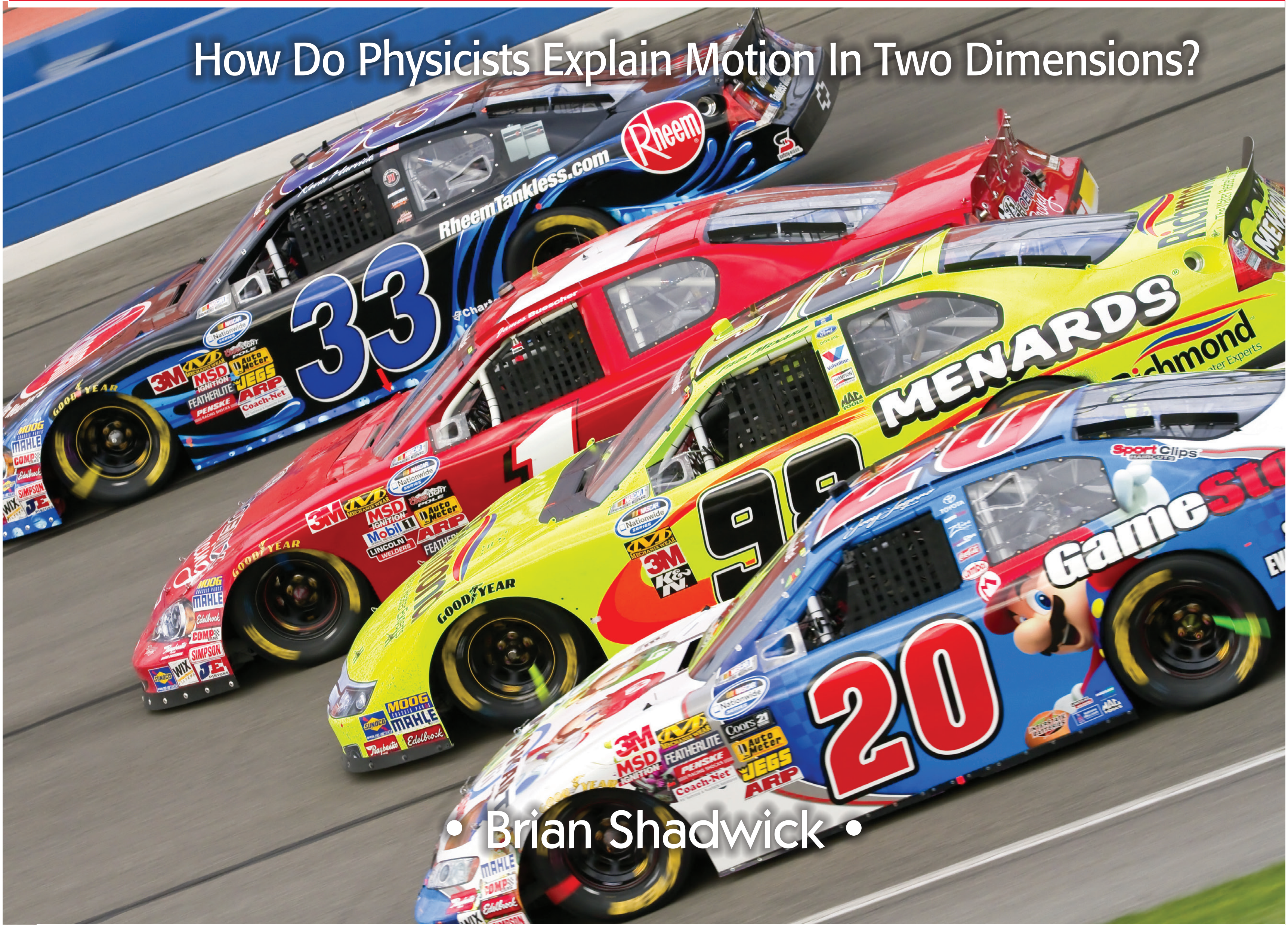
DOT POINT

VCE PHYSICS UNIT 3 AREA OF STUDY 1

How Do Physicists Explain Motion In Two Dimensions?



• Brian Shadwick •

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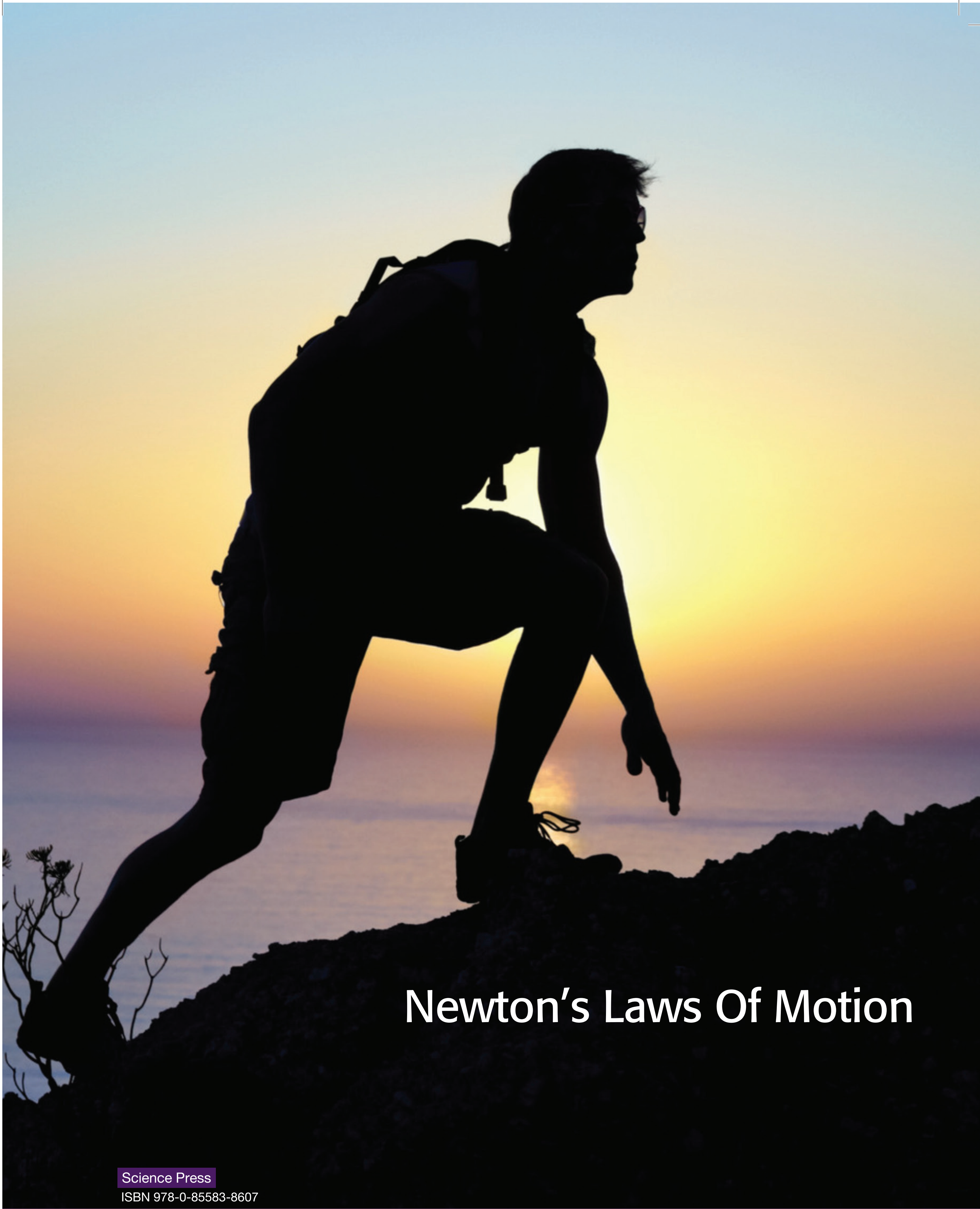

Newton's Laws Of Motion

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1. Newton's Laws Of Motion

Investigate and apply theoretically and practically Newton's three laws of motion in situations where two or more coplanar forces act along a straight line and in two dimensions.

Newton's first law of motion and inertia

Newton's first law

An object at rest or in constant motion will remain at rest or in constant motion unless acted on by an unbalanced force.

This law is often called 'the law of inertia'.

Note that Newton's first law applies to both objects at rest or moving with constant velocity.

Inertia

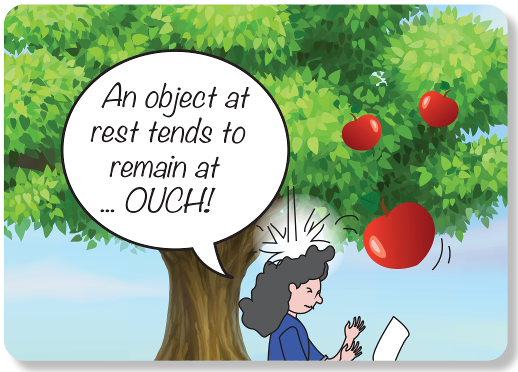
Inertia is the property all objects have (due to their mass) that causes them to resist any attempt to change their state of uniform motion.

1. Outline and explain the effect of inertia on a person if the school bus brakes suddenly.

2. A person in a plane accelerating down the runway said 'Wow – there's a strong force pushing me backwards!'. Evaluate this statement and explain the force the person experiences.

3. You are in a car that turns a corner quickly and feel as if you are 'thrown to the side'. Explain what is really happening and why 'thrown' is an incorrect way to describe this observation.

4. Explain the role of inertia in the cartoon.



5. Outline dangers presented by loose objects in a moving car and when these dangers can occur.

6. Explain why passengers without seat belts are at risk in moving vehicles.

7. Explain why harness seat belts are used in high speed racing cars rather than the lap-sash used in ordinary cars.

8. Use principles of physics to explain how air bags in cars reduce effects of inertia.

9. Explain why it is dangerous to leave loose objects on the back shelf of a car.

10. Identify two real life situations where Newton's first law is apparent, and explain how this affects the person involved.

11. Identify two real life situations where Newton's first law is not apparent, and explain why it is not apparent.

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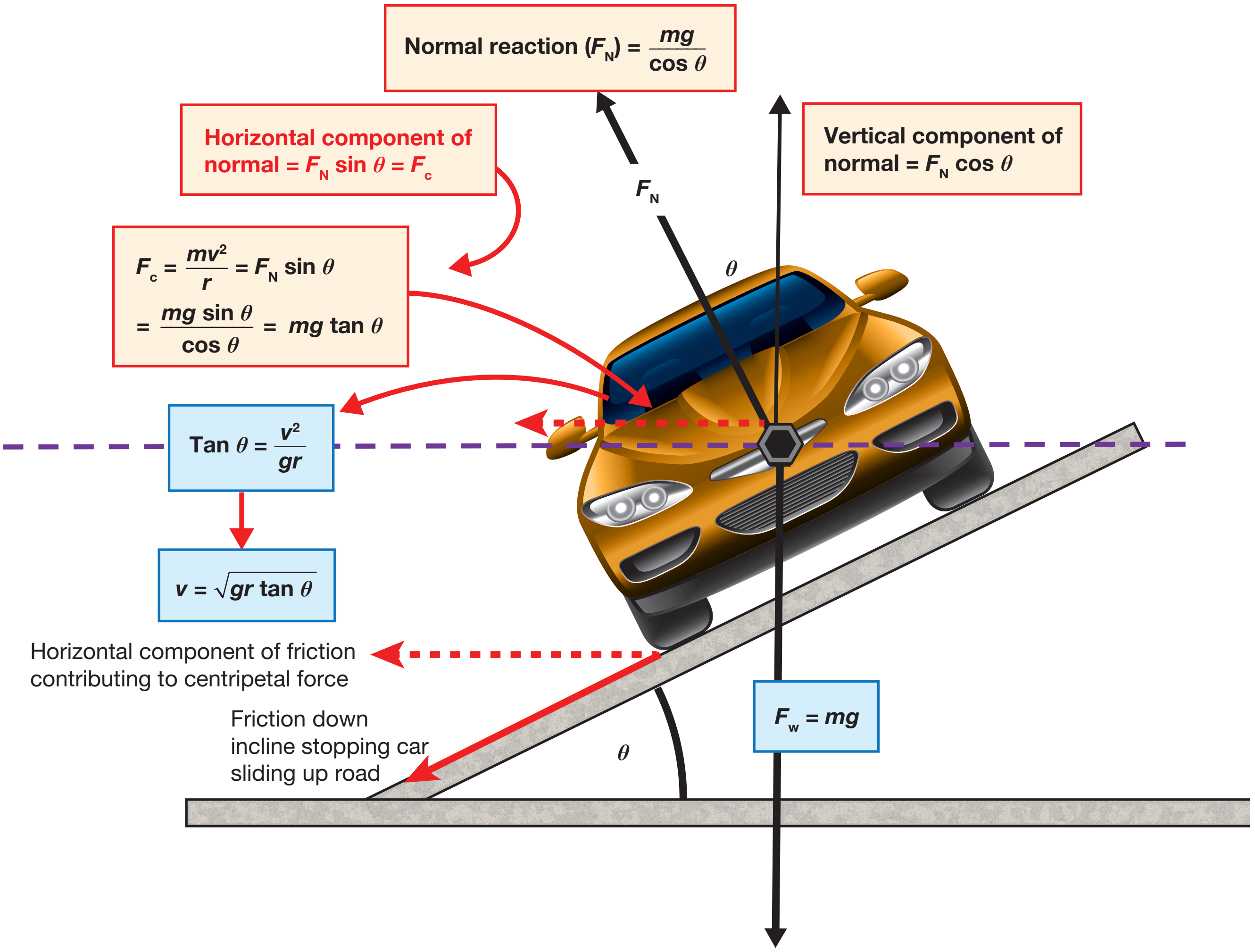
3. Circular Motion Around a Banked Track

Investigate and analyse theoretically and practically the uniform circular motion of an object moving around a banked track: ($F_{net} = \frac{mv^2}{r}$).

Uniform circular motion on a banked track

- The radius of the circle of motion is a **horizontal** line drawn from the car to a point above the centre of the curve.
- The radius of the circle is **not parallel** to the surface of the inclined plane.
- Because there is a component of the normal reaction directed towards the centre of the motion, the centripetal force will be less than for a horizontal curve.
- This component of the normal reaction also means that less fiction is required between the tyres and the surface to maintain a stable turn.
- Objects can therefore take banked curves at a faster speed than non-banked curves.



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4. Circular Motion On the End Of a String

Investigate and analyse theoretically and practically the uniform circular motion of an object moving on the end of a string: ($F_{net} = \frac{mv^2}{r}$).

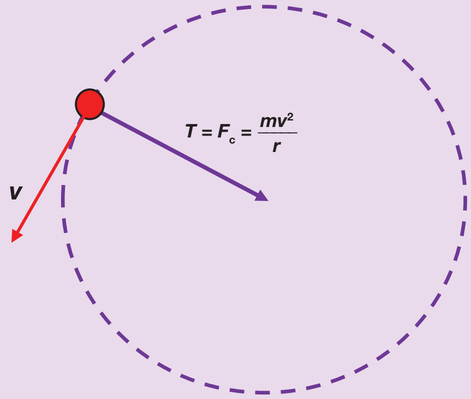
Uniform circular motion of an object on a string in a horizontal plane

Mass supported by the surface

$T = F_c = \frac{mv^2}{r}$

$T = F_c = ma_c$

$T = F_c = mr\omega^2$



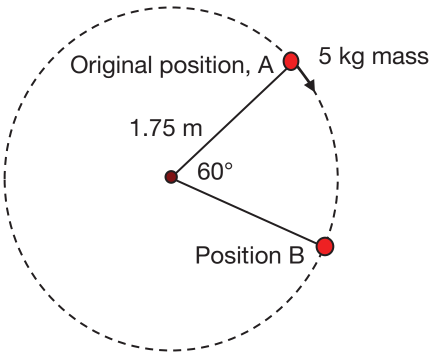
$a_c = r\omega^2$

$a_c = \frac{v^2}{r}$

$v = r\omega$

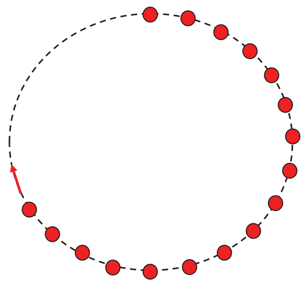
$\omega = 2\pi f$

1. A mass of 5.0 kg lies on a smooth horizontal surface and is connected to a light string which is 1.75 m long as shown. The mass completes three rotations per second. Find:



(a) The period of the rotation.
(b) The angular velocity of the mass.
(c) The linear speed of the mass.
(d) The acceleration of the mass.
(e) The magnitude of the tension in the string.
(f) The time to move from A to B.

2. The diagram shows a stroboscopic representation of the motion of a 3.0 kg mass which was rotating clockwise in a circle of radius 1.5 m in a horizontal plane. The stroboscope used had a frequency of 36 Hz. Find:



(a) The period of rotation of the mass.
(b) Its frequency of rotation.
(c) The time represented by the motion in the diagram.
(d) The linear speed of the mass.
(e) Its angular velocity.
(f) Its centripetal acceleration.
(g) The centripetal force on the mass.
(h) If the mass was tied to a string, what would be the tension in the string?

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3. A 500 g ball on a 0.8 m long string is moving in a horizontal circle at 0.75 rad s^{-1}.

(a) What is its instantaneous linear speed?
(b) What is the centripetal acceleration?
(c) Calculate the tension in the string.
(d) What is its period of rotation?
(e) What is its frequency of rotation?
(f) If the string was twice as long and angular velocity remained the same, how would this affect each of these values?

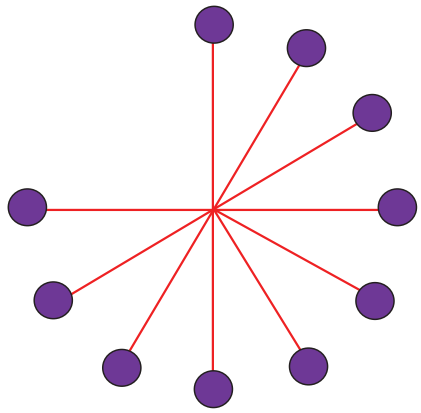
4. A 600 g ball on a string is moving in a horizontal circle with a period of 0.75 s. The tension in the string is 8.46 N.

(a) What is its frequency of rotation?
(b) What is its angular velocity?
(c) What is the radius of the circle of motion of the ball?
(d) What is the centripetal acceleration of the ball?
(e) What is the instantaneous linear speed of the ball?

5. A 300 g mass on a 0.6 m long string is moving in a horizontal circle with a frequency of 5 Hz.

(a) What is its period of rotation?
(b) Find its instantaneous linear speed.
(c) Calculate its angular velocity.
(d) What is its centripetal acceleration?
(e) What is the tension in the string?

6. The diagram shows the motion of a 400 g mass in circular motion in a horizontal plane made using a stroboscopic camera with a frequency of 15 Hz. Its linear speed was 1.75 m s^{-1}.



(a) Construct a vector analysis on a copy of the diagram to show that the change in velocity of the object over two successive intervals is directed towards the centre of the circle. Label your working.
(b) What is the period of rotation of the mass?
(c) What is its angular velocity?
(d) What is the radius of the circle of motion?
(e) What time is represented by the section of motion shown?
(f) What is the centripetal acceleration of the mass?
(g) What is the tension in the string connecting the mass to the centre?

7. A mass, M_1, connected to a string moves on a smooth table with uniform circular motion of radius r m. The other end of the string is connected through a small hole in the centre of the table to another mass M_2 (under the table) which provides the force to maintain the radius of the motion. Derive a formula to find the radius of the circular motion of M_1 in terms of M_1, M_2 and the period of the rotation.

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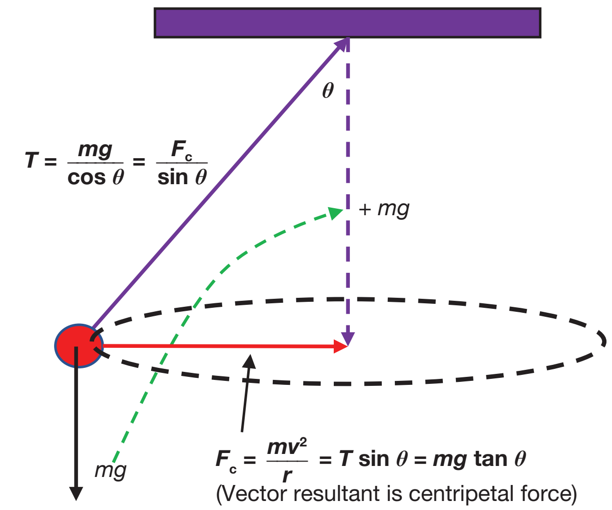
Conical pendulum – extension

Mass supported by string and moving in horizontal circle

$$T = \frac{mg}{\cos\theta} = \frac{F_c}{\sin\theta}$$

$$F_c = T\sin\theta = \frac{mg}{\cos\theta}\sin\theta = mg\tan\theta$$

Note that all other equations also apply.



1. A 1.2 kg mass is tied to a 1.5 m long string and whirled in a circle such that the string makes an angle of 30° to the vertical.

(a) What is the tension in the string?
(b) What centripetal force acts on the mass?
(c) What is the radius of the circle the mass traces out?
(d) What is the linear speed of the mass?
(e) What is its angular speed?
(f) Find the period of rotation of the mass.

2. A 2.0 kg mass is attached to a 2.5 m long string which is hung from the ceiling. The mass is pushed so that it moves around in a horizontal circle of diameter 1.2 m.

(a) Find the angle the string makes to the vertical.
(b) What is the tension in the string?
(c) What centripetal force acts on the mass?
(d) What is the linear speed of the mass?
(e) What is its angular speed?

3. A conical pendulum is 2.5 m long and its 250 g bob swings in a circle of radius 27 cm.

(a) What angle with the vertical does the string make?
(b) What is the tension in the string?
(c) What centripetal force acts on the mass?
(d) What is the linear speed of the mass?
(e) What is its angular speed?
(f) Find the period of rotation of the mass.

4. A conical pendulum has a length of 2.0 m with a mass of 100 g hanging on it. There is a tension of 3.92 N in its supporting string. Find:

(a) The angle the string makes to the vertical.
(b) The centripetal force on the mass.
(c) The radius of the circle of motion.
(d) Its linear speed.
(e) Its angular velocity.

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5. A conical pendulum is 3.0 m long and its 400 g bob swings in a circle of radius 1.20 m.

(a) What angle with the vertical does the string make?

(b) What is the tension in the string?

(c) What centripetal force acts on the mass?

(d) What is the linear speed of the mass?

(e) What is its angular speed?

(f) Find the period of rotation of the mass.

6. A conical pendulum has a length of 1.6 m with a mass of 300 g hanging on it. There is a tension of 6.25 N in its supporting string. Find:

(a) The angle the string makes to the vertical.

(b) The centripetal force on the mass.

(c) The radius of the circle of motion.

(d) Its linear speed.

(e) Its angular velocity.

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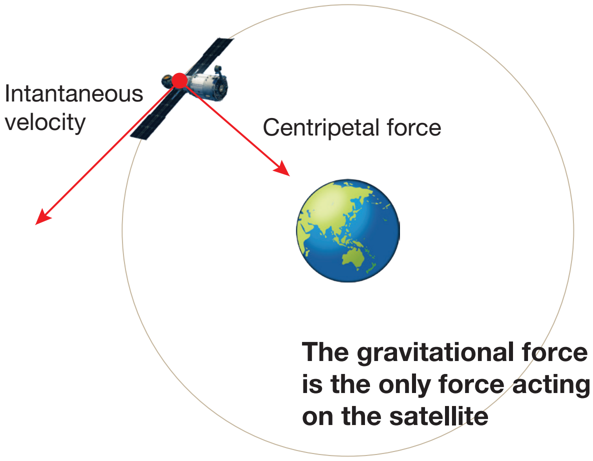
5. Satellite Motion As Uniform Circular Motion

Model natural and artificial satellite motion as uniform circular motion.

Newton, circular motion and orbital speed

When a satellite is in a stable orbit around the Earth, it is actually falling towards Earth all the time. The result is that it follows a curved path – the orbital path. Because its direction of travel is always changing, a force must be acting on it. The force involved in causing any object to move in a circular path is called a **centripetal force**. Since the only force acting on it is the gravitational force, then the **centripetal force is the gravitational force**. There is no normal reaction force because the satellite is falling freely.



Because the force of gravity is at 90° to the velocity of a satellite it is a centripetal force.

This means the satellite is undergoing circular motion and that all the circular motion equations apply.

- We have two equations to describe the force that attracts an orbiting satellite to Earth – Newton's gravitation equation and the equation for centripetal force.
- Equating these we get:

$$F_c = \frac{m_{satelite} v^2}{r} = F_g = \frac{G m_{satelite} m_{Earth}}{r^2}$$

Where

F_g = gravitational force (N)

v = orbital speed of satellite (m s^{-1})

r = radius of Earth + altitude = 6.38×10^6 m + altitude = **orbital radius**

$m_{Earth} = 5.97 \times 10^{24}$ kg

$G = 6.67 \times 10^{-11}$ N m^2 kg^{-1}

- Rearranging we get an equation for **orbital speed**:

$$v_{orbital} = \sqrt{\frac{G m_{Earth}}{r_{orbital}}}$$

- From this equation we can see that the orbital speed of a satellite is inversely proportional to the square root of its distance from the centre of the Earth (or appropriate planet).
- Therefore, the lower the orbit, the faster the satellite needs to go to stay in a stable orbit.
- Notice that the orbital speed does not depend on the mass of the satellite, only on the mass of the **primary** (the object being orbited).

- Note that orbital speed can also be found using the simple equations for linear motion in that:

$$v_{orbital} = \frac{\text{distance travelled}}{\text{time taken}}$$

$$v_{orbital} = \frac{\text{circumference}}{\text{time for one orbit}} = \frac{2\pi r}{T}$$

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1. Find the orbital velocity of a satellite in orbit above Earth at an altitude of 300 km.

2. Which of the following does *not* affect the orbital velocity of a satellite?

(A) Its altitude.
(B) Its mass.
(C) The mass of the planet it orbits.
(D) The gravitational force of the planet.

3. Which statement about the orbits of satellites is correct?

(A) The greater the mass and altitude, the slower the satellite travels.
(B) The greater the mass and altitude, the faster the satellite travels.
(C) The higher the altitude of the orbit, the faster the satellite travels.
(D) The higher the altitude of the orbit, the slower the satellite travels.

4. Three satellites, masses M, $4M$ and $9M$ orbit Earth. Their orbital radii are R, $4R$ and $9R$ respectively. Determine the ratio of their orbital velocities.

5. Three satellites, masses M, $3M$ and $6M$ orbit the Earth. They each have the same orbital velocity.

(a) Determine the ratio of their orbital radii.
(b) Determine the ratio of the gravitational force acting on them at the positions of the satellites.

6. (a) Three satellites of masses M, $4M$ and $16M$ orbit the same planet. If their orbital velocities are the same, what is the ratio of their orbital radii?
(b) Three identical satellites orbit planets with masses of M, $4M$ and $16M$. If their orbital velocities are the same, what is the ratio of their orbital radii?
(c) Three identical satellites orbit planets with masses of M, $4M$ and $16M$. If their orbital radii are the same, what is the ratio of their orbital velocities?

7. A 200 kg satellite is orbiting Earth at an altitude of 250 km at 27 800 km h^{-1}. If the mass of the Earth is 6×10^{24} kg and its diameter is 12 760 km, find:

(a) The centripetal force on the satellite.
(b) Its centripetal acceleration.

8. (a) What will be the orbital velocity of a 600 kg satellite in orbit at an altitude of 350 km around planet X which has a mass of 3.5×10^{25} kg and a diameter of 12 000 km?
(b) At what altitude above planet X would a 300 kg satellite have an orbital speed of 8000 m s^{-1}?
(c) A 500 kg satellite orbits planet X's only moon with an orbital radius of 2000 km and a velocity of 2750 m s^{-1}. What is the mass of the moon?

9. (a) Calculate the orbital speed of Mercury in its orbit around the Sun given the distance between the Sun and Mercury as 5.8×10^7 km, and the mass of the Sun as 2×10^{30} kg.
(b) Determine the acceleration of Mercury about the Sun.

10. A satellite, mass 1250 kg, is in an orbit of radius 8.68×10^3 km above Earth. Find its orbital speed.

11. A 250 kg satellite is orbiting Earth with an orbital speed of 7000 m s^{-1}.

(a) What is its orbital radius?
(b) What is its altitude?
(c) Repeat these calculations for a satellite with a mass of 500 kg with the same orbital velocity.

12. The orbital radius of Jupiter is 7.43×10^8 km, and the mass of the Sun is 2.0×10^{30} kg. Find:

(a) The orbital speed of Jupiter around the Sun.
(b) The acceleration of Jupiter about the Sun.

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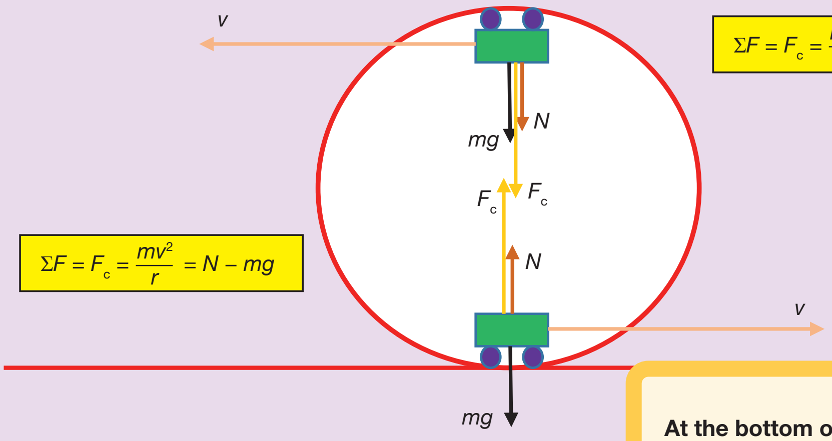
6. Circular Motion In a Vertical Plane

Investigate and apply theoretically Newton's second law to circular motion in a vertical plane (forces at the highest and lowest positions only).

Vertical circular motion on a track or string

Consider an object such as a roller coaster undergoing uniform vertical circular motion.

$\Sigma F = F_c = \frac{mv^2}{r} = N + mg$



$\Sigma F = F_c = \frac{mv^2}{r} = N - mg$

At the bottom of the track $\Sigma F = ma_c = N - mg = \frac{mv^2}{r}$

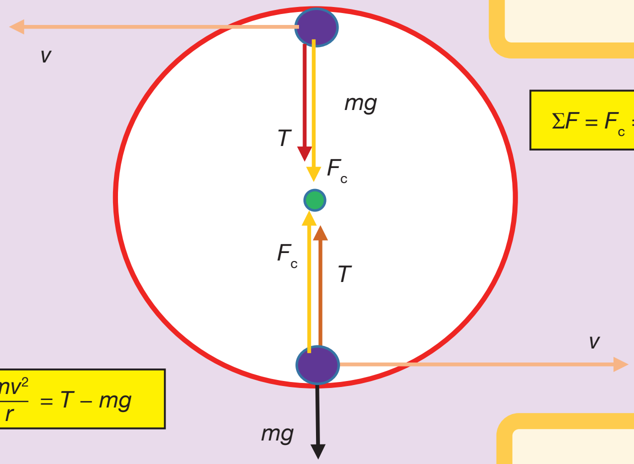
So $N = \frac{mv^2}{r} + mg$

At the top of the track $\Sigma F = ma_c = N + mg = \frac{mv^2}{r}$

So $N = \frac{mv^2}{r} - mg$

Or a mass on a string …

$\Sigma F = F_c = \frac{mv^2}{r} = T + mg$



$\Sigma F = F_c = \frac{mv^2}{r} = T - mg$

Note the similarity in the equations.

At the bottom of the circle $\Sigma F = ma_c = T_b - mg = \frac{mv^2}{r}$

So $T_b = \frac{mv^2}{r} + mg$

At the top of the circle $\Sigma F = ma_c = T_t + mg = \frac{mv^2}{r}$

So $T_t = \frac{mv^2}{r} - mg$

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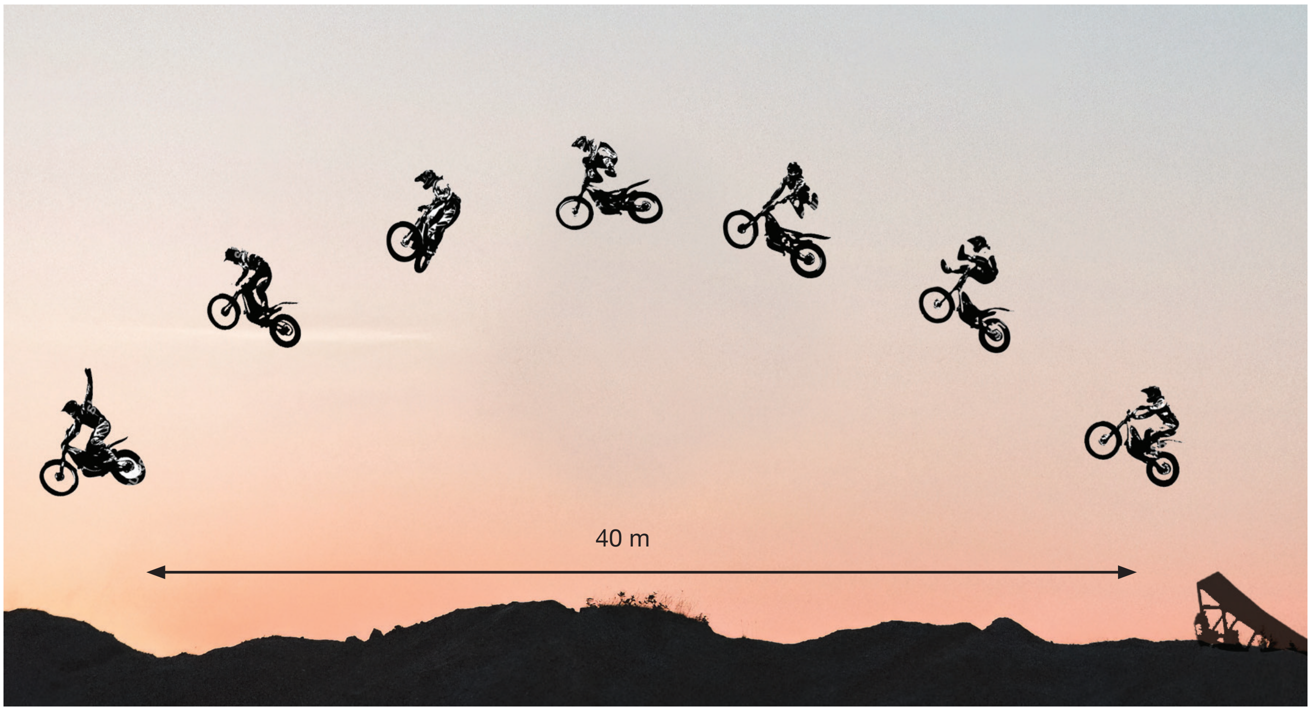
Projectile motion practical analysis 2

1. The diagram represents a stroboscopic photograph of a motor bike stunt rider jumping across a gap from a ramp inclined at 40°. The distance between the back of the first bike in the photo and the last bike is 40 m.

The camera used to take the pictures took one frame every 0.43 s. The diagram has been drawn to scale.



(a) How long did it take the bike to travel the 40 m shown?

(b) Estimate the horizontal velocity of the bike and rider.

(c) By drawing a vector diagram of the motion, find the initial vertical velocity of the rider.

(d) Calculate his initial velocity.

(e) What was his maximum height above the top of the launch ramp?

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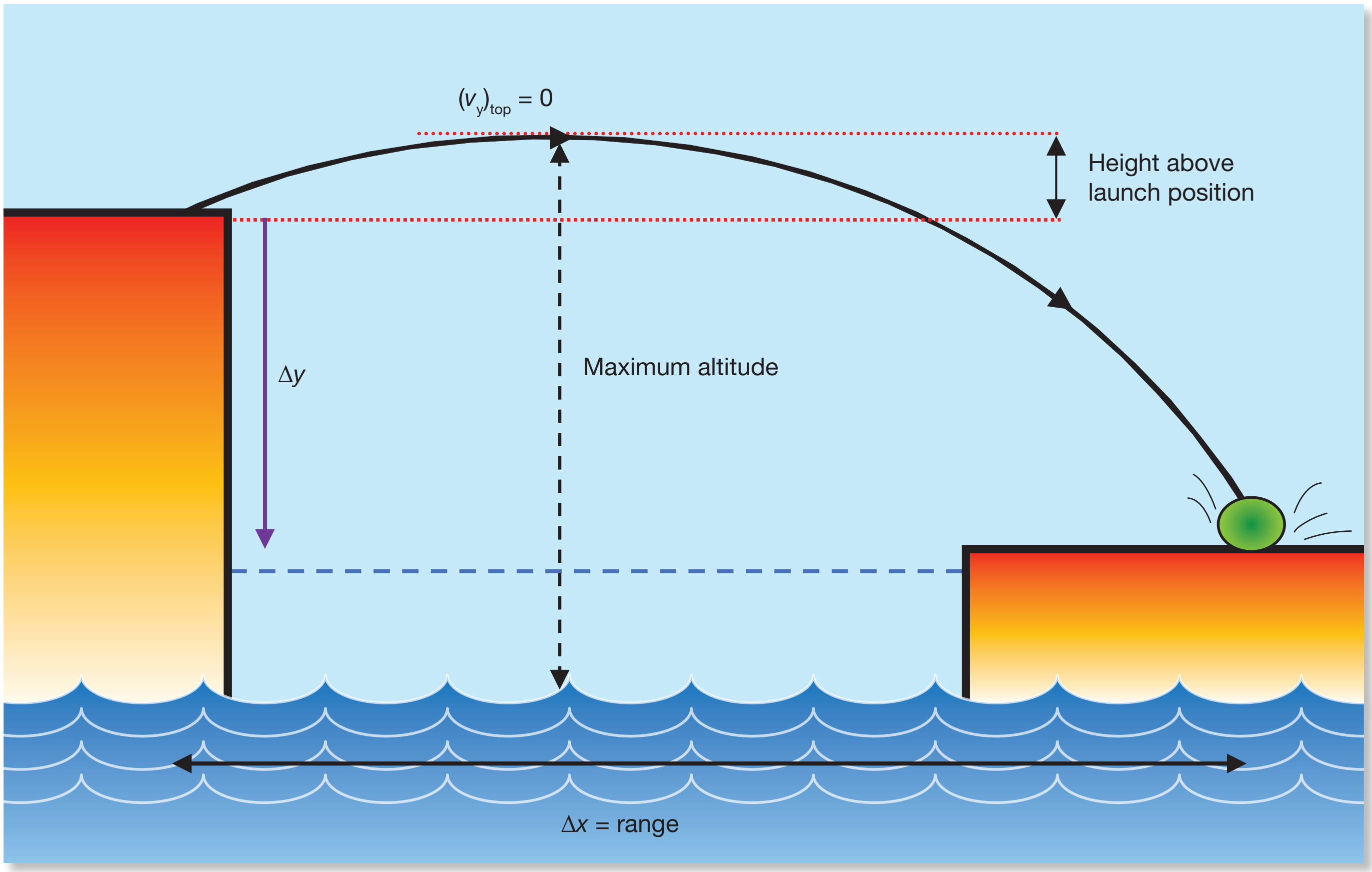
Projectile motion problems 3 Projectiles landing at a different level

Special considerations

- Vertical displacement = difference in height between the two levels
- If target lower (as shown), then vertical displacement is negative (assume upward direction positive)
- If target higher, vertical displacement positive
- Vertical velocity at top of flight = 0
- Time to rise **does not** equal time to fall
- Time to rise **is not** half time of flight
- Speed at launch **does not** equal speed at landing
- Angle of launch **does not** equal angle of landing
- Two halves of flight are **not** symmetrical
- Maximum height occurs when vertical velocity = 0
- Taking initial vertical velocity upwards as positive, **acceleration is negative**
- Range depends **only** on the horizontal component of the launch velocity
- Maximum height depends **only** on the vertical component of the launch velocity

Note that for *all* projectiles, maximum range is achieved when launch angle = 45°.

Note also that the angle of projectiles with complementary launch angles will be the same.



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Relationships Between Force, Energy And Mass

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10. Work Done By Forces

Investigate and apply theoretically and practically the concept of work done by a force using: work done = force × displacement.

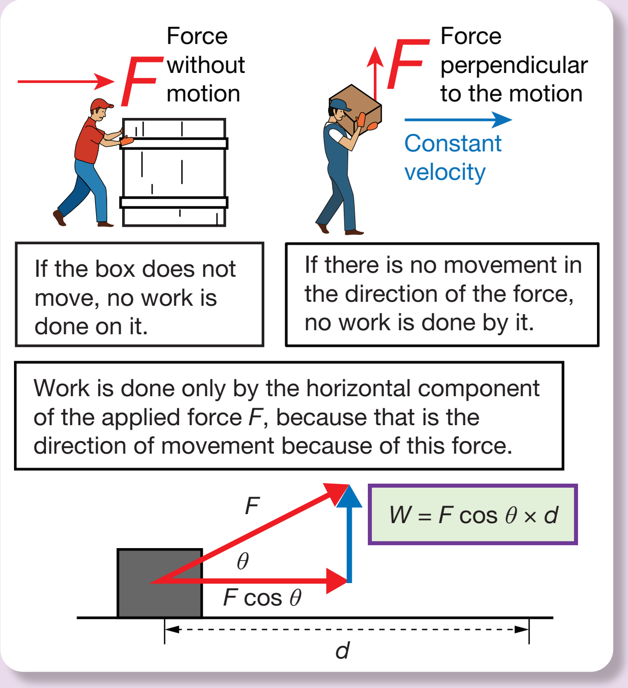
Work done by forces

Work

- Work is done whenever energy is changed from one form to another.
- For example, when a ball is thrown into the air, its initial kinetic energy changes into gravitational potential energy.
- When it falls back down to Earth, the gravitational potential energy changes back into kinetic energy.
- Work done is measured in joules (J) and is a scalar quantity.

Work and force

- When energy changes, a force is involved.
- In the example above a force has to be applied to throw the ball into the air.
- From that point onwards, gravity applies a downward force to the ball to slow it down, then return it to Earth.
- *Note:* If there is no displacement in the direction of the applied force, no work is done.



Work, energy and friction

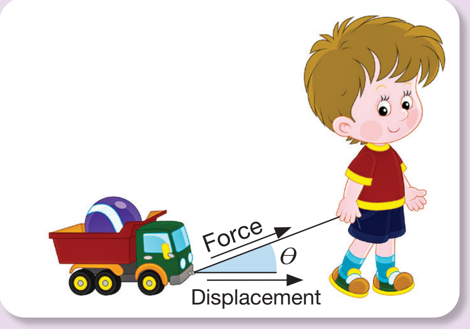
- In order to move an object across a surface a force needs to be applied to overcome the frictional force between the object and the surface.
- Any net force remaining will accelerate the object across the surface.

Calculating work done

- Because there are many forms of energy, the equations we can use to find work done are numerous, depending on the initial and final forms of energy, and whether or not friction is involved.
- In general: **Work done = change in energy = applied force × distance object moves**
- Specifically, depending on the individual situation:

$$W = \Delta E_K = \frac{1}{2}m(v^2 - u^2) = \Delta E_P = mg(h_2 - h_1) = Fs$$

- (*Note:* The formula for calculating gravitational potential energy, $E_P = mg\Delta h$, is only applicable close to the Earth's surface.)



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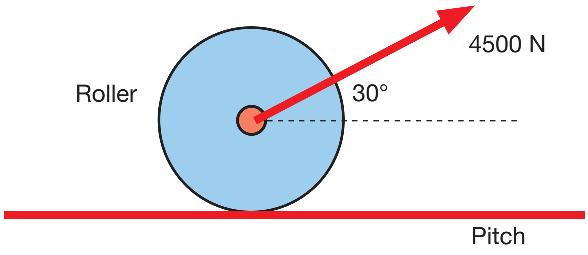
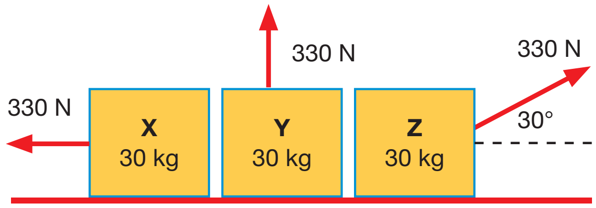
1. Give a definition of work.
2. In general, when is work done?
3. A ball is thrown up into the air. Explain who or what does work on the ball during its flight.
4. A spring is stretched and then let go.
   (a) What does the work when it is stretched?
   (b) What does the work when it returns to its original length?
5. Describe a situation where work is done by an applied force. Make sure you identify the force.
6. What work is done by a 15 N force which pushed a toy car 6.0 m to the west?
7. A car moves at a constant speed of 5.0 m s^{-1} along a 6.0 km road against frictional forces of 150 N km^{-1}. How much work has to be done by the car to maintain its constant speed?
8. A girl of mass 45 kg is on a merry-go-round at the show. The merry-go-round moves at a constant speed of 3.0 m s^{-1} in a horizontal circle of radius 15 m.
   (a) What is the net force acting on the girl?
   (b) How much work does this force do in half a revolution?
   (c) How much work is done on the girl by this force each complete revolution?
   (d) Explain your answers to (b) and (c).
9. An 800 g car moving at 2.0 m s^{-1} is brought to rest by a constant force acting over a distance of 12 m.
   (a) Calculate the work done by this force.
   (b) Calculate the value of the applied force.
10. A slope rises 1.0 m for every 15 m of its inclined length. A car of mass 800 kg travels at a constant speed of 2.0 m s^{-1} a distance of 30 m up the slope against a frictional force of 200 N.
   (a) Calculate the work done in overcoming friction.
   (b) Calculate the total work done in moving the car 30 m up the incline.
11. A roller is used on a cricket pitch between innings. It is moved by a constant force of 4500 N at 30° to the horizontal as shown in the diagram. The roller moves a distance of 28 m each time it rolls up or down the pitch. Calculate the work done in moving the roller from one end of the pitch to the other.



12. 330 N forces act on three identical 30 kg blocks as shown. Each is initially at rest on a surface which has a frictional force of 1.5 N kg^{-1}. If the forces each act to move each object 5 m, find the work they do.



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11. Force-Displacement Graphs

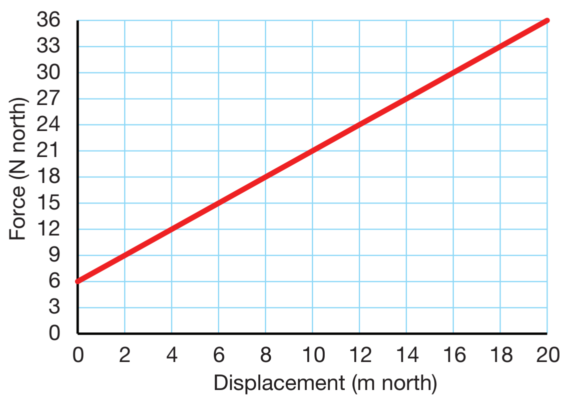
Investigate and apply theoretically and practically the concept of work done by a force using: work done = area under force versus distance graph (one dimensional only).

Force-displacement graphs

From a force-displacement graph we can:

- Read forces directly from the graph.
- Read displacements directly from the graph.
- Use the **area** under the graph to find the **work done** by the force (equal to the kinetic or potential energy the object gains due to the application of the force.
- Note that the gradient of a force-displacement graph is not a sensible quantity in physics, so it is not used.

1. The graph shows the relationship between the force applied to an object and its displacement. The object was initially at rest.

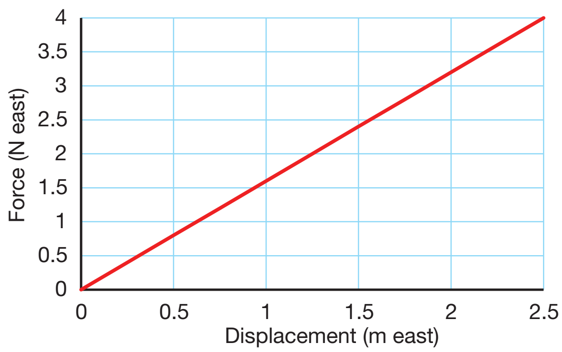


(a) What work is done in moving the object from a displacement of 6 m north to a displacement of 12 m north?

(b) According to the graph, what is the total work done on the object?

(c) If the mass of the object was 6.0 kg, what would be its velocity at the 20 m displacement mark?

2. The graph shows how the force acting on a 150 g toy car varies with distance. The car was initially at rest.



(a) What total amount of work was done on the car?

(b) What was the final kinetic energy of the car?

(c) How fast was the car going at displacement 2.5 m east? (Ignore friction.)

(d) How much work was done on the car in moving it 1.5 m?

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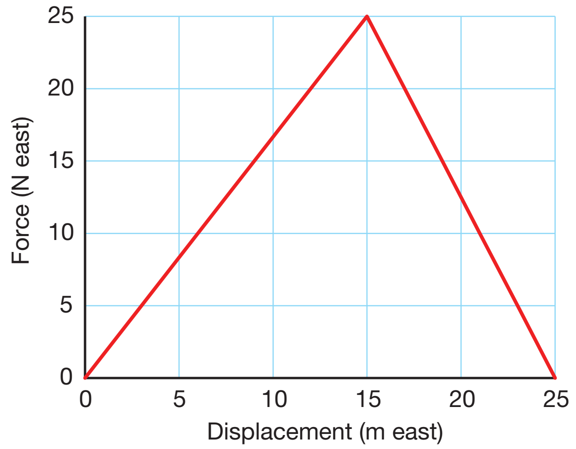
3. The graph shows how the force acting on a 4.0 kg object varies with distance. The object was initially at rest.



(a) How much work was done on the object in moving it 15 m?

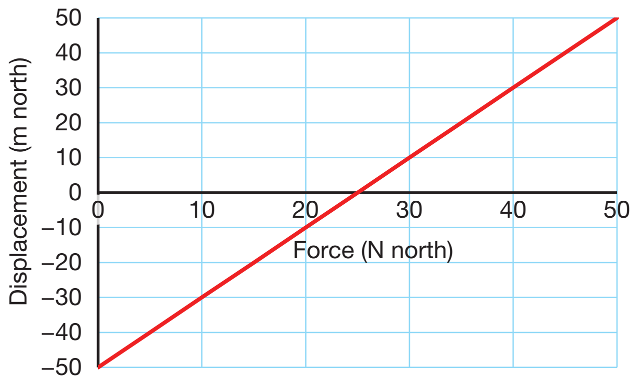
(b) What work was done in moving it from 15 m to 25 m?

(c) What total amount of work was done on the object?

(d) What was the velocity of the object at the 25 m mark?

(e) Suggest a possible reason that the displacement of the object as the force decreased was less than its displacement as the force increased.

4. The graph shows the force acting on a 2.0 kg object and the displacement it caused.



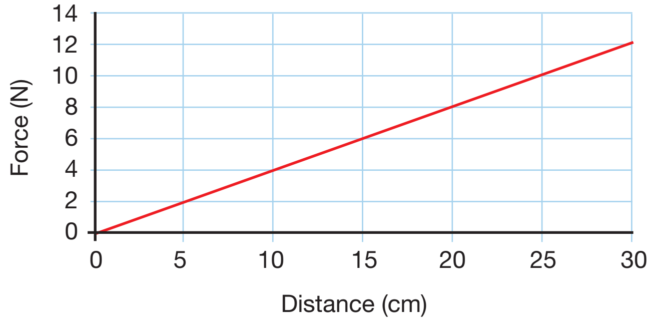
(a) What was the total displacement of the object?

(b) What was the final displacement of the object?

(c) What total work was done on the object?

(d) If it started from rest, what was its final velocity?

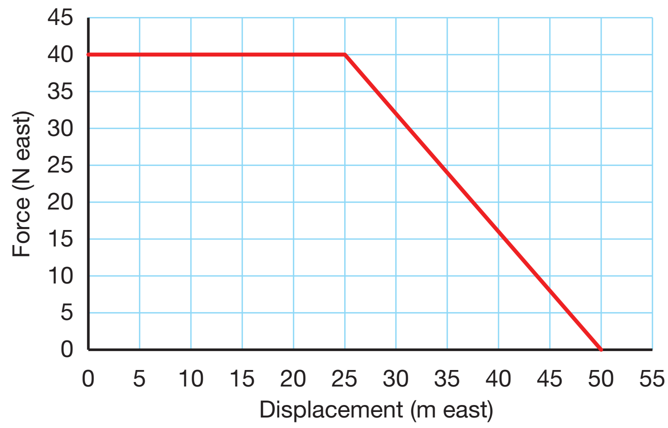
5. The graph shows the force required to lift a toy car various distances above the bench top.



(a) How much gravitational potential energy does the car have when it is 25 cm above the bench?

(b) Calculate the mass of the toy car.

6. The graph shows the force acting on a 6.0 kg object plotted against its displacement. The object was initially at rest.



(a) During which displacement interval was the force uniform?

(b) What was the acceleration of the object when its displacement was 20 m east?

(c) How much work was done on the object to displace it from zero to 20 m east?

(d) Find its kinetic energy when its displacement was 20 m east.

(e) How much work was done on the object to displace it from 20 m east to 50 m east?

(f) What was the acceleration of the object when the displacement was 40 m east?

(g) How much work was done on the object to displace it from zero to 40 m east?

(h) What was the kinetic energy of the object when its displacement was 40 m east?

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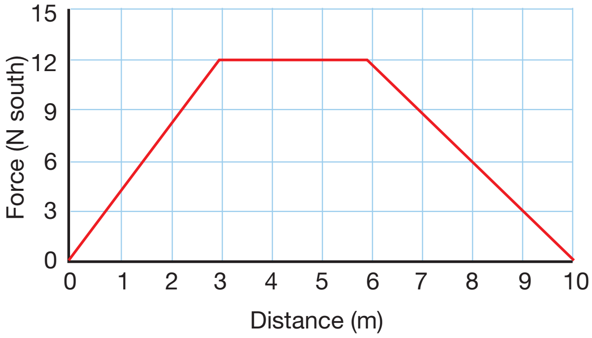
7. The graph shows how the force acting on a toy car varies with distance. The car was initially at rest.

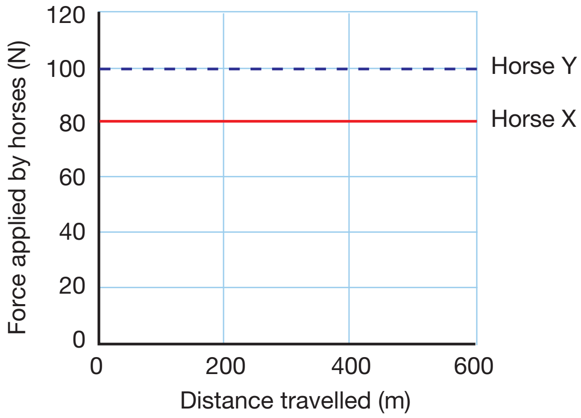


(a) How much work was done on the car in moving it the first 3.0 m?

(b) What would be the kinetic energy of the car after 10 s?

(c) How much work was done on the car between the 5th and the 8th second of its trip?

8. The graph shows the work done by two horses pulling a loaded cart along a horizontal road at constant velocity.



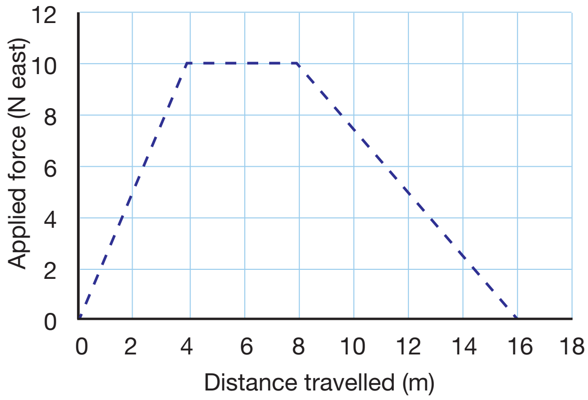
(a) How much work has been done by X?

(b) How much work has been done by Y?

(c) What total work has been done on the cart?

(d) On what has work been done?

9. The graph shows how the force acting on a 5 kg object changed as it travelled a distance of 16 m. The object was initially at rest.



(a) How much work was done by the force in moving the object a distance of 4 m?

(b) How fast was the object going as it reached the 4 m mark?

(c) What was the kinetic energy of the object after it had moved 12 m?

(d) What was the increase in the kinetic energy of the object between the 4th and the 16th metre?

(e) What was the object's final velocity?

(f) What total impulse was applied to the object?

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Answers

1. Newton's Laws Of Motion

Newton's first law of motion and inertia

1. The inertia of the person keeps them moving forwards until their seat belts stops their forward motion.

2. The statement is incorrect, there is no forward force – it is all due to their inertia keeping them in the same place while the plane moves forwards and pushes them forwards. What the person is feeling is their normal reaction force against the back of the seat which is pushing them forwards.

3. 'Thrown' is incorrect because there is no sideways force acting on you. The real situation is that your inertia forwards keeps you moving forwards as the car turns, so the side of the car moves against your side. You interpret your reaction force in the car door as a sideways push.

4. In the tree, the apple is in static equilibrium – gravity pulling it down, the stem holding it up – so Newton's first law holds. When the stem weakens and breaks, there is a net force downwards, so the apple falls – Newton's first law no longer holds.

5. When cars stop suddenly the inertia of loose objects causes them to keep moving forwards. They may hit passengers or go through the windscreen. Loads not properly secured can keep moving forwards if a vehicle brakes suddenly and can impact on the driver or vehicle in front.

6. Their inertia keeps them moving forwards when the vehicle brakes suddenly. They can impact on the dash or the windscreen or go through the windscreen thus suffering considerable injury.

7. Harness seat belts will secure the drivers more securely from inertial forces in a multiple of directions as a vehicle rolls or goes end over end.

8. On impact, the air bag is released and fills the space between the passenger and steering wheel or dash and so stops them continuing (inertia) forwards to impact on a hard surface. The 'give' in the air bag increases the time of the collision with it and so reduces the force involved in the impact. Air bags have to be very carefully designed so that they are not still filling when the person impacts on them – this can cause as much injury as if they were not there at all.

9. If the car brakes suddenly the inertia of the object can cause it to continue to move (Newton's first law of motion). It will therefore 'fly' to the front of the car and can injure anyone it hits on the way.

10. For example: You walk along and then step off a moving walkway at normal walking speed, the inertia you have due to the motion of the walkway 'throws' you forwards with more speed than you sometimes expect.

When an elevator moves up from rest, knees 'buckle' as inertia of your body tries to keep it where it was.

11. For example: When you are in a car turning a corner, you feel a (fictitious) force which apparently tries to push you to the side. This is actually your forwards inertia trying to keep you moving straight ahead.

If you are sitting in a car moving with constant velocity in a straight line, your inertia is not apparent. It only becomes noticeable when the car brakes.

12. (a) The lift accelerates upwards for a short time, then travels with constant speed upwards until it starts to decelerate and stop.

(b) During the acceleration upwards, your knees bend and you slump downwards a little. During the constant speed you feel normal. During the deceleration you feel 'lighter' and your tummy 'jumps' upwards a bit.

(c) During the acceleration upwards the inertia of your body initially resists this acceleration and you feel as if a force downwards is acting on you. Actually, your body is simply tending to stay in the same position until the upward force acts on it. During the constant speed you feel normal because you are travelling at the same speed upwards as the lift – action and reaction forces are equal in magnitude. During the deceleration you feel 'lighter' because your inertia keeps you moving upwards when the lift slows down.

13. (a) The lift accelerates downwards for a short time, then travels with constant speed upwards until it starts to decelerate and stop.

(b) During the acceleration downwards you feel 'lighter' and your tummy 'jumps' upwards a bit. During the constant speed you feel normal. During the deceleration at the bottom your knees bend and you slump downwards a little.

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(c) During the acceleration downwards, you feel 'lighter' because your inertia keeps you stationary and the lift 'falls out' from under you. The reaction force acting on you is less because you are not exerting as much force on the floor of the lift (note that your weight force – due to the action of gravity on you – has not changed). During the constant speed you feel normal because you are travelling at the same speed upwards as the lift – action and reaction forces are equal in magnitude. During the deceleration your inertia keeps you moving downwards at the same rate, until the deceleration of the lift also acts on you. You feel heavier because the floor is reacting to your normal weight force plus your inertial force.

14. (a) Provided the friction between the card and the coin is small, the inertia of the coin will keep it in position above the glass while the card moves away from under it.

(b) It would not work as well with the 10 cent coin because the mass of a 10 cent coin is less and it will not have as much inertia. It may well move sideways more with the card.

15. (a) The head of the hammer is heavy. When the hammer is moved downwards towards the hard surface, the hammer head is also moving down. The hard surface stops the handle sharply, but the inertia of the head keeps it moving down so that it jams more tightly onto the handle.

(b) Hitting the bottom of the bottle moves it down briefly, but quickly. Our other hand stops the bottle, but the inertia of the sauce inside the bottle keeps it moving downwards towards the opening.

16. (a) The inertia of the plates keeps them in the same position as the force on the tablecloth has not been applied to them. Provided friction is low, they will tend to stay in their same positions provided the motion of the tablecloth is fast.

(b) A smooth, shiny (satin, silk, polished cotton) tablecloth with minimum friction would be best.

(c) The heavier the better, and with glazed bases rather than rough bases.

17. If there is an applied force it does not transfer through to the second string. When the bottom string is pulled gently, the top string has to support the weight of the ball plus the added pulling force. It breaks.

18. The inertia of the apple keeps it in its original position while the tree branches move sideways.

19. There is no air resistance or friction between vehicle tyres and the road in space. It is these forces, which acts against the inertia of a car to slow it down and stop it.

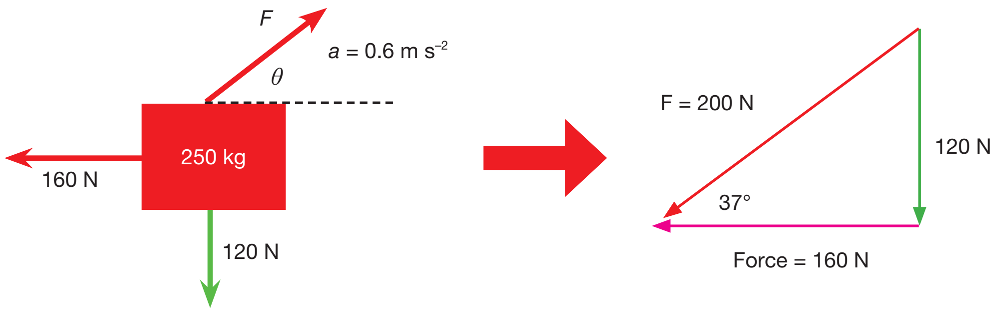
20. When the bike hits the wall, the force involved in the collision stops it. However, this stopping force does not act on the rider to stop him, so he keeps moving forwards due to his inertia.

21. In the first diagram, the bus is stopping quickly, and the passengers and hanging ceiling straps all continue forwards according to Newton's first law. In the second diagram, the bus is accelerating quickly, and the inertia of the passengers and straps holds them in place until the force of the seat and the ceiling anchor points push and pull them forwards (Newton's first law).

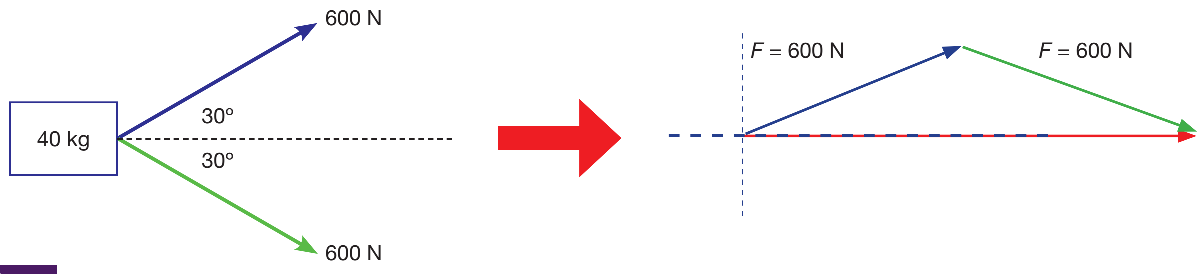
Newton's second law of motion

1. Net force will be 250 × 0.6 = 150 N in direction of the red arrow. This force also needs to overcome the pull of the other two forces. The vector diagram shows the resultant of the other two forces = 200 N.

Therefore the value of F must be 200 + 150 = 350 N and from the vector diagram, angle θ = 37°.



2. (a) From the vector diagram, resultant force = 1039.2 N bearing 090°.



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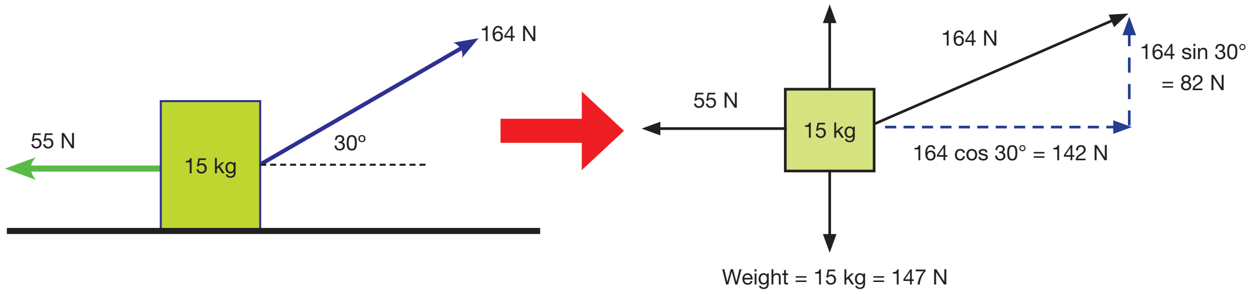
(b) From $F = ma = 1039.2 = 40a$
Acceleration is 26 m s^{-2} bearing 090° (25.98 rounded).

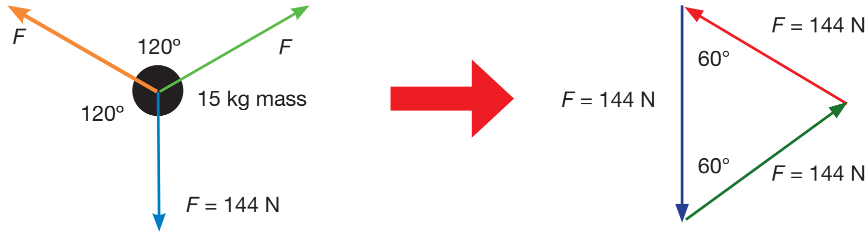
3. F = weight – 164 sin 30° = 147 – 82 = 65 N



(a) Net F vertically = 147 down – 82 up = 65 N down (therefore block stays on the surface)
Net F horizontally = 142 right – 55 left = 87 right = accelerating force

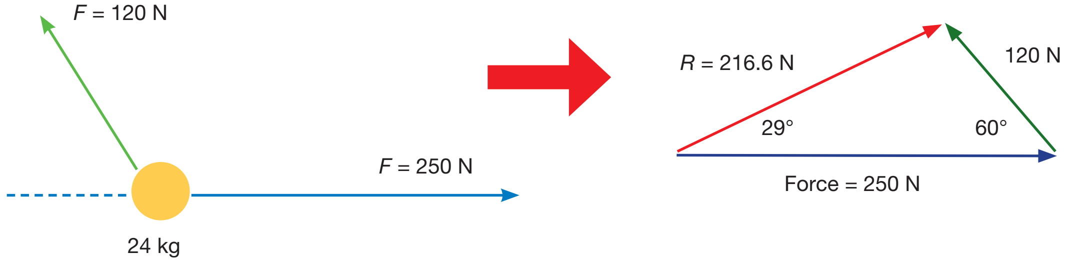
(b) From $F = ma = 87 = 15a$
Therefore, a = 5.8 m s^{-2} to the right

4.



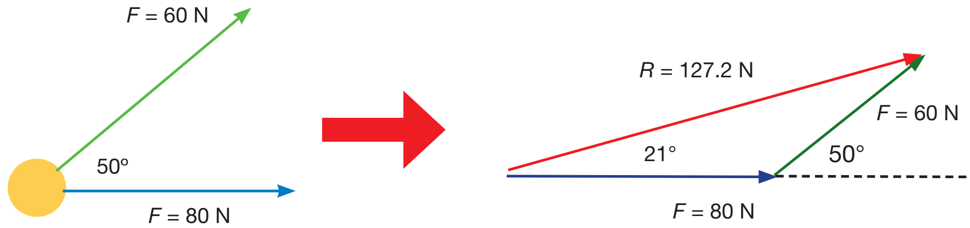
Net force on object is zero, therefore acceleration = 0

5.



Net force on object is 216.6 N to the right and up at 29° to the horizontal.
Therefore acceleration = $\frac{216.6}{24}$ = 9.0 m s^{-2} (rounded from 9.025) to the right and up at 29° to the horizontal.

6.



Net force on object is 127.2 N at 21° to the right and up from the horizontal.
Therefore acceleration = $\frac{127.2}{12}$ = 10.6 m s^{-2} at 21° to the right and up from the horizontal.

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7. (a) From $F = ma = 20 \times 150 = 3000$ N

(b) From weight force = mg, $3000 = 9.8m$, therefore $m = 306.1$ kg

(c) Very unlikely. Not many mothers (or fathers) can lift 300 kg!

(d) Children should not be travelling in cars without being in seat belts. Parents holding children will not be strong enough to protect them in the event of a collision.

(e) Newton's first law (an object will stay at rest or continue to move until an unbalanced force changes its motion), Newton's third law (to every action there is an equal and opposite reaction).

8. (a) A positive force acts in the direction of motion of an object causing it to go faster while a negative force acts against the direction of the motion of the object causing it to go more slowly.

(b) Accelerating from rest, accelerating away from a corner, coasting downhill.

(c) Braking as it approaches a corner or stop sign, coasting uphill.

9. (a) From $F = ma = 2500 \times 0$ = zero (constant velocity)

(b) From $F_{parallel} = mg \sin\theta = 2500 \times 9.8 \times \sin 15° = 6341.1$ N

(c) 6341.1 N up the slope

(d) Slow down, stop momentarily and then accelerate down the incline, all at 2.54 m s^{-2} (ignoring friction)

10. (a) From $F = ma = 60 \times 0.4 = 24$ N up the slope

(b) From $F_{parallel} = mg \sin\theta = 60 \times 9.8 \times \sin 15° = 152.2$ N down the slope

(c) Total force to move block up slope = component down + net force = 152.2 + 24 = 176.2 N

But rope is inclined at 20°, so tension in rope = $\frac{\text{total force}}{\cos 20°}$ = 187.5 N acting both ways

11. (a) From $F_{parallel} = mg \sin\theta = 62 \times 9.8 \times \sin 40° = 390.6$ N down the slope

(b) From $F_N = mg \cos\theta = 62 \times 9.8 \times \cos 40° = 465.4$ N up at 90° to the surface

(c) Friction = $0.2mg = 121.5$ N

(d) Net force = component of weight down slope – friction = 390.6 – 121.5 = 269.1 N down slope

(e) $a = \frac{\text{net force}}{m} = \frac{269.1}{62} = 4.34 \text{ m s}^{-2}$

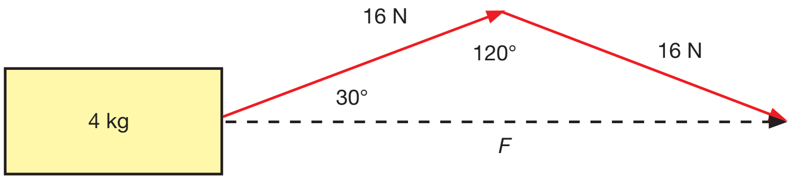
12. (a) From cosine rule:

$F = \sqrt{(16^2 + 16^2 - 2 \times 16 \times 16 \times \cos 120°)}$

= 27.7 N to the right

(b) From $a = \frac{F}{m} = \frac{27.7}{4}$

$a = 6.93 \text{ m s}^{-2}$ right



13. (a) From cosine rule:

$F = \sqrt{(500^2 + 500^2 - 2 \times 500 \times 500 \times \cos 120°)}$

= 866 N to the right

(b) From $a = \frac{F}{m} = \frac{866}{25} = 34.64 \text{ m s}^{-2}$ to the right

14. (a) Resultant force = horizontal component right – force left

= 48 cos 30° – 26 = 15.57 N right

(b) From $a = \frac{F}{m} = \frac{15.57}{5}$

$a = 3.1 \text{ m s}^{-2}$ right

15. (a) Net force = force down incline + component of weight down incline – component of 16 N up incline

= 5 + (4 × 9.8 sin 30°) – 16 cos 30° = 10.74 N down the incline

(b) From $a = \frac{F}{m} = \frac{10.74}{4}$

$a = 2.7 \text{ m s}^{-2}$ down the incline

16. Net force = 2.5 × 0.25 = 0.625 N left

Force right = 25 cos 40° = 19.15 N

Therefore force left has to be 19.15 + 0.625 = 19.78 N

Therefore, 30 cos θ = 19.78 N

From which θ = 48.75°

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17. Net force = 50 cos 40° – *F* cos 30° = 3 × 0.6 = 1.8 N right

Therefore, 1.8 = 38.3 – 0.866*F*

From which *F* = 42.15 N

18. From the vector diagram of these forces we get:

Applying the cosine rule we get

Resultant force = $\sqrt{(30^2 + 20^2 - 2 \times 30 \times 20 \times \cos 35°)}$ = 17.8 N

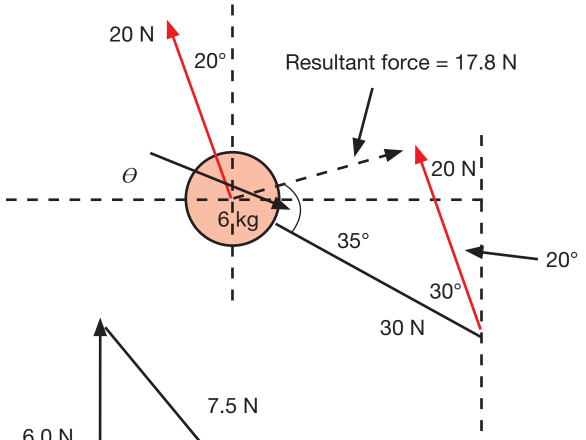
Applying sine rule to find angle θ, we get $\frac{17.8}{\sin 35°} = \frac{20}{\sin \theta}$

From which θ = 40° (to nearest degree)

So angle between resultant and horizontal = 5°

Therefore bearing of resultant force = 085°

Therefore resultant force = 17.8 N bearing 085°

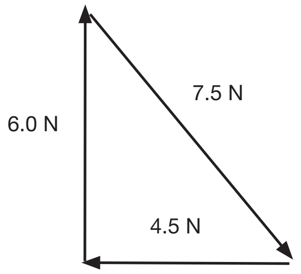


19. (a) Note that 4.5, 6.0 and 7.5 are in ratio 3 : 4 : 5, so the three forces will form a closed right angle triangle with the 7.5 N force as the hypotenuse when added to produce a net force of zero.

Force diagram must look like the one shown.

Therefore:

Angle *A* = 90°
Angle *B* = 127°
Angle *C* = 143°



(b) If the puck is moving with constant velocity, then the net force is zero, so this is the same situation as in (a).

Angle *A* = 90°
Angle *B* = 127°
Angle *C* = 143°

(c) This is best answered by drawing a scale vector diagram after calculating that the net force on the puck is = *F* = *ma* = 0.2 × 2.5 = 0.5 N.

So, the sum of the 6.0 N and the 7.5 N forces = 4.0 N to the right as in the diagram.

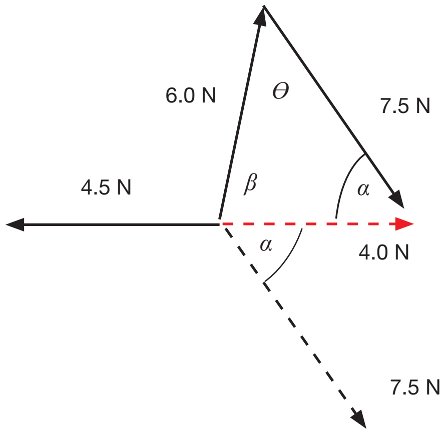
So, from cosine rule, $4^2 = 6^2 + 7.5^2 - 2 \times 6 \times 7.5 \times \cos \theta$

From which θ = 32°

So, from cosine rule,
$7.5^2 = 6^2 + 4.0^2 - 2 \times 4 \times 6 \times \cos \theta$

From which β = 85°

Therefore α = 180 – 32 – 85 = 63°



From these calculations, we get:

Angle *A* = 85° (180 – β)

Angle *B* = 117 (180 – 63)

Angle *C* = 158 (360 – 85 – 117)

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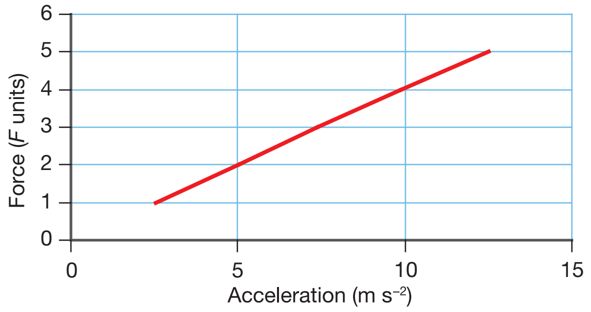
Newton's second law of motion practical analysis 1

1. (a)

Run	Accelerating force (N)	Time to travel 1.0 m (s)	Initial speed of trolley (m s⁻¹)	Average speed of trolley (m s⁻¹)	Final speed of trolley (m s⁻¹)	Acceleration of trolley (m s⁻²)
1	*F*	0.89	0	1.12	2.25	2.53
2	*2F*	0.63	0	1.59	3.17	5.03
3	*3F*	0.52	0	1.92	3.85	7.40
4	*4F*	0.45	0	2.22	4.44	9.87
5	*5F*	0.40	0	2.50	5.00	12.5

(b)



(c) Dependent variable = time to travel 1 m across the bench
Independent variable = accelerating force

(d) Take multiple readings for each accelerating force and see if the times for each run are close to the same.

(e) To increase reliability, uncontrolled variables have to be minimised. You could use a highly polished surface and pulley surface to reduce friction (which has not been considered in the original experiment). Using a light gate instead of a stopwatch would improve accuracy of the time measurement and therefore the reliability of the experiment.

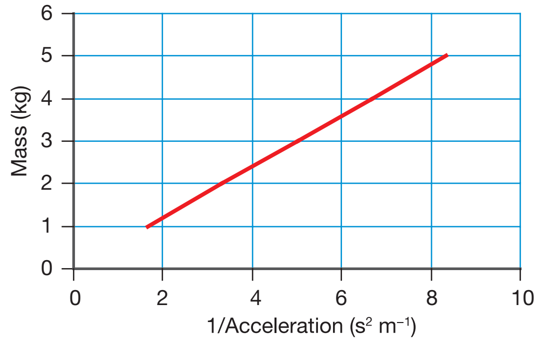
(f) The acceleration produced by forces applied to a constant mass is directly proportional to the force applied.

Newton's second law of motion practical analysis 2

1. (a)

Run	Trolley mass (kg)	Time to travel 1.0 m (s)	Initial speed of trolley (m s⁻¹)	Average speed of trolley (m s⁻¹)	Final speed of trolley (m s⁻¹)	Acceleration of trolley (m s⁻²)	(Acceleration)⁻¹
1	1.0	1.83	0	0.55	1.09	0.60	1.67
2	2.0	2.58	0	0.39	0.78	0.30	3.33
3	3.0	3.16	0	0.32	0.63	0.20	5.00
4	4.0	3.65	0	0.27	0.55	0.15	6.67
5	5.0	4.08	0	0.25	0.49	0.12	8.33

(b)



(c) The acceleration produced by a constant force acting on various masses is indirectly proportional to the mass.

(d) $F = ma$

(e) Experiment 1, force = 3.75 N (use gradient of graph)

Experiment 2, force = 0.6 N

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Newton's third law of motion

1. (a) Action is the force of foot kicking the ball, reaction is the force of the ball back on the foot.
   (b) Action is the force of hand punching the bag, reaction is the force of the bag back on the hand.
   (c) Action is the force of hammer hitting the nail, reaction is the force of the nail back on the hammer.
   (d) Action is the force of screw driver on the screw, reaction is the force of the screw back on the screw driver.
   (e) Action is the backward force the person's foot puts on the road. Reaction is the forward force the road puts on the person's foot.
   (f) Action is the forward force of the racquet on the ball. Reaction is the backward force of the ball on the racquet.
2. The equal and opposite forces act on different objects, one on the horse and one on the cart. They do not 'cancel each other'. Each is an unbalanced force so they will both be affected – the cart will be pulled forwards by the horse, and the horse will be slowed down as the cart pulls backwards on it.
3. (a) According to Newton's third law, when you throw the bundle forwards, you will experience an equal force backwards and will move backwards with equal but opposite direction momentum.
   (b) If you don't let the bundle go, then you have not applied an unbalanced force. You have perhaps pushed it forwards a little, but then you provided an equal and opposite force on it to stop it going forwards. You will not move from your position.
4. (a) 3000 N
   (b) No. They each have a force of 3000 N pulling them forwards through the rope, but they are also both pushing backwards on the ground through their feet with 3000 N – so there is no unbalanced force on either of them.
5. The dog shakes the bottle of drink causing much of the dissolved gas to come out of solution and build up pressure inside the bottle. When it takes the cork out of the bottle, the drink rushes out the opening putting an equal and opposite force backwards on the bottle and the girl holding it.
6. (a) The blade of the oar pushes on the water (which cannot move because of all the water behind it) and the water pushes equally backwards on to the blade. This force is transferred through the oar to the boat which is free to move, and is pushed through the water.
   (b) When we walk our foot pushes backwards and slightly downwards on the ground. This places equal and opposite forces forwards and upwards on us causing us to move forwards and upwards … hence the bob.
   (c) Our hand puts a force on the ball to stop it – the ball puts an equal and opposite force on our hand which, if large enough, can hurt.
   (d) When we kick the large rock, the time of impact is small so the impulse force is large – it hurts. When we kick the ball, the ball is deformed as it moves and our toes are in contact with it for a longer time. While the impulse may be the same, the time of contact is larger, so it doesn't hurt (as much).
7. (a) It recoils because the explosive charge which provides the force to accelerate the bullet forwards places an equal and opposite force backwards on the chamber the bullet is in (Newton's third law, law of conservation of momentum). This force transfers through to the rifle itself.
   (b) If the rifle is held firmly against the shoulder, the rifle and shoulder move back as one, more massive object. If the rifle is not held against the shoulder, the rifle moves back with greater speed and slams into the shoulder. While the shoulder provides a reaction force to stop the recoil, the force of the rifle butt on the shoulder can break it.
8. According to Newton's third law of motion, the pressure (= force per unit area) of the water rushing out of the hose puts an equal and opposite force on the person holding the hose. In this cartoon, this reaction force is enough to push the person backwards and over the fence.
9. The two readings will be the same according to Newton's third law of motion. The wall and the elephant are both immovable objects applying an equal and opposite direction force to that applied by the person.

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3. (a) From $v = r\omega = 0.8 \times 0.75 = 0.6$ m s^{-1}

(b) $a_c = \frac{v^2}{r} = \frac{0.6^2}{0.8} = 0.45$ m s^{-2} towards centre

(c) Tension = $F_c = ma_c = 0.5 \times 0.45 = 0.225$ N towards centre

(d) Period = $\frac{2\pi}{\omega} = 8.4$ s

(e) From $f = \frac{1}{T} = \frac{1}{8.4} = 0.12$ Hz

(f) From $v = r\omega$, if ω is the same but r doubles, then v doubles = v = ×2

$a = \frac{v^2}{4}$ therefore, acceleration = ×4

Therefore, tension = ×4

Period = same

f = same

4. (a) $f = \frac{1}{T} = \frac{1}{0.75} = 1.33$ Hz

(b) $\omega = \frac{2\pi}{T} = 8.38$ rad s^{-1}

(c) From $F_c = mr\omega^2$

$r = 8.46 \div (0.6 \times 8.38^2) = 0.2$ m

(d) $a_c = r\omega^2 = 0.2 \times 8.38^2 = 14$ m s^{-2} towards centre

(e) $v = r\omega = 0.2 \times 8.38 = 1.68$ m s^{-1}

5. (a) $T = \frac{1}{f} = \frac{1}{5} = 0.2$ s

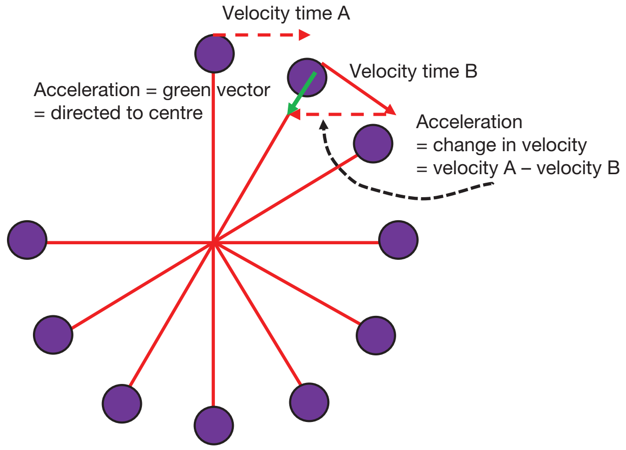
(b) $v = \frac{2\pi r}{T} = 18.85$ m s^{-1}

(c) $\omega = \frac{v}{r} = \frac{18.85}{0.6} = 31.4$ rad s^{-1}

(d) $a_c = \frac{v^2}{r} = \frac{18.85^2}{0.6} = 592.2$ m s^{-2} towards centre

(e) $F_c = \frac{mv^2}{r} = 0.3 \times \frac{18.85^2}{0.6} = 177.7$ N towards centre

6. (a) See diagram:



(b) From the spaces between top and bottom = 6 spaces

Half rotation = $6 \times \frac{1}{15} = 0.4$ s

Therefore period = 0.8 s

(c) $\omega = \frac{2\pi}{T} = 7.85$ rad s^{-1}

(d) $r = \frac{v}{\omega} = \frac{1.75}{7.85} = 22$ cm

(e) Section in diagram = 9 spaces = $\frac{9}{15} = 0.6$ s

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