SACE TWO – AUSTRALIAN CURRICULUM

PHYSICS

WORKBOOK
FIRST EDITION

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1.3 Circular Motion and Gravitation

Science Understanding

1. An object moving in a circular path at a constant speed undergoes uniform circular motion. This object undergoes centripetal acceleration, which is directed towards the centre of the circle.
2. The magnitude of the centripetal acceleration is constant for a given speed and radius and given by $a = \frac{v^2}{r}$.
3. The relationship $v = \frac{2\pi r}{T}$ relates the speed, v, to the period, T, for a fixed radius.
   - Solve problems involving the use of the formulae $a = \frac{v^2}{r}$ and $v = \frac{2\pi r}{T}$ and $\vec{F} = m\vec{a}$.
   - Use vector subtraction to show that the change in the velocity and hence the acceleration, of an object over a very small time interval is directed towards the centre of the circular path.
4. On a flat curve, the friction force between the tyres and the road causes the centripetal acceleration. To improve safety, some roads are banked at an angle above the horizontal.
   - Draw a diagram showing the force vectors (and their components) for a vehicle travelling around a banked curve.
   - Explain how a banked curve reduces the reliance on friction to provide centripetal acceleration.
5. Objects with mass produce a gravitational field in the space that surrounds them.
6. An object with mass experiences a gravitational force when it is within the gravitational field of another mass.
7. Gravitational field strength g is defined as the net force per unit mass at a particular point in the field.
8. This definition is expressed quantitatively as $g = \frac{F}{m}$, hence it is equal to the acceleration due to gravity.
   - Use Newton's Law of Universal Gravitation and Second Law of Motion to calculate the value of the acceleration due to gravity g on a planet or moon.
9. Every particle in the universe attracts every other particle with a force that is directly proportional to the product of the two masses and inversely proportional to the square of the distance between them.
10. The force between two masses, m_1 and m_2 separated by distance, r, is given by: $F = \frac{Gm_1m_2}{r^2}$
    - Solve problems using Newton's Universal Law of Gravitation.
    - Use proportionality to discuss changes in the magnitude of the gravitational force on each of the masses as a result of a change in one or both of the masses and/or a change in the distance between them.
    - Explain that the gravitational forces are consistent with Newton's Third Law.
11. Many satellites orbit the Earth in circular orbits.
    - Explain why the centres of the circular orbits of Earth satellites must coincide with the centre of the Earth.
    - Explain that the speed, and hence the period, of a satellite moving in a circular orbit depends only on the radius of the orbit and the mass of the central body (m_2) about which the satellite is orbiting and not on the mass of the satellite.
    - Derive the formula $v = \sqrt{\frac{GM}{r}}$ for the speed, v, of a satellite moving in a circular orbit of radius, r, about a spherically symmetric mass M, given that its gravitational effects are the same as if all its mass were located at its centre.
12. Kepler's Laws of Planetary Motion describe the motion of planets, their moons, and other satellites.
13. Kepler's First Law of planetary motion: All planets move in elliptical orbits with the Sun at one focus.
14. Kepler's Second Law of Planetary Motion: The radius vector drawn from the sun to a planet sweeps equal areas in equal time intervals.
    - Describe Kepler's first two Laws of Planetary Motion.
    - Use these first two Laws to describe and explain the motion of comets, planets, moons, and other satellites
15. Kepler's Third Law of Planetary Motion shows that the period of any satellite depends upon the radius of its orbit.

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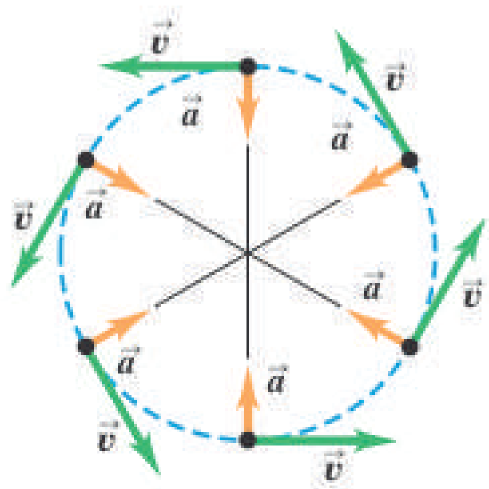
16. For circular orbits Kepler's Third Law can be expressed as: $T^2 = \frac{4\pi^2}{GM}r^3$.
    - Derive: $T^2 = \frac{4\pi^2}{GM}r^3$.
    - Solve problems using the mathematical form of Kepler's Third Law for circular orbits.
    - Solve problems involving the use of the formulae $v = \sqrt{\frac{GM}{r}}$, $v = \frac{2\pi r}{T}$ and $T^2 = \frac{4\pi^2}{GM}r^3$.
    - Explain why a satellite in a geostationary orbit must have an orbit in the Earth's equatorial plane, with a relatively large radius and in the same direction as the Earth's rotation.
    - Explain the differences between polar, geostationary, and equatorial orbits. Justify the use of each orbit for different applications.
    - Perform calculations involving orbital periods, radii, altitudes above the surface, and speeds of satellites, including examples that involve the orbits of geostationary satellites.

This topic uses the concepts of acceleration and force developed in the Stage 1, Subtopics 1.1: Motion under Constant Acceleration and 1.2 Forces.

Uniform circular motion

Uniform circular motion involves an object moving with **constant speed in a circular path**. The **velocity** at any point is at a **tangent to the circular path**.



It can be seen from the diagram above, that the object is constantly changing direction. This means that the velocity is constantly changing. Since $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$, an object undergoing uniform circular motion is accelerating.

The name given to this acceleration is **centripetal acceleration ($\vec{a}$)** and it can be shown using a vector subtraction that this acceleration is directed towards the centre of the circular path.

Centripetal acceleration

The acceleration experienced by an object undergoing uniform circular motion always act perpendicularly to the object's velocity and towards the centre of the circular path.

A vector subtraction can be used to show that the change in velocity and hence acceleration, over a short time interval is directed towards the centre of the circular path.

Consider an object moving in a circular path with constant speed v. Its velocity is at a tangent to the circular path at any instant of time. The magnitude of the velocity does not change, but its directing changes instantaneously as it moves around the circle. Consider an object moving from point A to B through over a small time interval Δt as shown in the diagram below.

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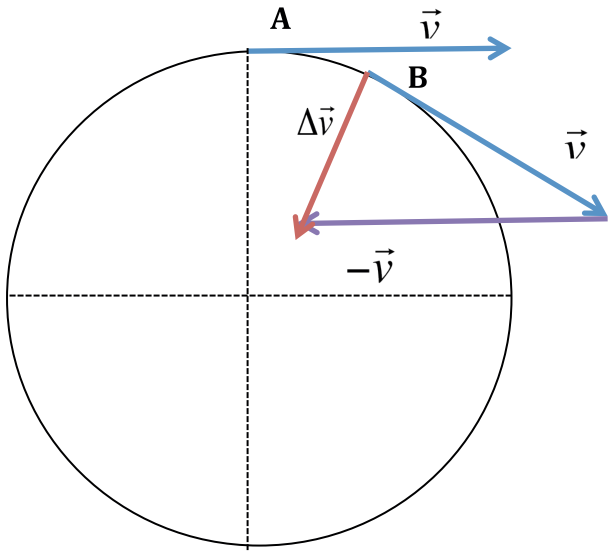


The change in velocity is given by $\Delta\vec{v} = \vec{v}_f - \vec{v}_i$. From the vector subtraction shown on the diagram, it can be seen that the change in velocity is directed towards the centre of the circular path.

Since $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$, it follows that acceleration is directed towards the centre of the circular path.

The magnitude of the centripetal acceleration is given by $a = \frac{v^2}{r}$

where v is the speed of the object undergoing uniform circular motion and r is the radius of the circular path.

The direction of the centripetal acceleration is always changing but is always directed towards the centre of the circular path.

Worked Example

A wind turbine has blades that rotate about a central axis. A typical 2.5 MW turbine has blades with a length of 50.0 m from the central axis and a blade tip speed of 84.0 ms^{-1}. Calculate the centripetal acceleration at the tip of the turbine blades.

$$a = \frac{v^2}{r} = \frac{84^2}{50} = 141\ ms^{-2} \text{ towards the central axis}$$

Force

Since $a = \frac{v^2}{r}$, then using Newton's Second Law, the magnitude of the force producing this centripetal acceleration is given by

$F = ma = \frac{mv^2}{r}$ where m is the mass of the object undergoing uniform circular motion.

Speed

Since speed is defined as the distance travelled per unit time, then for one complete circle

$v = \frac{s}{t} = \frac{2\pi r}{T}$ where T is the time taken for one revolution (called the period)
and $2\pi r$ is the distance travelled in one complete circle.

Different forces can cause a centripetal acceleration

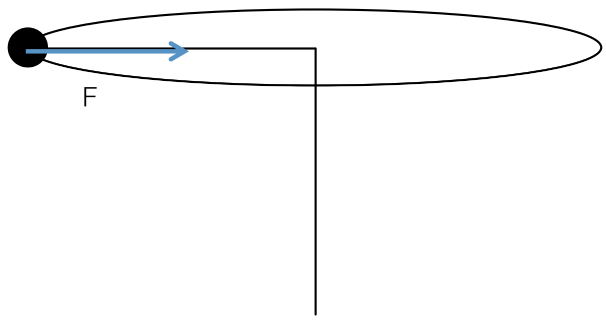
The centripetal acceleration can be caused by a

- Tension force in the case of an object being whirled in a circular path on a string.
- Frictional force in the case of a car turning a corner.
- Gravitational force in the case of an artificial satellite circling the Earth or a natural satellite such as the moon circling the Earth or a planet circling the Sun.

Each of these is discussed further in the section that follows.

1 Tension force

Consider an object being whirled in a circular path that is in a horizontal plane.



The tension force provides the centripetal acceleration. Since $F = ma = \frac{mv^2}{r}$, the tension in the string depends on three factors:

(i) The speed of motion: $F \alpha v^2$

The tension force providing the centripetal acceleration is proportional to the square of the speed of motion providing the mass (m) of the object and the radius of the circular path (r) does not change. If the speed doubles, the tension force required to keep the object in a circular path is four times larger. If the speed increases by a factor of ten, then the tension force required to keep the object in a circular path is one hundred times larger. Similarly, if the speed decreases by a factor of three, then the tension force decreases by a factor of nine.

Since increasing the speed of the object being whirled increases the tension force required to keep the object in a circular path ($F \alpha v^2$), then this means that there is a limit to the speed with which the object can be whirled because all strings have a maximum tension that they can withstand before they snap. If the object is whirled too fast, the maximum tension force that the string can provide is exceeded and the string snaps. If the force providing the centripetal acceleration of the object were suddenly removed, the object will travel off in a straight line that is tangential to the circular path.

(ii) The radius of the circular path: $F \alpha \frac{1}{r}$

An inverse proportional relationship exists between the tension force and the radius of the circular path providing the mass (m) and speed (v) of the object do not change. If the radius of the circular path is doubled then the tension force required to keep the object in a circular path is halved. If the radius of the circular path is increased by a factor of ten, then the tension force required to keep the object in a circular path is ten times smaller. Similarly, if the radius of the circular path is three times smaller, the tension force becomes is three times larger.

(iii) The mass of the object being whirled: $F \alpha m$

The tension force is proportional to the mass (m) of the object undergoing uniform circular motion providing the speed (v) and radius of the circular path (r) do not change. If the object being whirled is replaced with one having twice the mass, the tension required to keep the mass in a circular path is doubled. If the object being whirled is replaced with one having 10 times the mass, the tension required to keep the mass in a circular path is 10 times larger. Alternatively, if the object being whirled is replaced with one with a mass that is three times smaller, the tension force becomes three times smaller.

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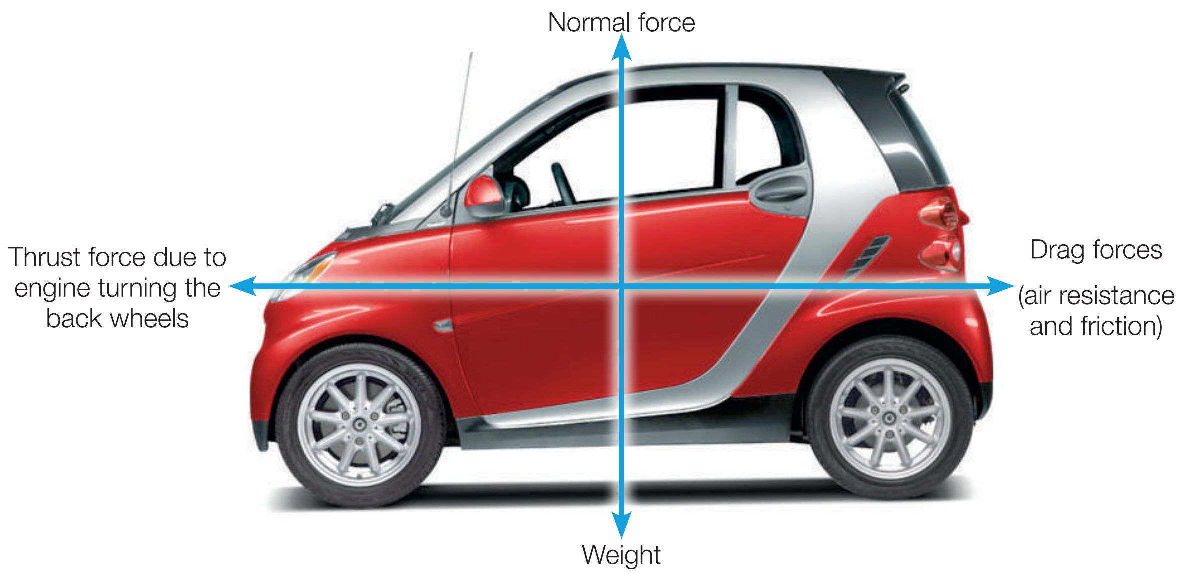
2 Frictional force

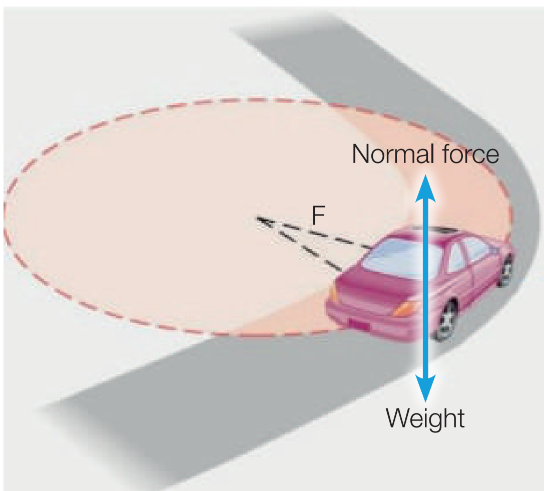
Consider a **vehicle travelling with constant velocity on a flat road**.



According to Newton's First Law of motion, a vehicle can only travel with constant velocity if the net force acting on the vehicle is zero i.e. There are no unbalanced forces acting.

The diagram above identifies the forces acting on the vehicle. The weight of the vehicle acts down towards the ground and is balanced by the normal force acting up (Newton's Third Law). In addition the forward force provided by the thrust of the engine is balanced with the total drag forces directed towards the rear of the vehicle while it travels with constant velocity.

Now consider a **vehicle turning a corner on a flat road**. The vehicle experiences a centripetal acceleration towards the centre of the circular path even though it is travelling with constant speed. The sideways frictional force between the tyres and the road provides this centripetal acceleration as shown in the diagram below.



Just like the object being whirled on a string, the magnitude of the frictional force depends on the mass of the vehicle, the speed of the vehicle and the radius of curvature of the circular path.

Since $F = ma = \frac{mv^2}{r}$, the greater the speed of the vehicle as it turns the corner, the greater the frictional force required to turn the corner ($F \alpha v^2$). There is a limit to the frictional force that can be provided by the tyres and therefore a limit to the speed with which a vehicle can safely round a corner of a given radius. If the maximum frictional force is exceeded, the vehicle slides off at a tangent to the circular path (from the point at which the frictional force is exceeded). As the tyres wear, the maximum amount of frictional force that the tyres can provide decreases and turning the corner at high speed can become dangerous.

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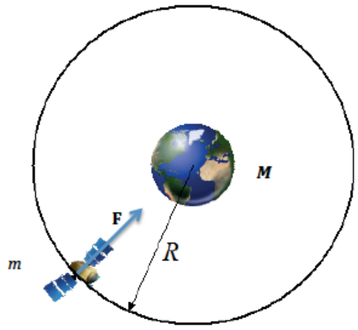
3 Gravitational force

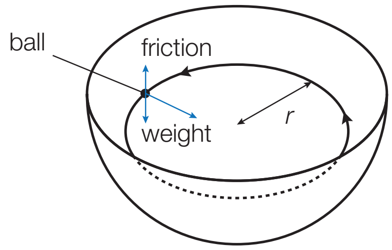


In the case of an artificial satellite circling the Earth or a planet (including Earth) circling the Sun, the gravitational force provides the centripetal acceleration. The magnitude of the force is given by $F = ma = \frac{mv^2}{r}$ where m is the mass of the satellite, r is the radius of orbit and v is the speed of the satellite. This force is equivalent to $F = \frac{Gm_1m_2}{r^2}$ as described later in this chapter.

4 Normal force

A ball can be made to move in a circular path inside a bowl. The wall of the bowl provides a force that is directed towards the centre of the circular path. This force is called a normal force and provides the centripetal acceleration for uniform circular motion.

The normal force provides the centripetal acceleration when a railway carriage or our local O-Bahn bus moves around a circular section of a track.



A train moving around a circular section of track

The O-Bahn bus moving around a circular section of track

Worked Example

1. A 225 g mass is attached to a wire and swung in a horizontal circle so that it completes 6 revolutions in 2.00 seconds. The radius of the circular path is 15.0 cm

   (a) Calculate the period of motion.

   $T = \frac{2}{6} = 0.333\ s$

   (b) Calculate the speed of the mass.

   $v = \frac{2\pi r}{T} = \frac{2\pi \times 0.15}{(0.333)} = 2.83\ ms^{-1}$

   (c) Calculate the centripetal acceleration experienced by the mass.

   $a = \frac{v^2}{r} = \frac{2.83^2}{0.15} = 53.4\ ms^{-2}$ *towards the centre of motion*

   (d) Calculate the tension in the wire.

   $F = ma = 0.225 \times 53.4 = 12.0\ N$ *towards the centre of motion*

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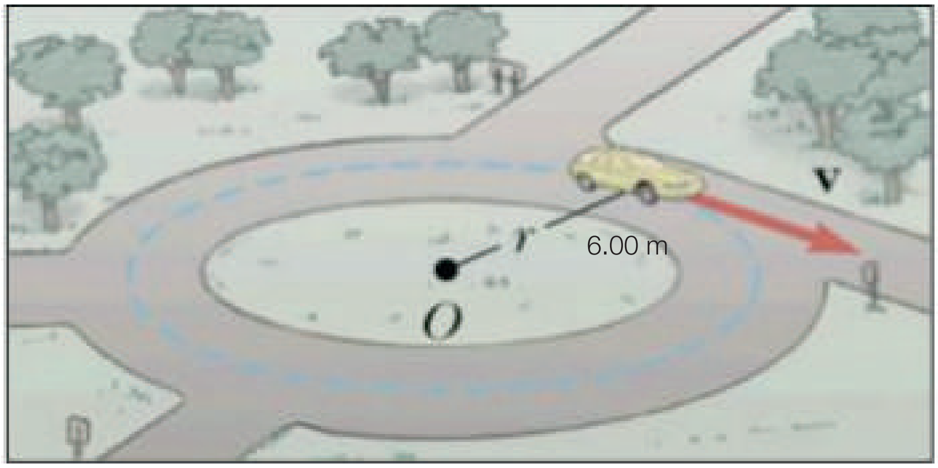
(e) Describe the path followed by the mass if the wire were to snap.

The mass would travel in a straight line at a tangent to the circular path and with a speed of $2.83\ ms^{-1}$.

2. A car with a mass of 1.50×10^3 kg enters a roundabout at an intersection. The road is flat and the radius of curvature of the roundabout is 6.00 m.



Calculate the maximum speed with which the car can safely circle this roundabout if the maximum frictional force the tyres can provide is 5.10×10^4 N.

$$F = ma = \frac{mv^2}{r} \quad \therefore \quad v = \sqrt{\frac{Fr}{m}} = \sqrt{\frac{5.1 \times 10^4 \times 6}{1.5 \times 10^3}} = 14.3\ ms^{-1}$$

Banked curves

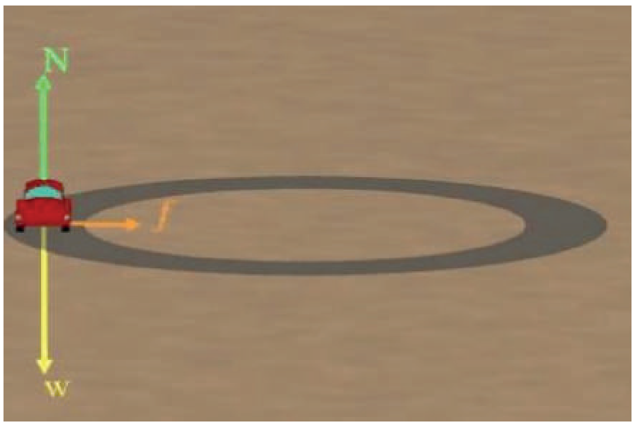


Figure 1

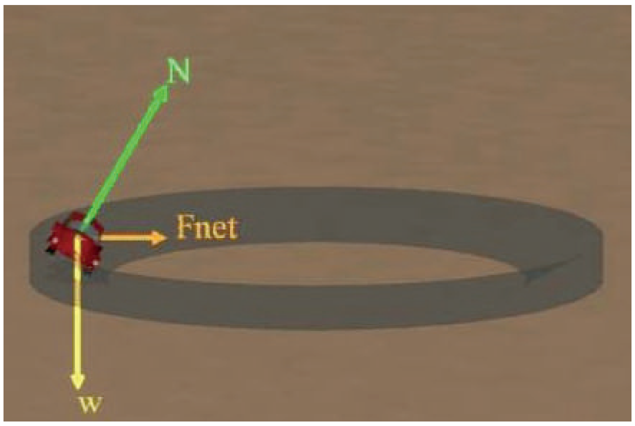


Figure 2

Earlier in the chapter the frictional force that provides the centripetal acceleration when a car undergoes uniform circular motion was discussed. The amount of frictional force needed to round a curve increases with speed. If the car is travelling too fast, the tyres may not be able to provide all of the friction needed to make the turn safely.

To improve safety, a road can be banked at an angle above the horizontal as shown in Figure 2. If a road is banked, it is possible to achieve a situation where friction is not required in providing the centripetal acceleration. This eliminates dangers involved with slippery roads and allows cars to move around a corner at higher speeds.

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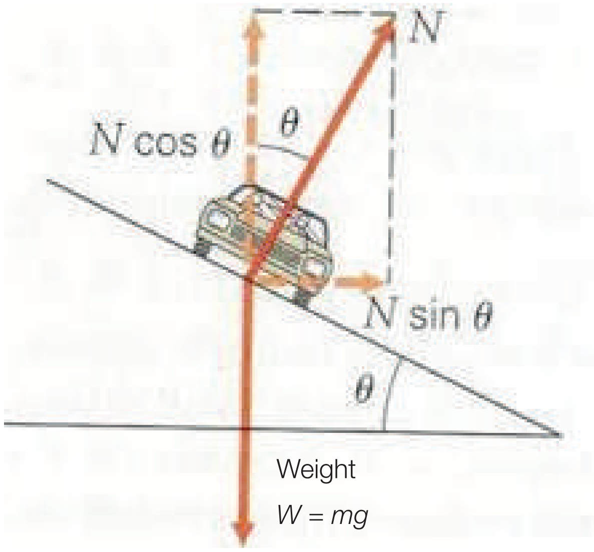

Figure 3

Figure 3 illustrates the forces acting on a vehicle when the road is banked at an angle above the horizontal.

The normal force (N) provided by the road can be resolved into two perpendicular vectors. The **vertical component** (N_v) is equal in magnitude but opposite in direction to the weight (mg) of the vehicle. Its magnitude is also given by $N\sin\theta$.

The **horizontal component** (N_H) points towards the centre of the circular path and can provide part or all of the centripetal acceleration. If the horizontal component provides all of the centripetal acceleration, no frictional force is required.

The banking angle (θ) needed to achieve this situation can be calculated using the equation $Tan\theta = \frac{v^2}{rg}$ where v is the speed of the vehicle, g is the gravitational acceleration (9.8 ms^{-2}) and r is the radius of the circular path.

Derivation

Using Figure 3, the vertical component (N_v) of the normal has a magnitude of mg. If the horizontal component (N_H) points towards the centre of the circular path and provides all of the centripetal acceleration,

then $N_H = ma = \frac{mv^2}{r}$. It follows that $\tan\theta = \frac{opp}{adj} = \frac{F_H}{F_v} = \frac{\frac{mv^2}{r}}{mg} = \frac{v^2}{rg}$

This means that when a vehicle travels around a banked curve at the correct speed for the banking angle, the horizontal component of the normal (not the frictional force) causes the centripetal acceleration.

If the banking angle is less than that calculated using $\tan\theta = \frac{v^2}{rg}$, then friction between the tyres and the road provides some of the force required to cause centripetal acceleration of the car. Similarly if the vehicle travels faster that the correct speed for the banking angle, then friction between the tyres and the road provides some of the force required to cause centripetal acceleration of the car.

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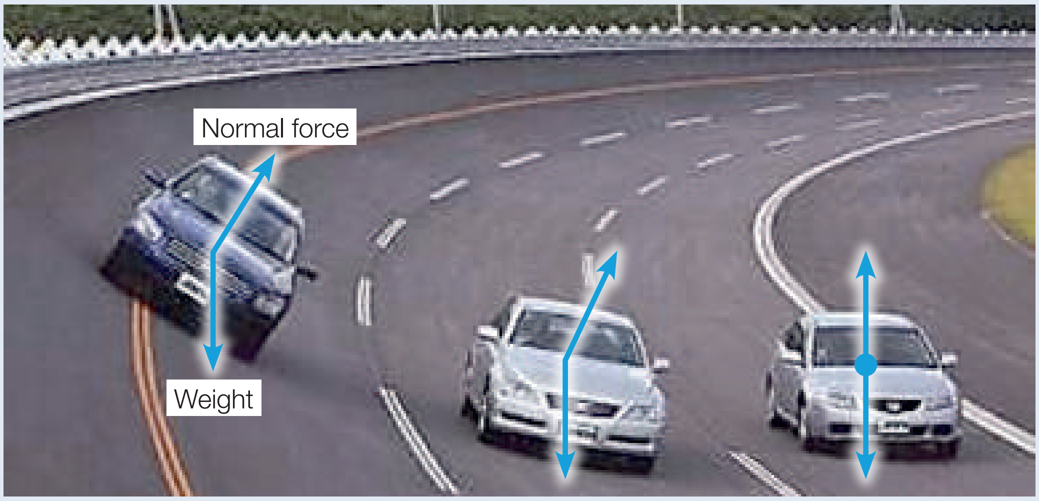
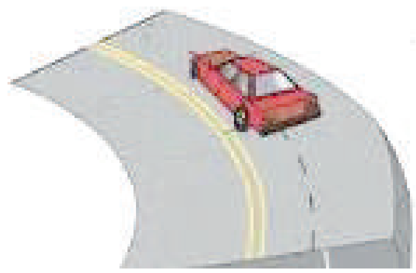
Worked Example

1. Draw vector arrows to represent the forces acting on each of the three cars shown in the diagram below.



2. A section of a road of radius r = 300.0 m, is banked so that a car may make a turn at a speed v = 108 kmh^{-1} without depending on friction.



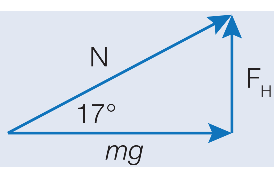
(a) Calculate the angle θ at which the road is banked.

108 kmh^{-1} = 30.0 ms^{-1}

$$tan\theta = \frac{v^2}{rg} = \frac{30^2}{300 \times 9.8} \quad \therefore \ \theta = 17.0°$$

(b) The car has a mass of 1450 kg. Calculate the magnitude of the normal force on the car.

$$\cos 17 = \frac{mg}{N} \quad \therefore \quad N = \frac{mg}{\cos 17} = \frac{1450 \times 9.8}{\cos 17} = 1.49 \times 10^4 \ N$$



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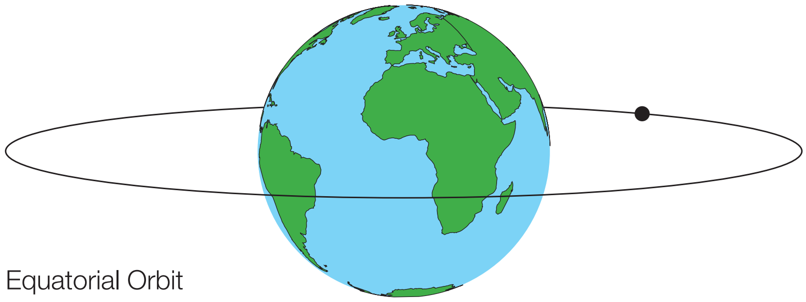
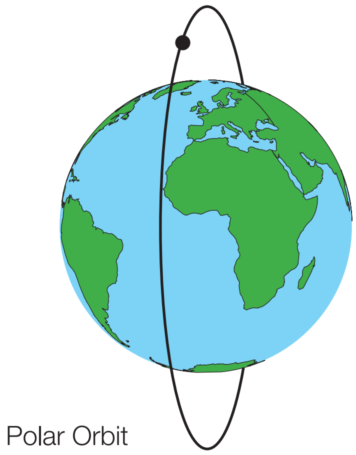
Types of orbits

1. **Equatorial orbit –** the satellite is in an orbit such that it moves directly above the equator as it circles the Earth.



2. **Polar orbit** – the satellite is in an orbit such that it moves over the North and South poles as it orbits the Earth.



3. **Geostationary orbit** – the satellite remains fixed over one point of the Earth's surface. The characteristics of such an orbit were explained earlier in the chapter.

Applications

Equatorial orbit/Geostationary

Geostationary orbits allow for constant communication between two ground stations. This is because the satellite is always in the same position and communication is not interrupted by the motion of the satellite or the rotational motion of the Earth. Geostationary satellites also allow continuous monitoring of a particular region of the Earth's surface since they are in a fixed position. It should be noted that the radius of orbit being large, positions the satellite at a large altitude above the surface of the Earth. This has the advantage of a large coverage (approximately one third of the Earth's surface) but the disadvantage of producing images with low resolution.

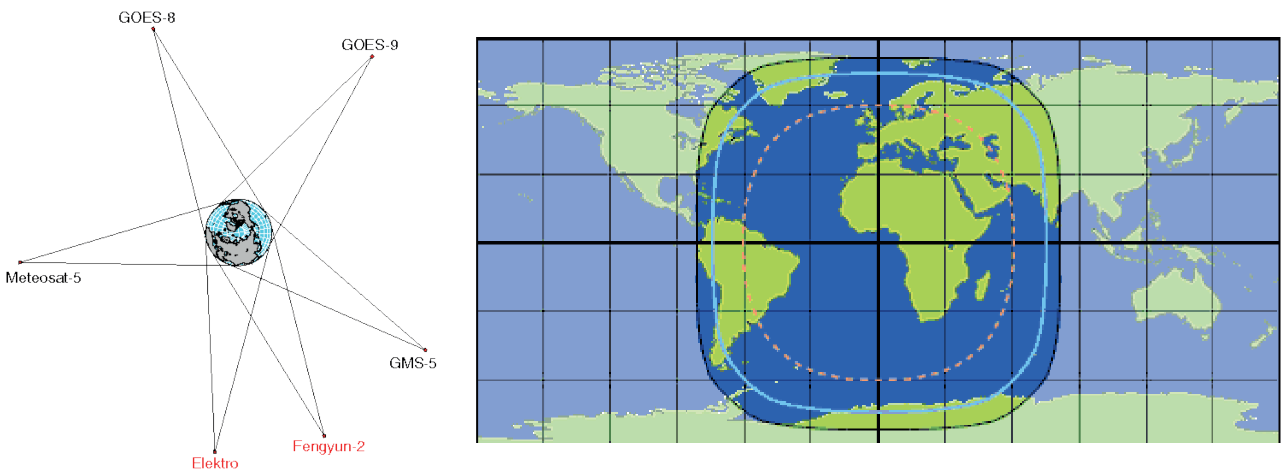


Figure 5

There are currently 6 meteorological geostationary satellites. The diagrams above shows their location and coverage.

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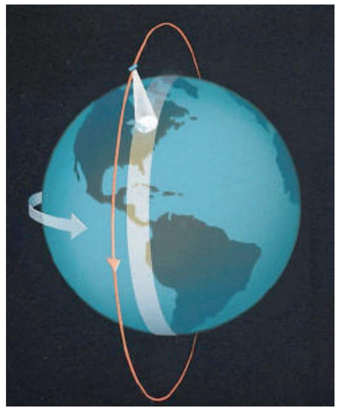
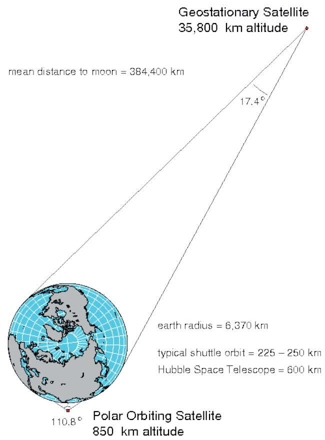
Polar orbit



Geostationary satellites are not always the best choice for surveillance and meteorology. Low-altitude polar-orbit satellites are often used. The low altitude produces images with a higher resolution as the satellite is closer to the ground. In addition, these satellites take images directly beneath their path. This means that distortion of the images produced is low. For these reasons, low-altitude polar-orbit satellites are useful for surveillance.

A low-altitude polar-orbit satellite is also useful for meteorology. Such a satellite passes over the North and South poles of the Earth many times a day and scans a full picture of the Earth's surface, one strip at a time as the Earth rotates beneath it. This results in a full picture of the Earth's surface. Bad weather conditions can be detected and precautions taken.

The diagram opposite illustrates the relative altitude of a geostationary and polar orbiting satellite.



For further discussion in class

Below are some ideas for further discussion with your teacher:

- How can we use Kepler's Laws to explain the motion of comets and predict times when they may be seen?
- How can data giving the orbital radii and periods of the natural satellites of a planet be used to determine the mass of a planet (e.g. for Saturn)? Is there a technique to determine the mass of the Sun?
- What is the geometric definition of an ellipse and its relation to planetary and satellite motion.
- Explore the eccentricities of planets within the solar system to explore how Kepler's Laws may be modelled as uniform circular motion.

? Science inquiry practical

Track satellites in real time at:

http://www.n2yo.com/?s=00050

Design an investigation based on one or more satellite.

Science as a human endeavour

Some suggestions for possible investigations

- Analyse how the models for the motion of planets, stars, and other bodies were modified in the light of new evidence.
- Research the benefits, limitations, and/or unexpected consequences of the uses of satellites. Examples include: the Hubble Space Telescope, the International Space Station, GPS satellites, and decommissioned satellites.
- Use Kepler's Laws to analyse highly elliptical orbits, such as HD 80606 b and HD 20782. Consider the effect of these orbits on the composition and temperature changes on these exoplanets.
- Investigate how Kepler's Laws can be used to estimate the mass of black holes, including Sagittarius A* — the black hole hypothesised to exist within the Milky Way Galaxy.

Helpful online resources

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Exercises

Uniform circular motion

1. Describe the following terms

   (a) uniform circular motion

   ....

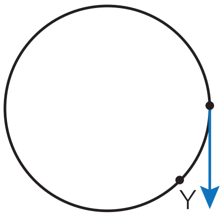
   ....

   (b) centripetal acceleration

   ....

   ....

2. The vector arrow drawn at point X, represents the velocity *v*, of an object undergoing uniform circular motion at the point X.



   (a) Draw a vector arrow at the point Y to represent the velocity of the object at the point Y.

   (b) Annotate the diagram and show that the object experiences an acceleration towards the centre of the circular path as it travels from point X to point Y.

   ....

   ....

3. A 20.0 g marble circles the rim of a bowl of diameter 38.0 cm. It completes 10 revolutions in 8.50 s.

   (a) State the name of the force that provides the centripetal acceleration in this case.

   ....

   (b) (i) Define the term period as it relates to the motion of the marble.

   ....

   ....

   (ii) Calculate the period of motion for the marble.

   ....

   ....

   (c) Calculate the speed of the marble as it circles the rim of the bowl.

   ....

   ....

   ....

   (d) Calculate the magnitude and direction of the force acting on the marble.

   ....

   ....

   ....

   ....

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4. A 26 g rubber stopper is whirled horizontally in a circular path of radius 54 cm with a speed of 5.0 ms^{-1}.

   (a) Calculate the period of revolution of the mass.

   (b) Calculate the centripetal acceleration experienced by the mass.

   (c) Calculate the tension in the string.

   (d) The mass is progressively whirled faster. Explain why the string will eventually break.

5. Consider the amusement ride below. When it is spinning at its maximum speed of 15 ms^{-1} the carriages and their occupants move out into a horizontal circular path. The radius of the circular path traced by the carriages is 8.0 m.

Assuming the average mass of a carriage and its occupant is 74 kg, calculate the

   (a) centripetal acceleration $\vec{a}$ experienced by each carriage.

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(b) average tension in the carriage support wires.

(c) time taken for the carriages to complete ten revolutions.

6. A centripetal acceleration of 6.0 ms^{-2} acts on a mass undergoing uniform circular motion.

Describe the effect on the centripetal acceleration and state its new value if the

(a) speed *v* of the mass is increased to *5v*.

(b) radius of the circular path *r* is changed to $\frac{r}{4}$.

7. A 1250 kg car rounds a curve of radius 85.0 m with a speed of 17.0 ms^{-1} on a level road. Calculate the frictional force that the tyres provide during the turn.

8. A young boy hangs an increasing number of weights to the end of piece of fishing wire. He can hang 3.75 kg of mass vertically before the fishing wire snaps.

(a) Calculate the maximum tension that the fishing wire can withstand.

(b) The young boy whirls a 50.0 g mass on the end of a 40.0 cm length of the fishing wire in a horizontal circular path.

Calculate the maximum speed achievable before the fishing wire breaks.

(c) Calculate the minimum period of revolution of the 50.0 g mass.

9. A force of magnitude ***F*** Newton acts on an object moving in a circular path at constant speed.

Use proportionality to describe the effect on the magnitude of the force acting if each of the following changes occur. State the new force in terms of ***F***.

(a) The object is replaced with one having three times its mass.

(b) The speed of the object is reduced by a factor of four.

(c) The radius of the circular path is halved.

10. A 1500 kg satellite circles the Earth. The satellite has a period of revolution of 3.0 hours.

(a) Determine the altitude at which the satellite moves. (Take the mass of the Earth to be $M_E = 6.0 \times 10^{24}$ kg and the radius of the Earth to be $r_E = 6.4 \times 10^6$ m)

(b) Calculate the magnitude of the force acting on the satellite.

(c) Name the force that provides the centripetal acceleration in this situation.

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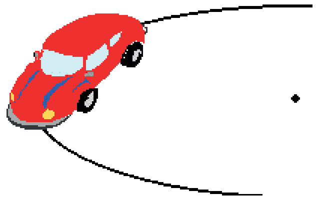
11. A 1.6 tonne car rounds a corner with a radius of curvature of 250 m.

    (a) Draw vector arrows on the car to represent the velocity and the force acting on the car as it turns the corner illustrated below.



    (b) Calculate the frictional force acting if the car makes the turn with a speed of 60.0 kmh^{-1}.

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    (c) The tyres can provide a maximum frictional force of 4000 N, calculate the maximum speed with which the car can turn this corner safely.

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    (d) Explain why the tyres don't need to provide as much frictional force, if any at all, when the road is banked.

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12. A geostationary satellite is one that remains fixed over a certain point of the Earth's surface. It has a period of 24.0 hours and is positioned approximately 3.70×10^4 km above the surface of the Earth which has a radius of 6.38×10^6 m.

    (a) Calculate the speed of the satellite.

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    (b) Calculate the centripetal acceleration $\vec{a}$ experienced by the satellite.

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    (c) Calculate the force $\vec{F}$ acting on the satellite given it has a mass of 10^3 kg.

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    (d) Name the force acting on the satellite to provide the centripetal acceleration for uniform circular motion.

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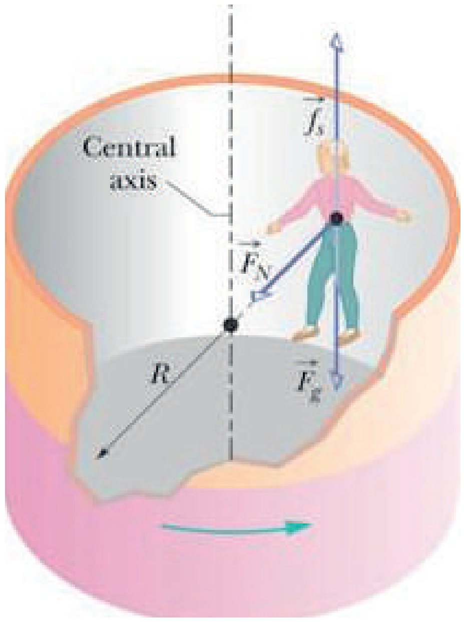
13. The amusement park ride shown below rotates at a high speed of 24 revolutions per minute before the floor drops and the occupants remain suspended against the outside wall of the ride. The ride has a radius *R* of 6.6 m.



(a) Name **each of the forces acting on the** person enjoying the ride. The forces are represented by the vector arrows A, B and C.

A..........

B..........

C..........

(b) Calculate the period of rotation of this amusement ride.

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(c) The person shown enjoying the ride has a mass of 67 kg. Determine the magnitude of each of the forces A, B and C.

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14. Consider the bob sled track shown below.

The bob sled maintains a constant speed along the track. Calculate the ratio of

(a) the magnitude of the centripetal acceleration experienced by the bob sled as it rounds the first turn to the centripetal acceleration experienced by the bob sled as it rounds the second turn.

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(b) the period of motion of the bob sled as it rounds the first turn to the period of motion of the bob sled as it rounds the second turn.

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15. With the aid of a labeled diagram show that a road should be banked at an angle given by $tan\theta = \frac{v^2}{rg}$ in order for a vehicle to turn a road of radius r at a speed v without any frictional force contributing to the centripetal acceleration.

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Space for diagram

16. Calculate the banking angle for a road with a radius of curvature of 120 m such that a vehicle can make the turn with a speed 25 ms^{-1} without friction providing any of the centripetal acceleration.

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17. A circular velodrome with a radius 19.0 m is banked at 45.0°. Calculate the speed with which a cyclist can move around the velodrome without friction affecting the cyclist's motion.

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18. A section of a road of radius r = 300 m, is banked so that a car can make a turn at a speed v = 100 kmh^{-1} without relying on friction.

(a) On the diagram above, draw a vector, showing the direction of the normal force acting on the car. Label this vector N.

(b) Explain how the horizontal and vertical components of the normal force affect the motion of the car.

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(c) Calculate to the nearest degree, the angle θ at which the road is banked.

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(d) Given that the mass of the car is 1300 kg, calculate the magnitude of the normal force acting on the car. Ignore friction between the car and the surface of the road.

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(e) Calculate the magnitude of the net force acting towards the centre of the curve.

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Gravitation

1. (a) Sketch the gravitational field in the space surrounding the Earth pictured below.

(b) Define the term gravitational field strength.

(c) A mass of 3.40 kg experiences a gravitational force of 37.4 N on the surface of Uranus. Calculate the gravitational field strength on Uranus.

2. The gravitational field strength on Mars is 3.7 Nkg^{-1}. Calculate the magnitude of the gravitational force that a 10.0 kg object would experience on the surface of Mars.

3. (a) State Newton's Universal Law of gravitation in words.

(b) Calculate the magnitude and direction of the gravitational force acting between two point masses, m_1 = 20.0 kg and m_2 = 55.0 kg placed 1.80 m .

(c) Explain why gravitational forces are consistent with Newton's Third Law of motion.

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4. Two dancers are standing 1.00 m apart. One dancer has a mass of 55.0 kg and the other a mass of 62.0 kg.

(a) Calculate the gravitational force $\vec{F}$ acting between the two dancers.

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(b) Add vector arrows to represent the force acting on each dancer depicted above.

(c) Calculate the magnitude and direction of the acceleration experienced by the 62.0 kg dancer.

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5. Two identical masses separated by a distance of 5.0 cm, experience a gravitational force of attraction of magnitude 5.0 N.

(a) Calculate the magnitude of the masses.

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(b) Without performing a calculation, describe the effect on the force between the masses if

(i) one mass is replaced with another having half its mass.

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(ii) one mass is replaced with another having half its mass and the other mass is replaced with a mass six times heavier.

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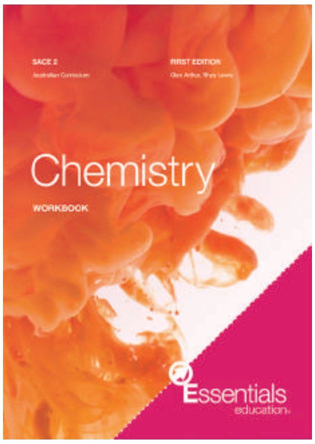

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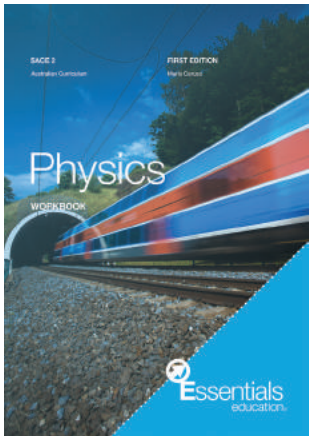

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