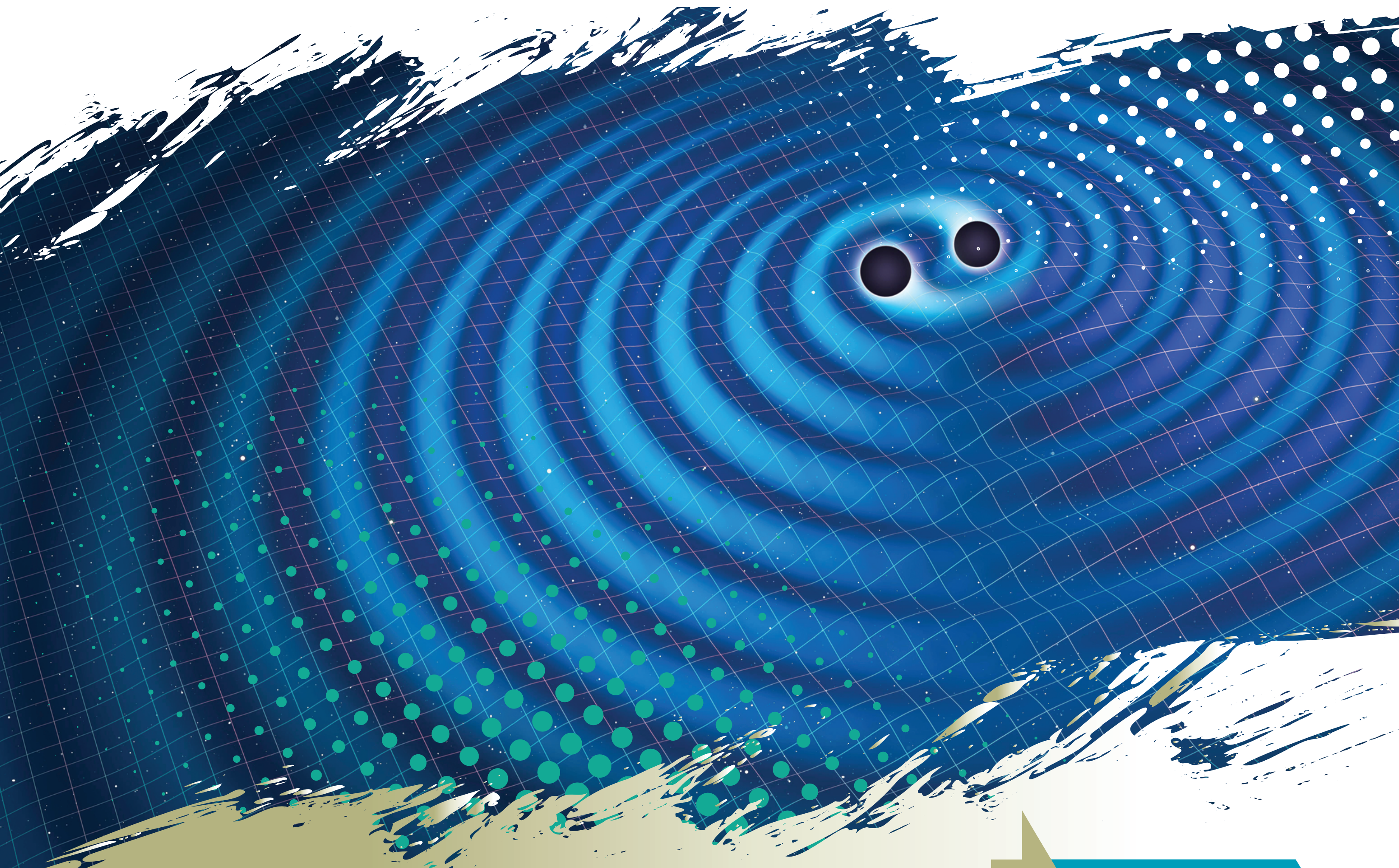
PEARSON PHYSICS QUEENSLAND

UNITS 3 & 4

2nd EDITION



Student Book

QCE 2025 Physics SYLLABUS

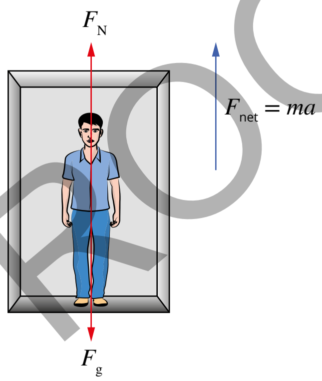
Chapter 3 Inclined planes

The answers to questions that involve calculations are given to the least number of significant figures as given in the question. See page e26XX in Chapter 1 for more details.

3.1 Inclined planes

Try yourself 3.1.1

FREE-BODY DIAGRAMS

A 66.0 kg student is standing in a lift on the ground floor of a building. The student presses the button marked '2' to go up to the second floor. The lift accelerates upwards at 0.820 m s^{-2} for a few seconds before it then moves at a constant velocity.	
a Draw a free-body diagram showing the forces that act on the student as the lift accelerates upwards.	
Thinking	**Working**
There are two forces acting on the student: gravitational force and normal force. They are drawn parallel to each other, with the net force acting upwards.	
b Calculate the normal force the student experiences as the lift accelerates upwards.	
Thinking	**Working**
There are two values given and these are mass and acceleration.	m = 66.0 kg a = 0.820 m s^{-2} upwards
Use the second law of motion to calculate the net force. As acceleration is upwards, F_N is greater than F_g.	$F_{net} = F_N - F_g$
Calculate the gravitational force.	$F_g = mg$ $= 66.0 \times 9.8$ $= 650$ N
Substitute the known vales to find F_N.	$ma = F_N - F_g$ $66.0 \times 0.820 = F_N - 647$ $54.1 = F_N - 650$ $F_N = 54.1 + 650$ $= 701$ N
Write the normal force as a vector with magnitude and direction.	F_N = 701 N upwards

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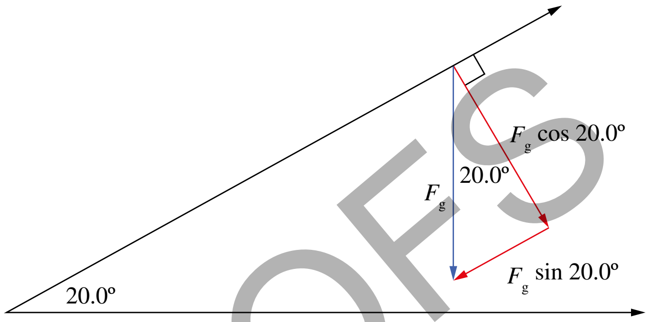
Try yourself 3.1.2

INCLINED PLANES I

A skier of mass 85.0 kg is skiing freely down an icy slope that is inclined at 20.0° to the horizontal. Assume that friction is negligible and that the acceleration due to gravity is $9.8\,m\,s^{-2}$.	
a Determine the components of the gravitational force of the skier perpendicular to the slope and parallel to the slope.	
Thinking	**Working**
The components of gravitational force perpendicular and parallel to the slope are given by trigonometric equations.	
Calculate the gravitational force of the skier.	$F_g = mg$ $= 85.0 \times 9.8$ $= 833\,N$
F_{gx} is the component of the gravitational force parallel to the slope.	$F_{gx} = F_g \sin 20.0°$ $= 833 \sin 20.0°$ $= 285\,N$ down (parallel to the slope)
F_{gy} is the component of the gravitational force perpendicular to the slope.	$F_{gy} = F_g \cos 20.0°$ $= 833 \cos 20.0°$ $= 783\,N$ down (perpendicular to the slope)
b Determine the normal force acting on the skier.	
Thinking	**Working**
The normal force is equal in magnitude but opposite in direction to F_{gy}.	$F_N = -F_{gy} = 783\,N$ up (perpendicular to the slope)
c Calculate the acceleration of the skier down the slope.	
Thinking	**Working**
The net force is down the slope, so this will be equal to the sum of all forces acting parallel to the slope. The acceleration is then equal to the net force divided by the mass of the skier.	$F_{net} = ma = F_{gx}$ $= 285$ $a = \frac{F_{net}}{m} = \frac{285}{85.0} = 3.35$ $a = 3.35\,m\,s^{-2}$ down the slope

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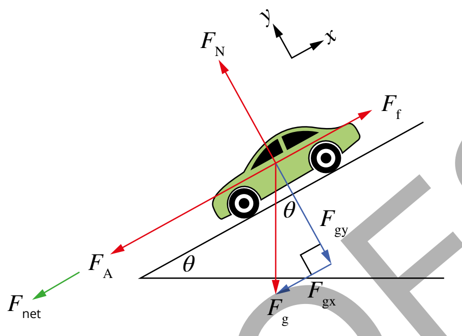
Try yourself 3.1.3

INCLINED PLANES II

Calculate the acceleration of the car if the same car turns around and is now accelerating down the slope with the same frictional force and applied forces acting. Take g as $9.8\,\text{m s}^{-2}$.	
Thinking	**Working**
Draw a free-body diagram of the car on the inclined plane showing all the forces acting on it. For calculations, take forces down the slope as negative and forces up the slope as positive.	
Calculate the component of the gravitational force acting parallel to the slope, F_{gx}.	$F_{gx} = F_g \sin 12.0°$ $= 850.0 \times 9.8 \sin 12.0°$ $= 1732$ N down (parallel to the slope)
Use the second law of motion to determine all forces acting parallel to the slope.	$-F_{net} = m \times -a$ $= -F_A + F_f - F_{gx}$
Substitute the values for m, F_A, F_f and F_{gx}.	$-F_{net} = m \times -a = -F_A + F_f - F_{gx}$ $= -850.0a = -2444 + 500.0 - 1732$ $= -850.0a = -3600$ $a = \frac{-3676}{-850.0} = 4.3$
Write the acceleration as a vector with magnitude and direction.	The acceleration of the car down the slope is $4.3\,\text{m s}^{-2}$.

3.1 KEY QUESTIONS

Describe

1 newton (N)

2 It is always straight down regardless of the angle of the inclined plane.

3 It is always perpendicular from the surface on which the object is resting.

4 As the angle to the horizontal on an inclined plane increases, the normal force decreases.

Apply

5 The normal force is the force acting on an object on a surface due to the surface itself pushing back on the object. If the object is not in contact with the surface, then the surface cannot push back on it and hence there is no normal force.

6 As the normal force is always perpendicular to the surface, on horizontal surfaces the normal force acts directly upwards. On inclined planes, as the surface is on an angle to the horizontal, the normal force also acts on an angle to the horizontal.

7 The gravitational force and the normal force on inclined planes don't balance. They are different sizes and point in different directions.

8 As the angle of the bridge increased, F_g remained constant, F_N decreased, but the frictional force acting on the tyres increased to balance the increased force acting down the incline.

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Analyse

9 $F_N = -F_g \cos\theta$

$= mg \cos\theta$

$= 65.0 \times 9.8 \times \cos 25.0$

$= 577\ \text{N}$

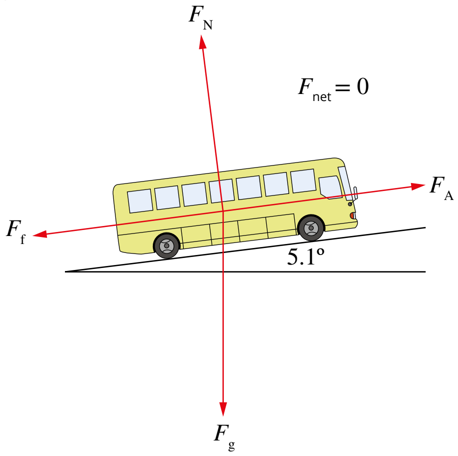
10 $F_{net} = -F_g \sin\theta$

$= mg \sin\theta$

$= 88.0 \times 9.8 \times \sin 12.5$

$= 187\ \text{N}$

11 First, draw a free-body diagram of the forces acting on the bus. They are friction, applied force, normal force and gravitational force.



The bus is moving at a constant velocity, so the net force on it must be zero. This means the sum of the forces parallel to the inclined plane is zero.

$$a = \frac{F_{net}}{m}$$

$$F_{net} = ma = 0 = F_A - F_f - F_{gx}$$

$$F_A = F_f + F_{gx}$$

$$= F_f + mg\sin\theta$$

$$= 1600 + 35000 \times 9.8 \times \sin 5.1°$$

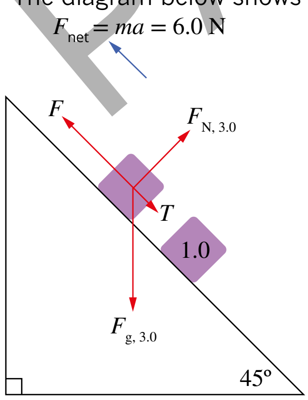
$$= 1600 + 30490$$

$$= 32000\ \text{N}$$

So, the applied force from the bus's engine is 3.2×10^4 N, up the slope.

12 As there are *two* masses involved in this question, each needs to have its own free-body diagram drawn.

The diagram below shows the forces acting on the 3.0 kg mass.



There is no friction but there is still a force from the 1.0 kg mass pulling on the 3.0 kg mass. As this force is along the rope connecting the two masses, this force is the tension in the rope.

The net force is equal to the mass of the 3.0 kg mass multiplied by its acceleration, 2.0 m s^{-2}, which gives:

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$a = \frac{F_{net}}{m}$

$2.0 = \frac{F_{net}}{3.0}$

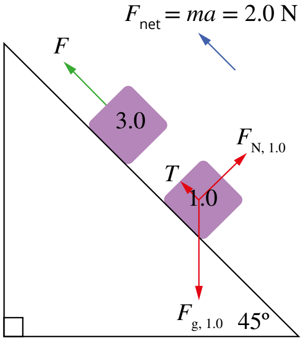
$F_{net} = 2.0 \times 3.0 = 6.0\,\text{N}$

And F_{net} is up the incline, so the sum of the magnitudes of the forces acting parallel to the incline is:

$$\begin{aligned} F_{net} &= F - T - F_{3.0,\,x} \\ &= F - T - mg\sin\theta \\ 6.0 &= F - T - 3.0 \times 9.8 \times \sin 45° \\ &= F - T - 20.8 \end{aligned}$$

So, $F - T = 27\,\text{N}$

The next diagram shows the forces acting on the 1.0 kg mass. The tension in the rope is of the same magnitude as in the previous diagram but it is now in the opposite direction, since the tension is pulling the 1.0 kg mass upwards.



Since both masses are moving up the incline with the same acceleration, the net force on the 1.0 kg mass is also up the incline and given by:

$a = \frac{F_{net}}{m}$

$2.0 = \frac{F_{net}}{1.0}$

$F_{net} = 2.0 \times 1.0 = 3.0\,\text{N}$

Note that the net force on each mass is different because, even though the accelerations are the same, the masses are different. F only acts on the 3.0 kg mass.

F_{net} is up the incline, so the sum of the magnitudes of the forces acting parallel to the incline is:

$$\begin{aligned} F_{net} &= T - F_{1.0,\,x} \\ &= T - mg\sin\theta \\ 2.0 &= T - 1.0 \times 9.8 \times \sin 45° \\ &= T - 6.9 \end{aligned}$$

So, $T = 8.9\,\text{N}$

Rounding to two significant figures, the tension in the rope is 8.9 N away from the 1.0 kg mass and away from the 3.0 kg mass.

Substituting the tension in the rope into the equation for the 3.0 kg mass:

$F - T = 27\,\text{N}$

So, $F = 27 + T$

$\quad = 27 + 8.9 = 36\,\text{N}$ up the incline.

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3.2 Circular motion

Try yourself 3.2.1

UNITS OF CIRCULAR MOTION

A typical internal hard disc drive (HDD) for a desktop computer can rotate at up to 7200 revolutions per minute.	
a Determine the period of the HDD.	
Thinking	**Working**
Calculate the frequency by dividing the revolutions per minute by 60.	Revolutions per second $= \frac{7200}{60} = 120\,\text{rps}$ Revolutions per second = 120, which is the frequency in Hz. $f = 120\,\text{Hz}$
Calculate the period by taking the reciprocal of the frequency.	$f = \frac{1}{T}$ $120 = \frac{1}{T}$ $T = \frac{1}{120} = 0.00833\,\text{s}$ $= 8.33 \times 10^{-3}\,\text{s}$
b Calculate how fast, in m s^{-1}, a point on the edge of the HDD rotates if the diameter of the HDD is 8.89 cm.	
Thinking	**Working**
Calculate the circumference of the edge of the HDD. Don't forget to convert cm to m.	$C = 2\pi r$ $= 2 \times \pi \times 8.89 \times 10^{-2}$ $= 0.559\,\text{m}$
The average speed is the circumference divided by the period.	$v = \frac{0.5586}{8.333 \times 10^{-3}}$ $= 67.0\,\text{m s}^{-1}$

Try yourself 3.2.2

AVERAGE SPEED AND PERIOD AROUND A CIRCLE

A hammer is being thrown in the cage by another athlete who rotates 3.60 times each second. The total length of the athlete's arms and hammer is 1.95m.	
a Determine the period of the hammer's motion.	
Thinking	**Working**
Calculate the period by taking the reciprocal of the frequency.	$f = \frac{1}{T}$ $T = \frac{1}{f}$ $= \frac{1}{3.60}$ $= 0.278\,\text{s}$

b Calculate the average speed of the hammer.	
Thinking	**Working**
The average speed of the hammer is the circumference divided by the period.	$v = \frac{2\pi r}{T}$ $= \frac{2 \times \pi \times 1.95}{0.278}$ $= 44.1\ \text{m s}^{-1}$
c Calculate the average velocity of the hammer.	
Thinking	**Working**
The average velocity of the hammer is the displacement divided by the period.	$v = \frac{s}{T}$ $= \frac{0}{0.278}$ $= 0\ \text{m s}^{-1}$

3.2 KEY QUESTIONS

Describe

1 period (s), frequency (Hz), average speed (m s^{-1}), average velocity (m s^{-1})

2 The frequency and period are inversely related by $f = \frac{1}{T}$. As the period increases the frequency will decrease.

3 Period is a measurement of the time taken for an object in circular motion to complete one full rotation.

4 'Uniform' circular motion is the motion of an object moving around a circle with a constant speed.

Apply

5 As frequency is a measure of revolutions per second, the frequency can be calculated by dividing the rpm by 60.

$$f = \frac{1200}{60} = 20\ \text{Hz}$$

6 The average speed of the object is the total distance travelled (i.e. the circumference) divided by the total time taken (i.e. the period). The average velocity of the object is the total displacement divided by the period. The average velocity will be zero, as the displacement after completing one full rotation will be zero.

7 The period of an object moving in a circle with constant speed is equal to the total time taken for one rotation. It is measured in seconds. The frequency of the object's motion is the inverse of the period, or how many full rotations it completes in one second. The unit of frequency is the hertz, Hz or s^{-1}.

8 Velocity is defined as the change in displacement divided by time. Velocity is a vector, so it requires magnitude and direction. Even if the magnitude is constant, if the direction of an object changes, then its velocity also changes.

Analyse

9 Average speed = total distance divided by period

$$v = \frac{2\pi r}{T}$$
$$= \frac{2 \times \pi \times 50}{44.9}$$
$$= 7.0\ \text{m s}^{-1}$$

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10 $v = \dfrac{2\pi r}{T}$

$28.3 = 2\pi r 40 \times 10^{-3}$

$r = 28.3 \times 40 \times 10^{-3} 2\pi$

$= 0.18\,\text{m}$

11 a Average speed = total distance divided by period

$= \dfrac{2\pi r}{T}$

$= \dfrac{2 \times \pi \times (6400 + 540) \times 10^3}{95.47 \times 60}$

$= \dfrac{4.361 \times 10^7}{5728}$

$= 7.6 \times 10^3\,\text{m s}^{-1}$

b Average velocity is the displacement divided by period $= \dfrac{0}{5728} = 0\,\text{m s}^{-1}$.

12 The distance travelled is one quarter of the circumference of the circle with the radius of 1250 m.

$S = \dfrac{2\pi r}{4}$

$= \dfrac{2 \times \pi \times 1250}{4}$

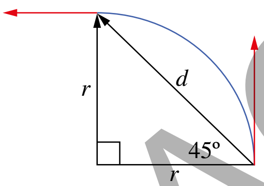
$= 1963.5\,\text{m}$

The time taken for this will be the distance divided by the average speed. First convert the given average speed to standard units.

$12.3\,\text{km h}^{-1} = \dfrac{12.3}{3.6} = 3.417\,\text{m s}^{-1}$

$t = \dfrac{1963.5}{3.417} = 575\,\text{s}$ (9.58 minutes)

Average velocity is the displacement divided by the time taken, so the displacement is to be worked out. Displacement is the distance, in a straight line, from the starting point to the finishing point, which is the hypotenuse of a right-angled triangle.



$s = \sqrt{1250^2 + 1250^2}$

$= 1767.8 = 1770\,\text{m}$

The direction is towards the north-west.

So, the cyclist's average velocity is $\dfrac{1767.8}{573} = 3.09\,\text{m s}^{-1}$ towards the north-west.

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3.3 Centripetal force

Try yourself 3.3.1

CENTRIPETAL FORCE AND ACCELERATION

Earth has a mass of 5.97×10^{24} kg and takes exactly 1.0 year to orbit the Sun at an average distance of 150 million km.

a Calculate the average speed of Earth in its orbit around the Sun.

Thinking	Working
Convert the period and radius to SI units.	$T = 1 \text{ year} = 1 \times 365 \times 24 \times 3600$ $= 31\,536\,000\,\text{s}$ $r = 150 \times 10^6\,\text{km} = 150 \times 10^9$ $= 1.5 \times 10^{11}\,\text{m}$
The average speed is the circumference of the circular orbit divided by the period.	$v = \frac{2\pi r}{T}$ $= \frac{2 \times \pi \times 1.5 \times 10^{11}}{31536000}$ $= 3.0 \times 10^4\,\text{m s}^{-1}$

b Calculate the centripetal acceleration of Earth.

Thinking	Working
Substitute the calculated value for v into the formula for centripetal acceleration.	$a_c = \frac{v^2}{r}$ $= \frac{(3.0 \times 10^4)^2}{1.5 \times 10^{11}}$ $= 6.0 \times 10^{-3}\,\text{m s}^{-2}$ towards the Sun

c Calculate the centripetal force acting on Earth.

Thinking	Working
Recall the equation for the centripetal force, substitute the values and solve. Note that this could also be calculated using $F_c = ma_c$.	$F_c = \frac{m_{Earth} v^2}{r}$ $= \frac{5.97 \times 10^{24} \times (3.0 \times 10^4)^2}{1.5 \times 10^{11}}$ $= 3.6 \times 10^{22}$ N towards the Sun

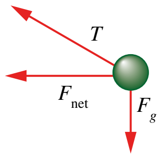
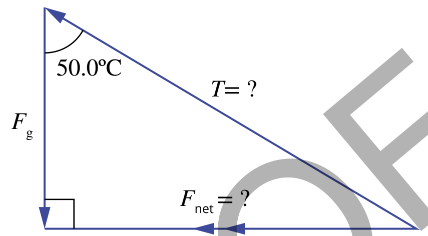
Try yourself 3.3.2

HORIZONTAL CENTRIPETAL FORCE AND ACCELERATION

The ball on the totem tennis pole is swapped with a slightly heavier ball with a mass of 175g. The same 1.50 m cord is used which is now swung 50.0° to the vertical.

a Calculate the radius of the ball's circular path.

Thinking	Working
Use an appropriate trigonometric ratio to determine the radius of the ball's path.	$\sin 50.0° = \frac{r}{1.50}$ $r = 1.50 \sin 50.0°$ $= 1.15\,\text{m}$

b Sketch a free-body diagram showing all the forces acting on the ball.	
Thinking	**Working**
Forces that act on the ball are the tension in the string and the gravitational force of the ball. No normal force exists because the ball is not in contact with a surface. Centripetal force ($F_c = F_{net}$) is the sum of the tension and the gravitational force of the ball.	
c Determine the net force acting on the ball.	
Thinking	**Working**
The net force on the ball is equal to the sum of the gravitational force and the tension in the string. This gives a vector acting directly to the left which is the centripetal force, since the ball is moving in a circle.	
Calculate the gravitational force first.	$F_g = mg = 0.175 \times 9.8 = 1.715$ $= 1.72$ N straight down
Using trigonometry and the vertical and horizontal components of the tension, the net force can be calculated. Note that that centripetal force cannot be directly calculated using the formula for centripetal force because neither the speed nor period are known.	$\tan 50.0° = \frac{F_{net}}{F_g}$ $F_{net} = F_g \tan 50.0°$ $= 1.715 \tan 50.0° = 2.044$ $= 2.04$ N towards the pole
d Calculate the tension in the string.	
Thinking	**Working**
The tension in the string can also be found using the force triangle in part **c**, using either the vertical or horizontal component of the tension.	$\cos 50.0° = \frac{F_g}{T}$ $T = \frac{F_g}{\cos 50.0} = \frac{1.715}{\cos 50.0}$ $T = 2.67$ N along the cord towards the top of the pole. or $\sin 50.0° = \frac{F_{net}}{T}$ $T = \frac{F_{net}}{\sin 50.0} = \frac{2.044}{\sin 50.0}$ $T = 2.67$ N along the cord towards the top of the pole.
e Calculate the speed of the ball.	
Thinking	**Working**
The speed of the ball can be found using the formula for centripetal force.	$F_c = \frac{mv^2}{r} = 2.044$ $v = \sqrt{\frac{2.044 \times 1.15}{0.175}} = 3.66\ \text{m s}^{-1}$

3.3 KEY QUESTIONS

Describe

1 Velocity is always at a tangent to the circle, that is, at right angles to the radius.

2 Centripetal acceleration acts directly towards the centre of the circle that the object is moving in.

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3 The net force must act at right angles to the object's velocity for the object to move in a circle.

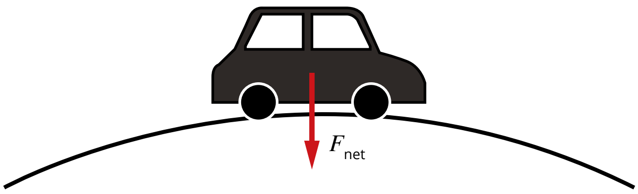
4 $a_c = \dfrac{v^2}{r}$

Apply

5 In order for an object to undergo uniform circular motion, the *net* force on the object must be towards the centre of the circle it is moving in, that is, at 90° to the velocity of the object. There can be many forces acting on an object, and the second law of motion states that the sum of the forces that act on an object directly is equal to the net force, or $F_{net} = ma$. The centripetal force is the result of the forces that would act on the object directly if they were all reduced to one single force. If the direction of the net force is at 90° to the velocity of the object, then the object will accelerate towards the centre of the circle.

6 Once they let go of their projectile there is no longer any centripetal force acting, so the projectile will move with the same speed and direction it had at the instant the centripetal force was removed. Assuming that the projectiles do not curve, then the hammer and discus thrower must release their projectiles when the hand(s) holding the hammer or discus form a right angle to the arena. They do not want to release their projectile when their hand(s) are pointing directly at the arena, because the projectile will move off at right angles and hit the safety cage.

7



As the car is experiencing uniform circular motion, the net force is acting towards the centre of the circle which is vertically down at the peak of the hill.

8 Using the formula $F_c = \dfrac{mv^2}{r}$, if mass and speed are constant then a smaller radius will increase the centripetal force acting on the car.

Analyse

9 The tension force is the net force acting on the cork. Mass and radius are kept the same, so the only value changing is velocity.

If the velocity is doubled, $v_{final} = 2 \times v_{initial}$

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

$$F_c = \frac{m(2v)^2}{r}$$

$$= 4 \times \frac{mv^2}{r}$$

$$= 4 \times 2.5$$

$$= 10\,\text{N}$$

If the velocity is increased by a factor of 2, the net force is increased by a factor of 4.

10 The period of a point on Earth's equator is 24 hours or $24 \times 60 \times 60 = 86\,400$ s.

The circumference of Earth along the equator $= 2 \times \pi \times 6378 \times 10^3 = 4.0074 \times 10^7$ m.

The average speed is $\dfrac{4.0074 \times 10^7}{86400} = 463.8\,\text{m s}^{-1}$.

So, $a_c = \dfrac{v^2}{r} = \dfrac{463.8^2}{6378 \times 10^3} = 0.0337\,\text{m s}^{-2}$

11 $F_{net} = \dfrac{mv^2}{r}$

$$= \frac{750 \times 4.0^2}{5.0}$$

$$= 2.4 \times 103\,\text{N}$$

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12 $F_c = \frac{mv^2}{r} = \frac{1.67 \times 10^{-27} \times v^2}{1.20} = 7.50 \times 10^{-13}\,N$

$V = \sqrt{\frac{rF_c}{m}} = \sqrt{\frac{1.20 \times 7.50 \times 10^{-13}}{1.67 \times 10^{-27}}}$

$= 2.32 \times 10^7\,m\,s^{-1}$

CHAPTER 3 REVIEW

Describe

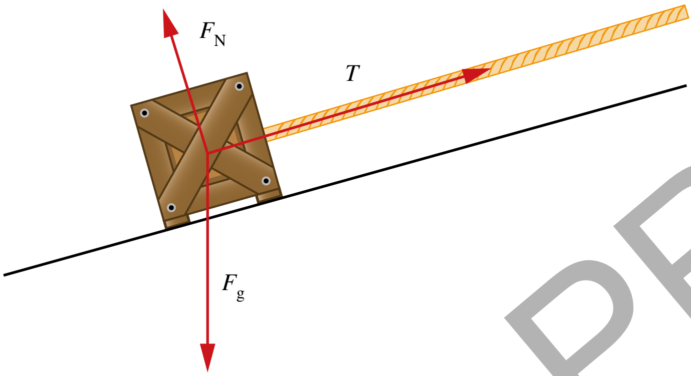
1 B. when the surface is at 0° to the horizontal

2 B. It moves with constant acceleration.

3 D. $F_c = \frac{mv^2}{r}$

4 Friction opposes the direction of motion, so an object moving down an inline plane will have a frictional force acting up the plane, parallel to the surface.

5



6 The normal force is equal in magnitude and opposite in direction to the vertical component of the gravitational force. Both the normal force and vertical component of the gravitational force are perpendicular to the surface of the plane.

7 There is no change in speed, as speed is constant in uniform circular motion.

8 Period is measured in seconds (s).

9 Using the formula $v = \frac{2\pi r}{T}$, you need the radius of the circular path and the period.

10 Centripetal force is the gravitational attraction between the object and Earth, which pulls the object towards the centre of Earth. As there is no normal force, $F_c = F_g$.

Apply

11 C. frictional force and the component of gravitational force parallel to the plane

12 C. The normal force is always perpendicular to the surface.

In the absence of friction, a component of the gravitational force causes the object to accelerate down the slope. But the normal force is perpendicular to the direction of motion, and therefore has no component in the direction of motion and so contributes nothing to the motion.

13 There is a horizontal component of the gravitational force which acts down the plane, parallel to the surface. This becomes the net force, F_{net}, which causes the box to accelerate down the plane.

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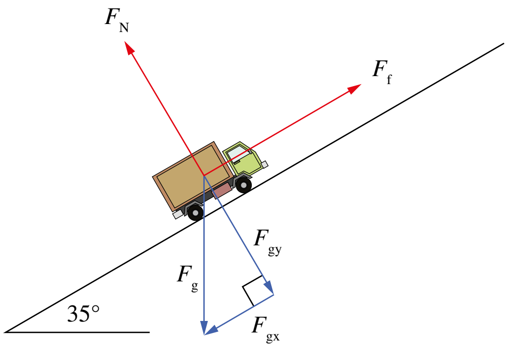
14 **a** Since the truck is resting on the plane, the net force and acceleration are zero.

b



c $F_{gx} = F_g \times \sin 35\,\theta = 2.58 \times 10^3 \times 9.8 \times \sin 35\,\theta = 1.5 \times 10^4$ N

$F_{gy} = F_g \times \cos 35\,\theta = 2.58 \times 10^3 \times 9.8 \times \cos 35\,\theta = 2.1 \times 10^4$ N

d The magnitude of the normal force is equal to the magnitude of F_{gy}, so $F_N = 2.1 \times 10^4$ N.

15 The velocity of an object in uniform circular motion is constantly changing as the direction changes. As the velocity is constantly changing, the object is accelerating.

16 Using the formula for velocity, $v = \frac{2\pi r}{T}$, average speed are inversely proportional. As average speed increases, the period (or time to complete one full rotation) will decrease.

17 $T = 60$ s, as it takes 60 s to complete one full rotation.

18 Centripetal force is the resultant force acting on the body. It only exists when the hammer thrower exerts tension on the rope holding the hammer. When the hammer is released, the tension is reduced to zero and so the centripetal acceleration is zero and the hammer moves off in a straight line. Technically, the path of the hammer will curve downwards because of its gravitational force acting vertically, but horizontally there is no force acting.

Analyse

19 **a** A. The frictional force is in the opposite direction to the velocity.

b C. The normal force is perpendicular to the slope.

c The sled is sliding down the incline at a constant velocity, so the acceleration is zero and the net force is also zero. This means the frictional force is equal to the component of the gravitational force acting parallel to the incline, F_{gx}.

So, $F_f = F_{gx} = F_g \times \sin 30.0°$

$= (102 \times 9.8) \times \sin 30.0°$

$= 5.0 \times 10^2$ N up the incline.

d Friction is now zero, so the only force acting down the incline is the component of the gravitational force parallel to the plane, F_{gx}.

$F_{net} = ma = F_{gx}$

$= 5.0 \times 10^2$ N down the hill

$$a = \frac{5.0 \times 10^2}{102} = 4.9\ \text{m s}^{-2}$$

So, $a = 4.9$ m s–^{2} down the hill.

e Since friction is ignored, the net force is equal to the component of gravitational force acting parallel to the plane, F_{gx}. F_{gx} has now changed since the mass has increased:

$F_{gx} = F_g \times \sin 30.0°$

$= (144 \times 9.8) \times \sin 30.0°$

$= 706$ N

And this will be equal to the net force:

$F_{net} = ma = F_{gx}$

$= 706$ N

So, $a = \frac{706}{144}$

$= 4.9\ \text{m s}^{-2}$ down the hill.

This is the same as the answer to part **d**, which means that mass has no effect on the acceleration if friction is zero.

20 **a** $F_N = F_{gy} = mg\cos 65°$

$= (57 + 3) \times 9.8 \times \cos 65°$

$= 250\,N$

b $F_{net} = F_{gx} = mg\sin 65°$

$= 60 \times 9.8 \times \sin 65°$

$= 530\,N$ down the ramp

c $a = \frac{F_{net}}{m}$

$= \frac{60 \times 9.8 \times \sin 65}{60} = 8.9$

$a = 8.9\,m\,s^{-2}$ down the ramp

d Use the equations of motion with $u = 0$, $s = 5.0\,m$, $a = 8.9\,m\,s^{-2}$:

$v^2 = u^2 + 2as$

gives $v = 9.4\,m\,s^{-1}$ down the ramp.

e If Declan is stationary then the net force acting on him is zero, which means friction will be equal to the component of gravitational force parallel to the ramp:

$F_f = 60 \times 9.8 \times \sin 65° = 530\,N$ up the ramp

21 **a** Average speed $= \frac{2\pi r}{T} = \frac{2 \times \pi \times 1.3}{1.0} = 8.17 = 8.2\,m\,s^{-1}$

b $a_c = \frac{v^2}{r} = \frac{8.17^2}{1.3} = 51.3 = 51\,m\,s^{-2}$ towards the centre of the athlete

c There are only two forces acting on the hammer: its gravitational force and the tension in the rope.

Tension is a force that always acts along a string or rope, away from the object it is supporting.

Gravitational force acts straight down. Since the centripetal force is acting horizontally (the hammer is moving in a horizontal circle), the gravitational force has no contribution to the centripetal force,

Thus the only force causing the centripetal force must be the tension in the rope acting away from the hammer, i.e. inwards. So the tension is the same as the centripetal force.

$F_c = ma = 7.00 \times 51.3 = 359 = 360\,N$, in towards the athlete.

22 **a** 250 000 revolutions per minute $= \frac{250\,000}{60} = 4200$ revolutions per second, which is the same as frequency in Hz. So $f = 4200\,Hz$.

b $f = \frac{1}{T}$

$T = \frac{1}{f} = \frac{1}{4200} = 2.4 \times 10^{-4}\,s$ or $0.24\,ms$

c Average speed $= \frac{2\pi r}{T} = \frac{2 \times \pi \times 6.0 \times 10^{-2}}{2.4 \times 10^{-4}} = 1.6 \times 10^3\,m\,s^{-1}$

23 **a** The average speed of the black hole is given as 85% of the speed of light:

$v = 0.85 \times 3 \times 10^8 = 2.55 \times 10^8\,m\,s^{-1}$

Average speed $= \frac{2\pi r}{T}$

$2.55 \times 10^8 = \frac{2 \times \pi \times 1.6 \times 10^9}{T}$

$T = \frac{2 \times \pi \times 1.6 \times 10^9}{2.55 \times 10^8}$

$= 39\,s$

b Frequency is the inverse of the period:

$f = \frac{1}{T} = \frac{1}{39} = 0.025\,Hz$

c The magnitude of the centripetal acceleration:

$a_c = \frac{v^2}{r} = \frac{(2.55 \times 10^8)^2}{1.6 \times 10^9} = 4.1 \times 10^7\,m\,s^{-2}$

24 The passenger feels weightless as there as no normal force acting on them as they travel through the top of the loops. This occurs when the net force is equal in magnitude and direction as the force due to gravity:

$F_c = F_g$, or $\frac{mv^2}{r} = mg$

Interpret

25 **a** The net force is calculated using $F_{net} = ma$

So, the acceleration needs to be calculated.

Use the equations of motion with $u = 0$, s = slide length, a = ?, $v = 91.0\,\text{km h}^{-1}$ (= $25.28\,\text{m s}^{-1}$)

The slide length is the hypotenuse of the right-angled triangle formed by the ramp:

$$s = \frac{49.0}{\sin 60.0} = 56.6\,\text{m}$$

Using $v^2 = u^2 + 2as$

$$a = 5.65\,\text{m s}^{-2}$$

So, $F_{net} = ma$

$= 70.0 \times 5.65$

$= 395\,\text{N}$ down the slide.

b The net force is equal to the component of gravitational force down the slide minus the frictional force:

$F_{net} = F_{gx} - F_f$

$F_{net} = mg\sin\theta - F_f$

$395 = 70.0 \times 9.8 \times \sin 60.0 - F_f$

$F_f = 70.0 \times 9.8 \times \sin 60.0 - 395$

$= 199\,\text{N}$ parallel to the slide.

c The normal force is the equal to the component of the gravitational force perpendicular to the slide, F_{gy}:

$F_{gy} = mg\cos\theta = 70.0 \times 9.8 \times \cos 60.0° = 343\,\text{N}$ perpendicular to the slide.

26 **a** Weight of the changing mass = tension in the string = centripetal force on the constant mass:

Using $F_c = \frac{mv^2}{r}$ and $v = \frac{2\pi r}{T}$

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

$$mg = \frac{Mv^2}{r}$$

$$= \frac{M\left(\frac{2\pi r}{T}\right)^2}{r}$$

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

$$= \frac{4M\pi^2 r^2}{rT^2}$$

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

b Use the equation $mg = \frac{4\pi^2 Mr}{T^2}$ and make T the subject; the relationship between T and m is:

$$T \propto \frac{1}{\sqrt{m}}$$

To linearise the data, the x-axis will need to be changed from m to $\frac{1}{\sqrt{m}}$.

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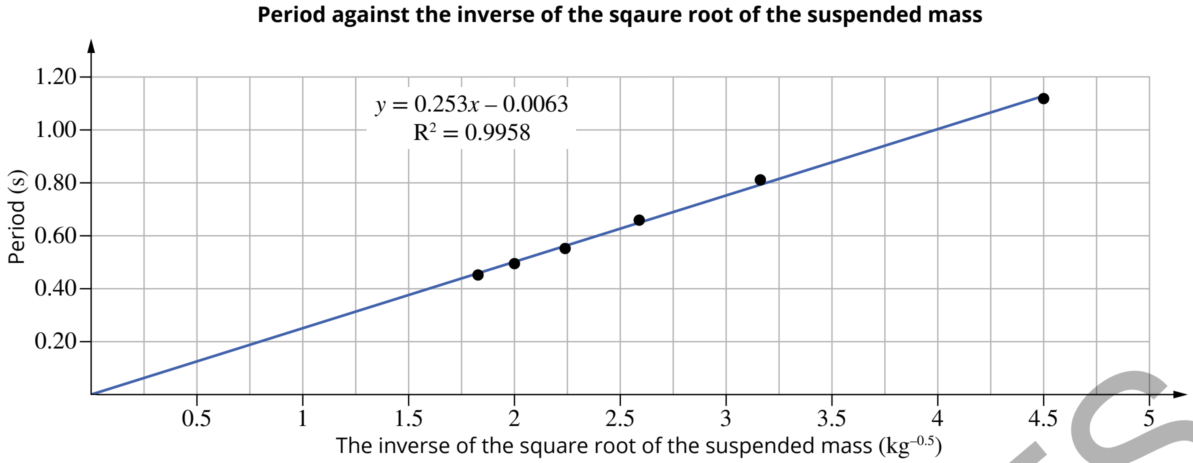
c



d gradient = $0.253\,\mathrm{s\,kg^{0.5}}$

The gradient should be $2\pi\sqrt{\frac{Mr}{g}}$.

$$\text{gradient} = 2\pi\sqrt{\frac{Mr}{g}}$$

$$= \frac{2\pi\sqrt{Mr}}{\sqrt{g}}$$

Therefore, $\sqrt{g} = \frac{2\pi\sqrt{Mr}}{\text{gradient}}$

and $g = \frac{4\pi^2 Mr}{\text{gradient}^2}$

$$= \frac{4\times\pi^2\times 0.05\times 0.030}{0.253^2}$$

$$= 9.3\,\mathrm{m\,s^{-2}}$$

Data analysis

Question 1 (3 marks)

The uncertainty of the gradient $= \pm\frac{11.6-10.1}{2}$

The uncertainty of the gradient = ±0.750 *(1 mark)*

The uncertainty of the y-intercept $= \frac{-0.899-(-0.572)}{2}$

The uncertainty of the y-intercept = ±0.1635 *(1 mark)*

$a = (11.6\pm 0.750)\sin\theta - (0.899\pm 0.16)$ *(1 mark)*

Question 2 (1 mark)

$a = 11.6\sin 45 - 0.899$

$= 7.3\,\mathrm{m\,s^{-2}}$ *(1 mark)*

Question 3 (3 marks)

The gradient of the linear trend line is 11.6±0.750

percentage uncertainty of the gradient $= \frac{0.75}{11.6}\times 100 = 6.5\%$ *(1 mark)*

The gradient represents: gradient $= \frac{a}{\sin\theta}$ *(1 mark)*

Using the equations $F_{net} = ma$ and $F_{net} = mg\sin\theta$ for a block down an incline plane:

$ma = mg\sin\theta$

$a = g\sin\theta$

gradient $= g = \frac{a}{\sin\theta} = 11.6\pm 0.750\,\mathrm{m\,s^{-2}} = 11.6\,\mathrm{m\,s^{-2}} \pm 6.5\%$ *(1 mark)*

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Question 4 (1 mark)

$$\text{percentage error (\%)} = \left(\frac{\text{measured value} - \text{true value}}{\text{true value}}\right) \times 100$$

$$\text{percentage error (\%)} = \left(\frac{11.6 - 9.80}{9.80}\right) \times 100$$

$$= 18.4\%$$

(1 mark)

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