = ...

(d) Explain, using gravitational field theory, how the actual height reached would compare with the value calculated in part (c).

You may assume there are no resistive forces such as air resistance.

(3)

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(Total for question = 10 marks)

Q16.

Which of the following is **not** a similarity between gravitational fields and electric fields?

(1)

☒ **A** For a point charge or point mass, the field follows the inverse square law.

☒ **B** For a point charge or point mass, the field is radial.

☒ **C** Both fields act at a distance.

☒ **D** Both fields act on all particles.

(Total for question = 1 mark)

Q17.

The Moon has an orbit around the Earth of radius 3.86×10^8 m, with a time period of 2.36×10^6 s.

(a) (i) Using the data provided, show that the product GM is about 4.1×10^{14} m^3 s^{-2}, where M is the mass of the Earth.

(3)

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(ii) At the surface of the Earth g is measured to be 9.81 N kg^{-1}.

Calculate a value for the radius of the Earth.

(2)

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Radius of the Earth = ...

(b) It has been estimated that, at any one time, there may be about a thousand small asteroids orbiting the Earth. These asteroids orbit at between five to ten times the distance of the Moon from the Earth. Most make no more than one orbit before being pulled out of this orbit by the Sun.

Suggest why these asteroids do not remain in a stable orbit around the Earth.

(2)

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(Total for question = 7 marks)

Q18.

Mars is our nearest neighbour in the solar system. In August 2003 the distance between Mars and the Earth was the closest in recorded history at 5.6×10^{10} m.

mass of Mars = 6.4×10^{23} kg

mass of Earth = 6.0×10^{24} kg

Calculate the gravitational force between Mars and the Earth when they were at this distance.

(2)

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Gravitational force = ...

(Total for question = 2 marks)

Q19.

Astronomers observing stars at the centre of our galaxy have suggested that many of them are orbiting a supermassive black hole. The mass of this black hole is 9.2×10^{36} kg.

The star S0-2 is in a highly elliptical orbit around the position of the black hole.

At its point of closest approach, S0-2 is at a distance of 1.8×10^{13} m from the centre of the black hole.

At the most distant point of its orbit, S0-2 is 2.7×10^{14} m from the black hole.

(i) Show that the change in gravitational potential between the closest and most distant points in this orbit is about 3×10^{13} J kg^{-1}.

(2)

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(ii) At its point of closest approach, the star is travelling at a speed of 8.1×10^{6} m s^{-1}.

Calculate the speed of S0-2 at the furthest point in its orbit using the change in gravitational potential.

mass of S0-2 = 2.4×10^{31} kg

(3)

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Speed = ...

(Total for question = 5 marks)

Q20.

In February 2021 the spacecraft Perseverance Rover landed on Mars. When the spacecraft was 11.0 km above the surface of Mars, parachutes opened to slow the descent. The parachutes detached from the spacecraft when it was 2.1 km above the surface of Mars.

Calculate the change in gravitational potential energy of the spacecraft during the parachute section of its descent.

mass of spacecraft = 1030 kg
mass of Mars = 6.39×10^{23}kg
radius of Mars = 3390 km

(3)

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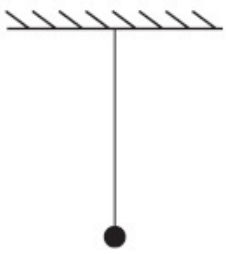
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Change in gravitational potential energy of the spacecraft =
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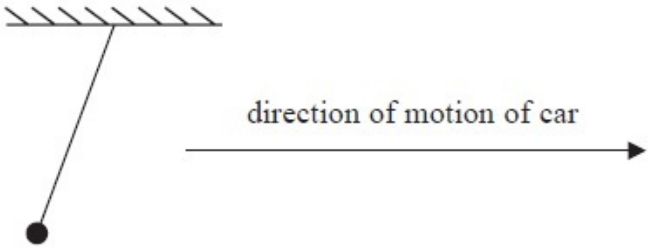
(Total for question = 3 marks)

Q21. Many hand held devices such as smartphones and tablet computers contain accelerometers. These allow changes in orientation of the device to be tracked.

A student models a simple accelerometer by attaching a small mass on a string to the roof of a car.



When the car starts moving, the string is seen to change position as shown below.



(a) (i) Complete a free body force diagram for the mass when the car starts moving.

(2)

(ii) Draw a vector diagram, in the space below, to show how the resultant force on the mass is produced.

(2)

(iii) When the string is at 7° to the vertical, show that the acceleration of the car is about 1 m s^{-2}.

(2)

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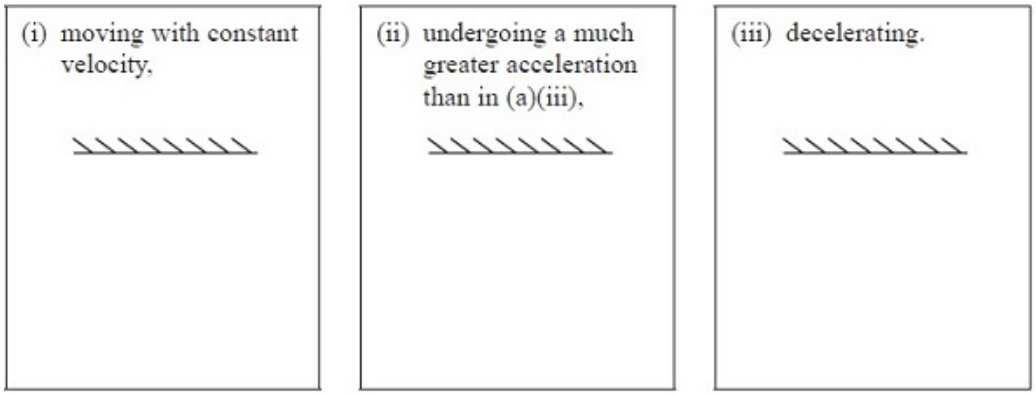
(b) Sketch the positions of the mass and string when the car is moving in the same direction and is:

(i) moving with constant velocity,

(ii) undergoing a much greater acceleration than in (a)(iii),

(iii) decelerating.

(3)



(c) Explain why the string would **not** become horizontal, however great the acceleration.

(2)

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(d) Suggest why many devices contain 3 accelerometers, arranged at right angles to each other.

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(Total for Question = 12 marks)

Q22.

A small satellite has a weight of 1200 N at the Earth's surface. It is launched into a circular orbit with radius equal to twice the radius of the Earth. The weight of the satellite in this orbit is

☒ **A** 0 N

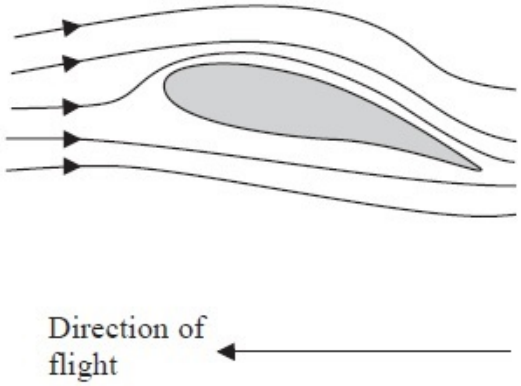
☒ **B** 300 N

☒ **C** 600 N

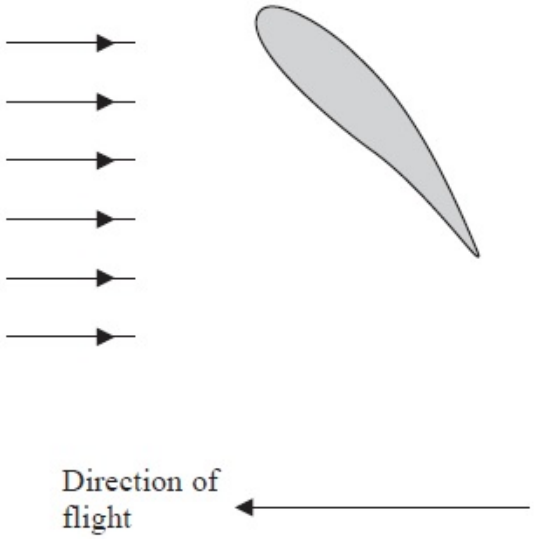
☒ **D** 1200 N

(Total for question = 1 marks)

Q23. The cross section of the wing of a bird is an aerofoil shape.



In order to fly higher, a bird can tilt its wings more. If it tilts them too much, as shown in the diagram below, the air flow above the wing becomes turbulent.



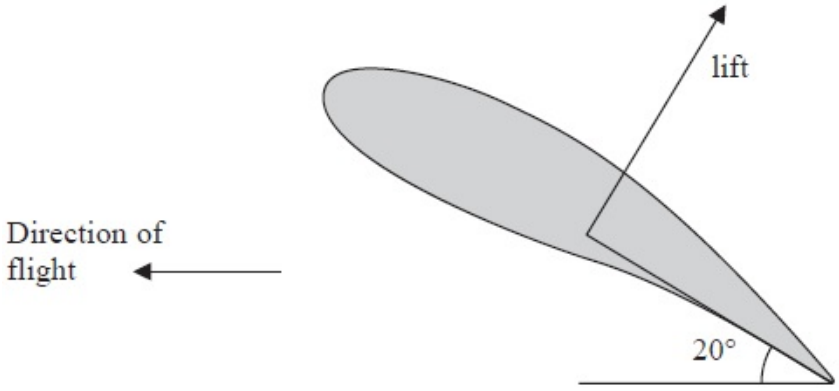
(a) Complete the diagram above to show the airflow around the wing.

(2)

(b) The tilting of the wing results in the air exerting a force on the wing which is called lift. The lift force acts perpendicular to the wing.

The total vertical component of the lift produced by both wings when tilted at an angle of 20° to the horizontal is enough to keep the bird flying at a constant height.

mass of bird = 0.063 kg



(i) Show that the total lift acting on the bird is about 1 N.

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(ii) Assuming that the only forces acting on the bird are the weight and lift, calculate its acceleration at this instant.

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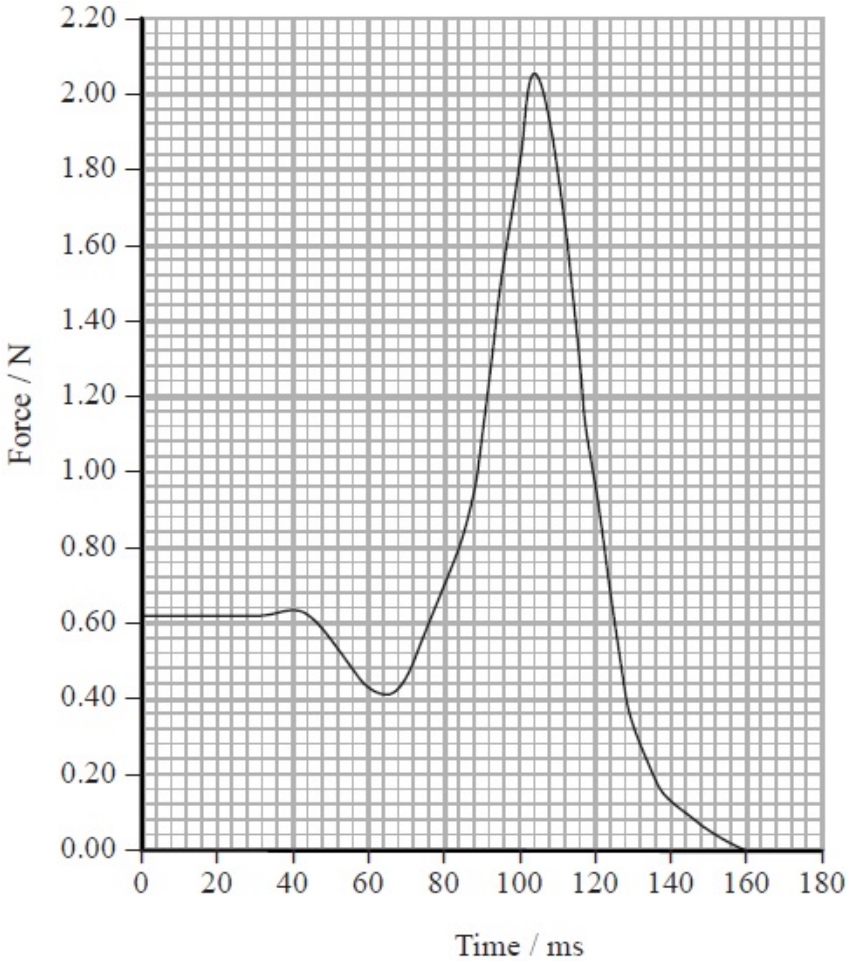
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Acceleration = ...

(c) When some birds take off from the ground there is no lift initially. These birds push off from the ground with their legs.

The following graph shows the downward force exerted by the leg on the ground during take off.



(i) With reference to Newton's laws explain how the downward force from the leg enables the bird to take off.

(4)

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(ii) Use the graph to calculate the maximum acceleration of the bird during take off.

mass of bird = 0.063 kg

(3)

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Maximum acceleration = ...

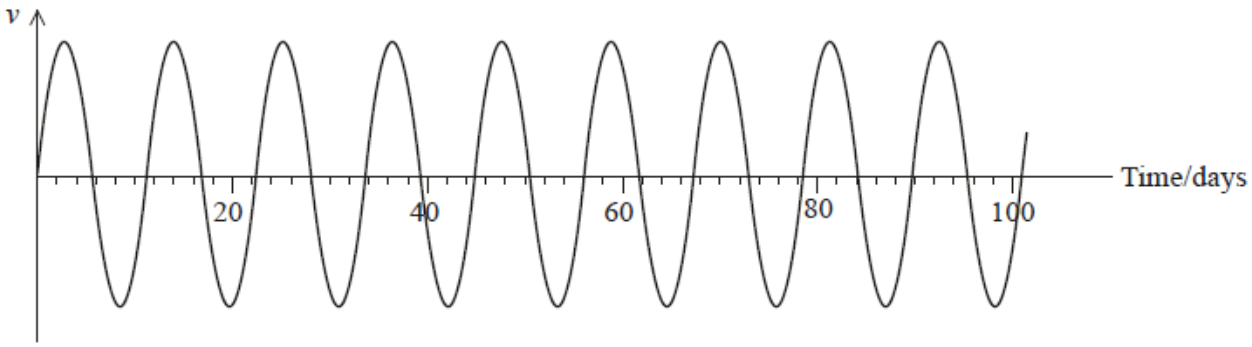
(Total for Question = 15 marks)

Q24.

In 2016 astronomers announced the discovery of an Earth-like planet orbiting Proxima Centauri, the closest star to the Sun.

The planet was detected because of the small movement of the star as the planet orbited. The movement was detected using the Doppler shift in the frequency of light travelling to the Earth.

The graph shows how the component of the star's velocity *v* towards the Earth varied over time.



(i) Use the graph to show that the angular velocity of the planet is about 6×10^{-6} radian s^{-1}.

(3)

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(ii) The mass of Proxima Centauri is 0.12 times the mass of the Sun.

Determine the distance of the planet from Proxima Centauri.

mass of Sun = 1.99×10^{30} kg

(3)

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Distance = ...

(Total for question = 6 marks)

Q25.

Astronauts on the 1971 Apollo 14 mission to the Moon brought back many rock samples. It is now believed that one of these contains a piece of rock that originated on Earth about 4 billion years (4×10^9 years) ago.

The piece of rock is believed to have been launched into space when an asteroid struck the Earth.

The gravitational potential between the Earth and the Moon due to the combined effect of their gravitational fields increases to a maximum value of $-1.28\,\text{MJ}\,\text{kg}^{-1}$ at a point between them.

Calculate the minimum speed at which a rock would have to leave the Earth in order to reach the Moon.

In your calculation, you may assume the rock has zero kinetic energy when it has maximum potential energy.

mass of Earth = 5.97×10^{24} kg
radius of Earth = 6370 km

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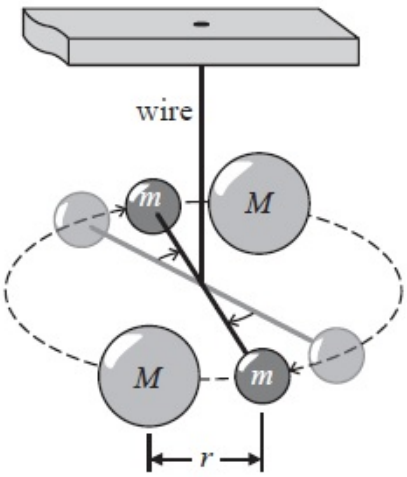
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Minimum speed = ...

(Total for question = 4 marks)

Q26. In the 18th century Henry Cavendish devised an experiment to determine the average density of the Earth. This involved the first laboratory determination of the universal gravitational constant *G*.

A light horizontal rod with a small metal sphere at each end was hung from a fixed point by a very thin wire. Two large lead spheres were then brought close to the small spheres causing the rod to oscillate and then settle into a new position of equilibrium.



(a) In a modern version of the experiment the following data was obtained:

mass of large lead sphere M = 160 kg

mass of small sphere m = 0.75 kg

distance r = 0.23 m

gravitational force between adjacent large and small spheres $F = 1.5 \times 10^{-7}$ N.

Use this data to calculate a value for G.

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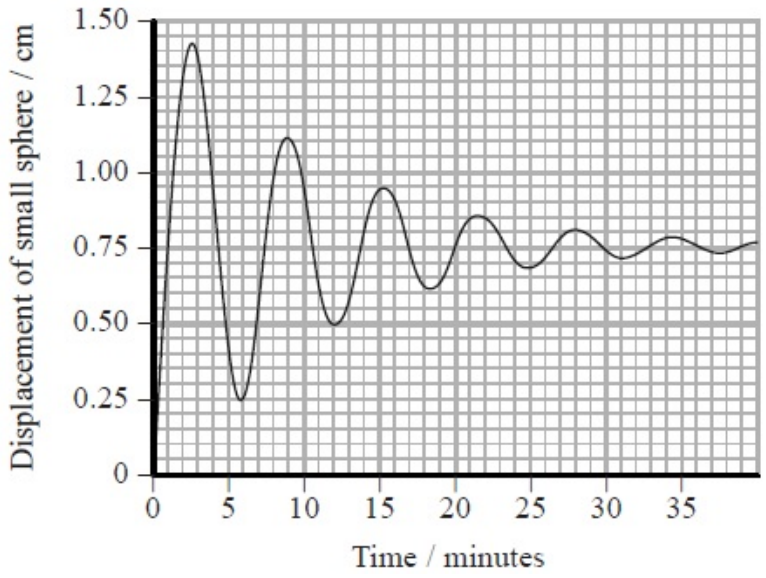
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G = ...$Nm^2\ kg^{-2}$

(b) The graph shows how the displacement of one of the small spheres varies with time.



(i) Use the graph to determine the period of oscillation of the sphere.

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Period = ...

(ii) The amplitude of the oscillation decreases with each cycle.

Explain why this effect is observed.

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(iii) It is suggested that the decrease in amplitude is exponential. Use the graph to determine if this is approximately true.

(3)

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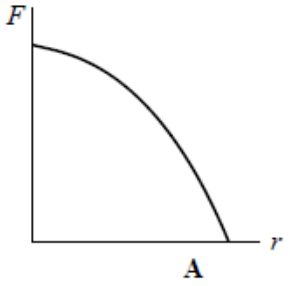
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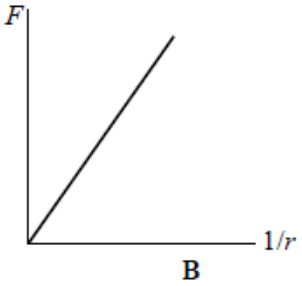
(Total for Question = 9 marks)

Q27.

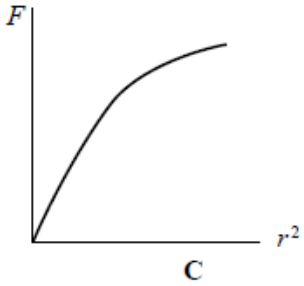
Select the graph that shows correctly the relationship between the gravitational force *F* between two masses and their separation *r*.



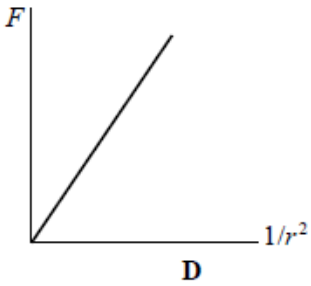
A



B



C



D

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(Total for question = 1 mark)

Q28. The force between two masses and the force between two charges can be modelled in a similar way, using gravitational and electric fields. A difference between these models is that

☒ **A** an electric field is always a radial field.

☒ **B** an electric field is always the stronger field.

☒ **C** a gravitational field cannot be shielded.

☒ **D** a gravitational field extends over an infinite range.

(Total for Question = 1 mark)

Q29.

The picture shows a toy hanging from a spring.



(Source: m4.sourcingmap.com/photo_new/20120821/g/ux_a12082100ux0119_ux_g03.jpg)

The toy has a mass of 0.066 kg. When it is hanging freely on the spring, the spring extends by 4.5cm.

When the toy is pulled downwards and released, it undergoes simple harmonic motion.

Calculate the frequency of the oscillations.

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Frequency = ...

(Total for question = 5 marks)

Q30.

Scientists are developing a space station equipped with large solar panels. The space station would be located in a geostationary orbit. The space station would transfer energy to Earth as microwaves.

(i) A space station in a geostationary orbit is above the equator and has a period of 24 hours.

Explain one advantage of locating the space station in a geostationary orbit.

(2)

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(ii) Calculate the height h of the space station above the equator when it is in a geostationary orbit.

mass of Earth = 6.00×10^{24} kg

24 hours = 8.64×10^{4} s

(4)

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h = ...

(Total for question = 6 marks)