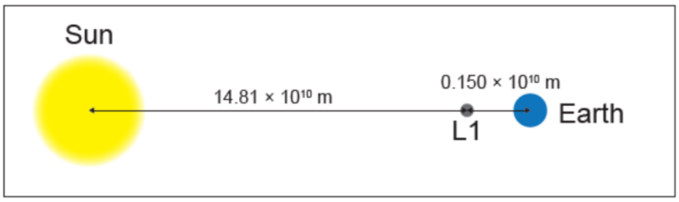
MECHANICS: CIRCULAR MOTION QUESTIONS

A SATELLITE IN AN UNUSUAL ORBIT (2021;2)

Mass of the Sun= 1.99×10^{30} kg, Mass of the Earth = 5.97×10^{24} kg

The Deep Space Climate Observatory satellite is in a very unusual orbit of the Sun, at the L1 point. In this position the satellite is attracted to both the Sun and the Earth, and it is in a stable orbit around the Sun with the same period as the Earth, keeping it always between the Sun and the Earth. The satellite is 14.81×10^{10} m from the Sun and 0.150×10^{10} m from the Earth.



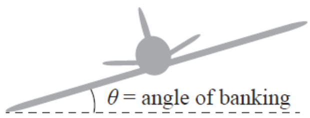
(a) A magazine article states that the L1 point is where the gravitational forces of the Sun and the Earth are balanced. Explain why this cannot be true if the satellite is moving in a stable circular orbit.

(b) The satellite, due to its L1 position between the Earth and the Sun, is under the influence of the gravitational field of the Sun as well as that of the Earth. Show that the net gravitational field strength, g, at position L1 on the satellite, if it is moving in a circular orbit and is consistent with it having a period of an Earth year (3.1536×10^7 s), is 5.88×10^{-3} N kg^{-1}.

QUESTION ONE (2020;1)

Tom flies a Boeing 737-800, which is an averaged-sized plane with a take-off mass of 7.50×10^4 kg. There are times when he flies it horizontally in a straight line, and there are times when he has to take a circular path such that the plane is banked at an angle to the horizontal. The diagrams below represent these two situations.

(a) Draw the force due to gravity and the lift force on the plane in the two situations below.



(b) Compare the size of the force due to gravity and lift force on the plane when Tom flies it horizontally in a straight line, and when he flies it in a horizontal circle banked at an angle. Give reasons why they are similar or different in each situation. *Numerical working is not necessary.*

(c) On one occasion Tom flies the plane of mass 7.50×10^4 kg in a circular path, with a speed of 54.0 m s^{-1}, banked at an angle of 35.0° to the horizontal. Calculate the radius of the circle that the plane describes. Explain your working for calculating the radius of the circular path the plane describes. *A diagram may assist your explanation.*

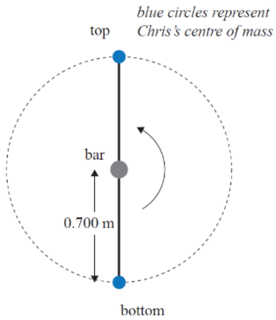
(d) Tom then flies his plane at a height of 1.28×10^4 m above the surface of the Earth. Calculate the gravitational field strength at the height Tom flies the plane.

Mass of Earth = 5.98×10^{24} kg
Radius of Earth = 6.37×10^6 m

QUESTION ONE (2019;1)

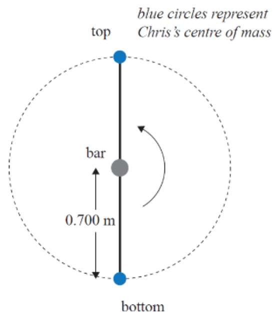
Ally and Chris are rollerblading. At one instant, Ally stops and Chris collides with her

To save himself from falling, Chris sees a horizontal bar and grabs it. He then swings on the bar in a vertical circle. Chris's motion can be simplified by analysing the motion of his centre of mass, which is 0.700 m from the bar. Assume the effects of friction are negligible.



(c) Calculate the minimum speed Chris's centre of mass would need to have at the top of the vertical circle, in order to swing up and over the bar. (Assume he continues in a circular path.)

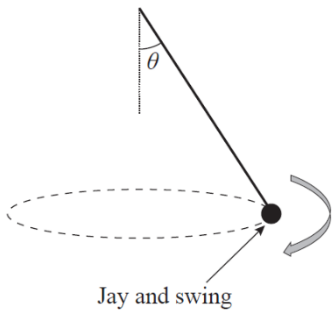
(d) Describe and explain the size and direction of the tension and weight forces at the bottom and the top positions, assuming Chris swings over the top at minimum speed. Include force labels on the diagram below to support your answer.



QUESTION THREE (2019;3)

Jay is enjoying a swing at the playground.

(d) Jay moves to a new swing that is a tyre hanging vertically on a single chain. The system is a conical pendulum. Jay travels at 2.61 m s^{-1} around a circle of radius 0.411 m. The total mass of Jay and the swing is 70.0 kg. Assume friction and the mass of the supporting chain are negligible. Calculate the tension in the chain supporting the swing and the angle of the chain from vertical.



QUESTION ONE (2018;1)

Mass of the Earth = 5.97×10^{24} kg
Radius of the Earth = 6.37×10^{6} m

The Electron Rocket developed by New Zealand company Rocket Lab has begun commercial launches of satellites from the Mahia Peninsula in Hawke's Bay. The rocket can carry a satellite of mass 1.50×10^{2} kg to a stable, circular orbit 5.00×10^{5} m above the Earth's surface.

(a) Show that the force due to gravity on the satellite in this orbit is 1270 N.

(b) The rocket, the satellite, and any space debris at the same altitude in stable, circular orbits, will all travel at the same speed. Show that this is always true by deriving the formula for orbital velocity shown and use this to determine the orbital velocity of the satellite

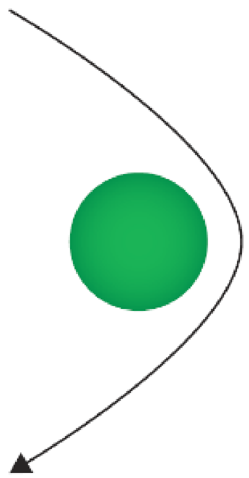
$$v_{\text{orbit}} = \sqrt{\frac{GM}{r}}$$

QUESTION ONE (2017;1)

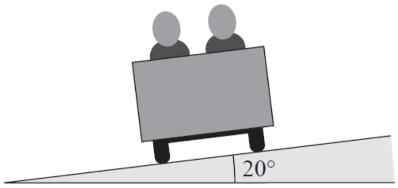
(d) When the spaceship reaches the planet, the spaceship goes into orbit around the planet with a period of 5.46×10^{3} s, and at a height of 351 km above the surface. Assume the orbit is circular. The planet has a radius of 5220 km.

(i) Calculate the mass of the planet.

(ii) On the return journey to Earth, the spaceship goes past a different planet. The spaceship's path is shown in the diagram. Explain how the spaceship's speed changes as it gets closer to the planet.



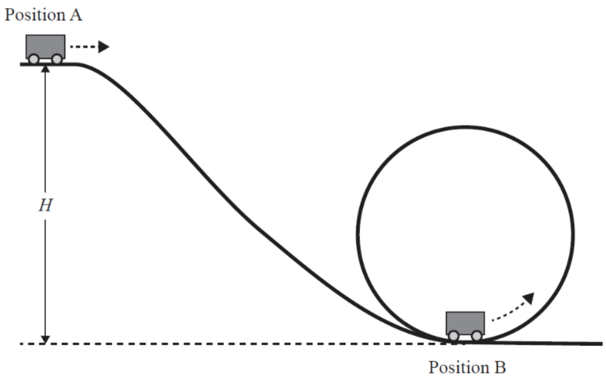
CIRCULAR MOTION (2016;1)



Alice is in a car on a ride at a theme park. The car travels along a circular track that is banked, as shown in the diagram.

(a) On the diagram, draw labelled vectors showing the two forces acting on the car. You may assume that friction is negligible.

(b) The mass of the car and passengers is 9.60×10^2 kg. The track is banked at an angle of 20°. Use a vector diagram to calculate the size of the centripetal force on the car.

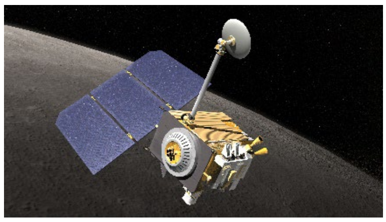


The diagram shows part of a roller coaster track with the car at two positions.

(c) Compare the force that the track exerts on the car when the car is at the top of the hill (Position A), with the force that the track exerts on the car when the car is at the bottom of the hill, entering the loop (Position B). Explain your answer.

(d) At the top of the circular loop the force that the track exerts on the car is zero. Using energy considerations, calculate the height H, of the hill if the radius of the loop is 5.0 m. You may assume that friction is negligible.

SATELLITES (2015;1)



Mass of Earth = 5.97×10^{24} kg

Universal gravitational constant = 6.67×10^{-11} N m^2 kg^{-2}

Digital television in New Zealand can be accessed by using a satellite dish pointed at a satellite in space. The satellite used to transmit the signals appears to stay still above the equator. The satellite, with a mass of 300 kg, is actually travelling around the Earth in a geostationary orbit at a radius of 4.22×10^7 m from the centre of the Earth.

(a) Name the force that is keeping the satellite in this circular orbit and state the direction in which this force is acting.

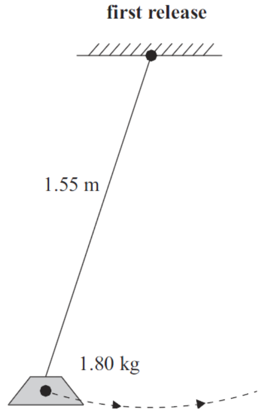
(b) Calculate the force acting on the satellite.

(c) Show that the speed of the satellite is 3.07×10^3 m s^{1}.

(d) Kepler's law states that, for any orbiting object, $T^2 \alpha\, r^3$, where r is the radius of the orbit, and T is the time period for the orbit. NASA uses a robotic spacecraft to map the Moon. The Lunar Reconnaissance Orbiter orbits the Moon at an average height of 50.0×10^3 m with a period of 6.78×10^3 s. The Moon has a radius of 1.74×10^6 m. Use Kepler's law to estimate the mass of the Moon. In your answer, you should:

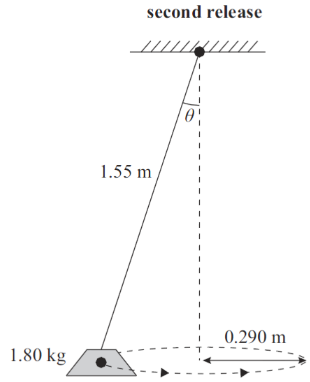
- use the relevant formulae to derive Kepler's law
- use Kepler's law to determine the mass of the Moon.

THE PENDULUM (2014;2)



A pendulum is set up, as shown in the diagram. The length of the cord attached to the bob is 1.55 m. The bob has a mass of 1.80 kg. The acceleration due to gravity of Earth = 9.81 m s^{-2}.

(b) Explain how the forces acting on the bob change the bob's speed as it travels from the point of release to the centre.

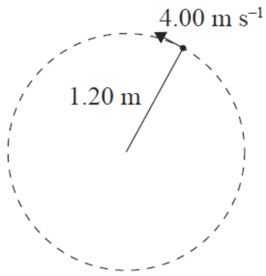


(c) The bob is released again in such a way that it swings in a horizontal circular path, with radius 0.290 m, as a conical pendulum.

(i) By first calculating the size of the angle that the cord makes with the vertical, show that the tension force in the cord is 18.0 N.

(ii) Calculate the speed that the mass must have been given when released, in order to attain a horizontal circular path at a radius of 0.290 m.

SWINGING BALLS (2013;2)



A ball on the end of a cord of length 1.20 m is swung in a vertical circle. The mass of the ball is 0.250 kg. When the ball is in the position shown in the diagram, its speed is 4.00 m s^{-1}.

(Acceleration due to gravity on Earth = 9.81 m s^{-2})

(a) Calculate the size of the centripetal force acting on the ball at the instant shown in the diagram.

(b) Explain why the ball moves fastest at the bottom of the circle.

(c)

Diagram 1

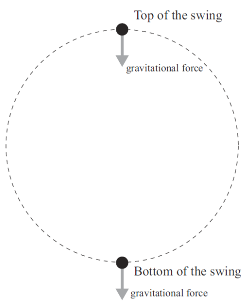
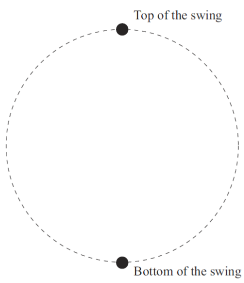


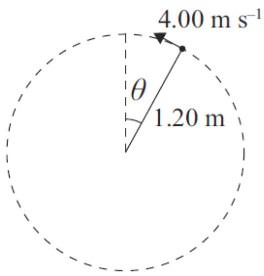
Diagram 2



(i) Diagram 1 shows the gravitational force acting on the ball at the top and bottom of the swing. Assuming the tension force is non-zero at all points, draw vectors to show the relative sizes of tension forces at the top and bottom.

(ii) Using the same scale, draw the centripetal force, on Diagram 2, at these two positions.

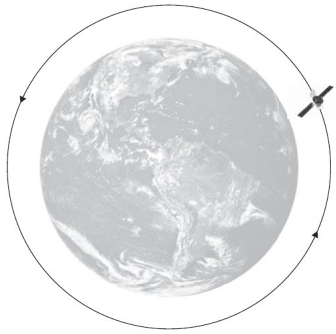
(d) Show that the minimum speed the ball must have during its circular motion is 3.43 m s^{-1} at the top. Explain your answer.



The ball drops to its minimum speed of 3.43 m s^{-1} at the top of the circle. Using conservation of energy, show that the angle at which the tangential speed of the ball is 4.00 m s^{-1}, is $\theta = 34.9°$.

GRAVITATION (2011;3)

The diagram shows a satellite in orbit around the Earth (not to scale).



Mass of the Earth = 5.97×10^{24} kg

Polar radius of the Earth = 6.36×10^{6} m

(a) Label the diagram to identify the nature and direction of the force / forces on the satellite.

(b) Calculate the net force on a 1.08×10^{3} kg satellite when it is in a polar orbit 2.02×10^{7} m above the Earth's surface.

(c) Show that the only stable orbit for the satellite orbiting at an altitude of 2.02×10^{7} m has a period of approximately 12 hours.

(d) For any object orbiting around a primary body, $R^3 \propto T^2$, where R is the radius of the orbit and T is the time period for the orbit. Show that this is true, and in doing so state the conditions required for a stable orbit and show that the conditions do not depend on the mass of the orbiting object.

(e) Discuss the particular requirements for an orbit that will keep a satellite vertically above a certain point on the Earth's surface.

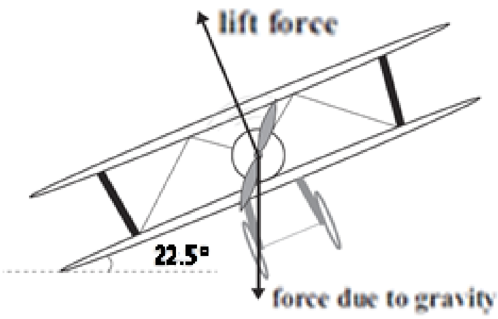
QUESTION ONE (2009;1)

Sam enjoys flying vintage aeroplanes. One of the planes Sam flies has a mass, when operating, of 635 kg.

In order to turn the plane in a horizontal circle at constant speed, Sam tilts, or banks, the plane at an angle of 22.5°. The free-body forces on the plane are shown in the diagram below.
(Acceleration due to gravity = 9.81 ms^{-2})

(a) Show that the size of the vertical component of the lift force is 6230 N.

(b) Calculate the size and direction of the resultant force on the plane during this turn.

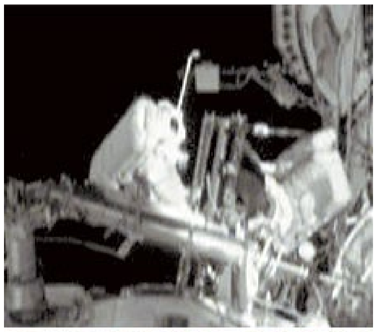


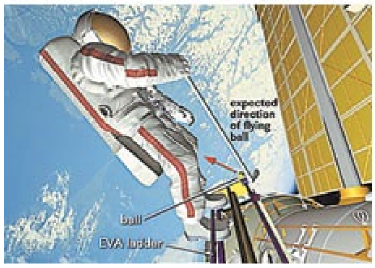
In another constant speed horizontal turn, the plane has a centripetal acceleration of 2.50 ms^{-2}.

(c) Calculate the angle of banking of the plane in this turn.

(d) For a plane to turn in a horizontal circle at a steady speed, it is necessary to tilt the plane. By considering all the forces that act on the plane, explain why this is the case.

GOLF IN SPACE (2008;4)





The universal gravitational constant = 6.67×10^{-11} m^3 kg^{-1} s^{-2}.

The radius of the Earth at the equator = 6.38×10^6 m

Mass of the Earth = 5.97×10^{24} kg

In November 2006, flight engineer Mikhail Tyurin hit a golf ball while he was in space, orbiting Earth on a mission on the International Space Station.

(a) The golf ball was a special light design with a mass of only 3.0×10^{-3} kg. The shot took place in low Earth orbit, 350 km above the surface of the Earth. Calculate the force of gravity between the ball and the Earth.

(b) Explain why the tiny, light ball could remain in a stable orbit at the same velocity as the massive, heavy space station.

SPACE – THE FINAL FRONTIER (2006;2)

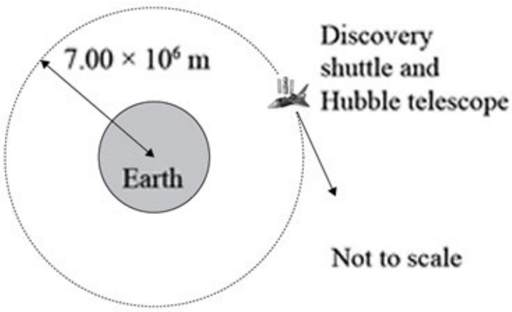
Universal Gravitational Constant = 6.67×10^{-11} Nm^2 kg^{-2}.

Mass of Earth = 5.98×10^{24} kg

Part One

The space shuttle Discovery went into a circular orbit of radius 7.00×10^6 m to release the Hubble space telescope, which was attached to the shuttle by a cable.

The diagram shows the shuttle / telescope system orbiting Earth before the shuttle and telescope separated.



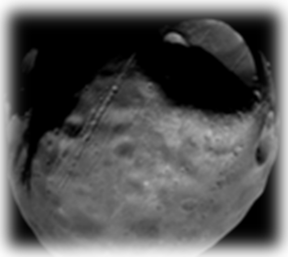
(a) Name the force that is keeping the shuttle / telescope system in this circular orbit and state the direction in which this force is acting.

(b) Calculate the value of the acceleration due to Earth's gravity (strength of Earth's gravitational field) at this height above Earth's surface. Write your answer to an appropriate number of significant figures.

(c) Weight is felt as a reaction force. Explain why an astronaut in the shuttle feels 'weightless' while in orbit about Earth.

Part Two

Phobos is one of the moons of Mars. It orbits around Mars at a mean radius 9.38×10^6 m with a period of 2.76×10^4 s.



(d) From this information, calculate the mass of Mars.

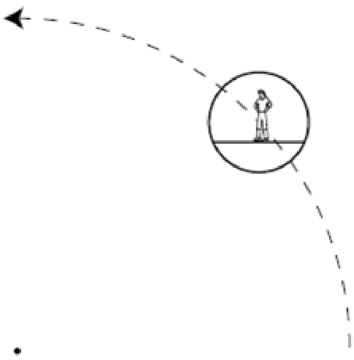
LINEAR AND ROTATIONAL MOTION (2005;1)

The London Eye is a giant rotating wheel that has 32 capsules attached at evenly spaced intervals to its outer rim. Passengers riding in the capsules get spectacular views over London, especially at the top.

Capsule

The capsules each have mass 1.0×10^4 kg and are at a distance of 68 m from the centre of the wheel. They travel at a constant speed of 0.26 m s^{-1}.

(a) Calculate the size of the centripetal force that is maintaining the vertical circular motion of a capsule about the centre of the wheel.



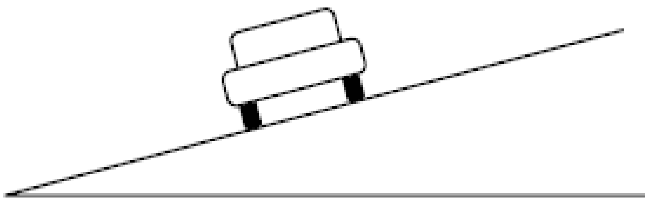
(n) On the diagram, draw a labelled free-body force diagram to show how the forces on the passenger combine to give the centripetal force causing her to move in a circle.

DRIVING ON BANKED CORNERS (2004;3)

Use the gravitational field strength = 9.80 N kg^{-1} (or acceleration due to gravity = 9.80 m s^{-2}).

Moana is driving home from work in her car. At one point, she drives around a bend in the road that has a horizontal radius of 90.0 m and banking at an angle of 6.50°. Bends in roads are banked so that cars can travel around them at the same speed as on straight parts without sliding. The mass of Moana and the car is 995 kg. Assume the friction force acting up or down the slope is zero.

(a) On the diagram, draw a free body force diagram to show the reaction force, F, and the gravitational force, F, acting on Moana's car. Label both vectors.



(b) On the diagram, draw and label an arrow to show the direction of the unbalanced force acting on the car.
(c) Calculate the value of the vertical component of the reaction force.
(d) In terms of the forces acting on the car, explain why the car will travel around the bend.
(e) Calculate the speed of the car as it drives around the bend.
(f) Explain what would happen to this speed if the banking angle of the road had been greater but friction remained zero.