2

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Level 2 Physics 2020

91171 Demonstrate understanding of mechanics

9.30 a.m. Monday 16 November 2020
Credits: Six

Achievement	Achievement with Merit	Achievement with Excellence
Demonstrate understanding of mechanics.	Demonstrate in-depth understanding of mechanics.	Demonstrate comprehensive understanding of mechanics.

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Make sure that you have Resource Sheet L2–PHYSR.

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Check that this booklet has pages 2–12 in the correct order and that none of these pages is blank.

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TOTAL

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QUESTION ONE: IN TOWN

Alex and Jo have decided to take a road trip. They start from rest on a straight road, and accelerate at 4.2 m s^{-2}.

(a) Show their velocity after 0.60 seconds is 2.5 m s^{-1}.

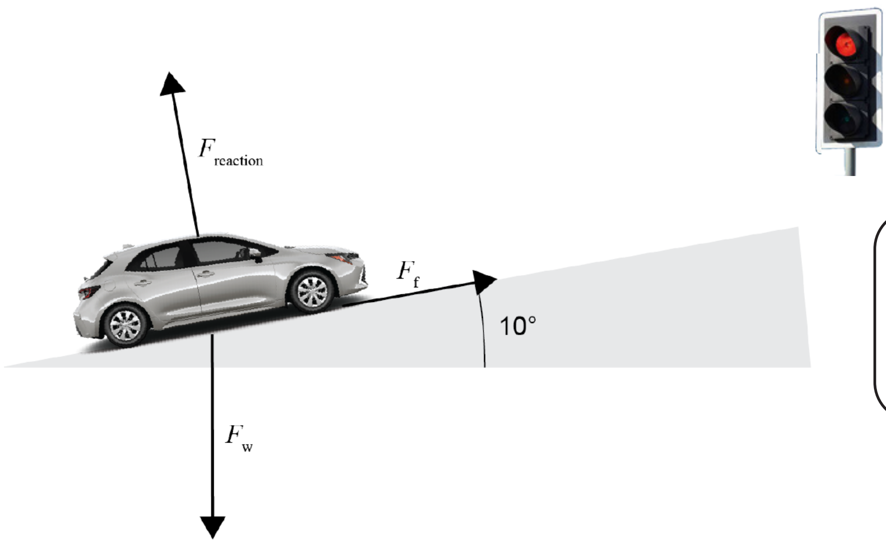
$$v_f = v_i + at$$

$$v_f = at$$

$$v_f = 4.2(0.60)$$

$$v_f = 2.5\ \mathrm{m\ s^{-1}}$$

(b) While waiting at traffic lights, Jo has to put on the handbrake to stop the car rolling down the steep (10°) slope they are on. The mass of the car and occupants is 1600 kg.



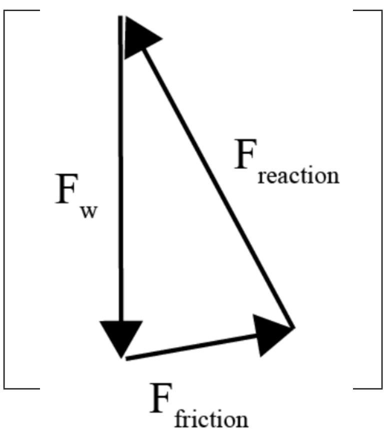
If you need to redraw your labelled arrows, use the spare diagram on page 9.

Adapted from: www.auto123.com/en/new-cars/technical-specs/toyota/corolla/2019/hatchback/base/
www.luxreview.com/2016/08/17/smart-traffic-lights-to-talk-to-drivers/

The diagram above shows the friction force acting between the tyres and the road.

(i) Add **labelled** arrows to show the other two forces acting on the stationary car.

(ii) Complete a **labelled** vector diagram showing how all three forces add together.



If you need to redraw your vector diagram, use the spare diagram on page 9.

(c) By first working out the force of gravity on the car, show that the value of the friction force required to keep the car stationary is 2700 N.

$$F_w = mg$$

$$F_w = 1600 \times 9.8$$

$$F_w = 15680 \text{ N}$$

$$F_f = F_w \sin 10^\circ$$

$$F_f = 15680 \sin 10^\circ$$

$$F_f = 2722 \text{ N} \approx 2700 \text{ N}$$

(d) While travelling at 50 km h^{-1}, Jo sees a pothole in the road 15 m ahead. She must reduce her speed from 50 km h^{-1} to 20 km h^{-1} to avoid damaging the car.

If the time needed for safe braking from 50 km h^{-1} to 20 km h^{-1} is 2.3 seconds, show by calculation whether there is enough time to complete braking before reaching the pothole.

You should start by showing that 50 km h^{-1} = 13.89 m s^{-1}.

$$v(\text{m s}^{-1}) = \frac{v(\text{km h}^{-1})}{3.6}$$

$$50 \text{ km h}^{-1} = \frac{50}{3.6} = 13.89 \text{ m s}^{-1}$$

$$20 \text{ km h}^{-1} = \frac{20}{3.6} = 5.56 \text{ m s}^{-1}$$

$$d = \frac{v_i + v_f}{2} t$$

$$d = \frac{13.89 + 5.56}{2}(2.3)$$

$$d = 22.4 \text{ m}$$

$$22.4 > 15$$

Not enough time / distance to brake safely before the pothole.

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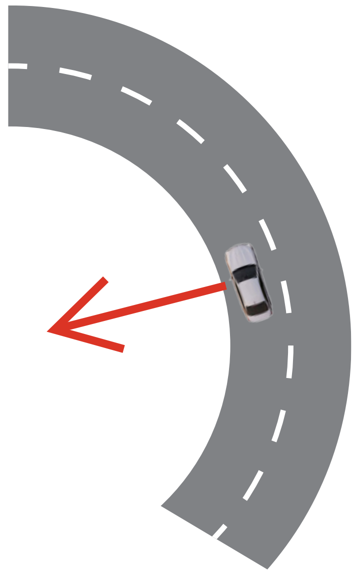
QUESTION TWO: OPEN ROAD

Jo and Alex continue their drive and take a sharp bend in the road at a constant speed of 12 m s^{-1}.



If you need to redraw your arrow, use the spare diagram on page 10.

(a) Draw an arrow on the car on the diagram above to show the direction of the acceleration at this point.

(b) Calculate the size of the acceleration if the radius of the bend is 25 m, and explain what causes this acceleration.

$$a = \frac{v^2}{r} = \frac{12^2}{25} = 5.76 \text{ m s}^{-2}$$

Unbalanced inward force created by friction causes inward acceleration

(c) State TWO external factors that could change the motion of the car as it travels around the corner, and explain how these factors would affect the motion.

If the car hits ice / oil / gravel / wet road / or tyre condition

- this will change the friction forces and either reduce or increase centripetal force
- and so direction will change due to change in unbalanced forces.

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(d) The pair continue on their journey at a constant speed of 12 m s^{-1}. The car is fitted with a crumple zone. Alex says the crumple zone can increase the time of impact in a collision from 0.2 seconds to 0.8 seconds.

The mass of the car and occupants is 1600 kg.

Use physics principles and appropriate calculation(s) to explain how having a crumple zone can make this car safer for the occupants during a collision.

$$\Delta p = F\Delta t$$

$$\Delta p = p_f - p_i$$

$$p = mv$$

Assuming the car stops:

$$\Delta p = 0 - (1600)(12)$$

$$\Delta p = -19200 \text{ kg m s}^{-1}$$

$$F = \frac{\Delta p}{\Delta t}$$

Crumple zone ($\Delta t = 0.8$ s):

$$F = \frac{-19200}{0.8}$$

$$F = -24000 \text{ N}$$

No crumple zone ($\Delta t = 0.2$ s):

$$F = \frac{-19200}{0.2}$$

$$F = -96000 \text{ N}$$

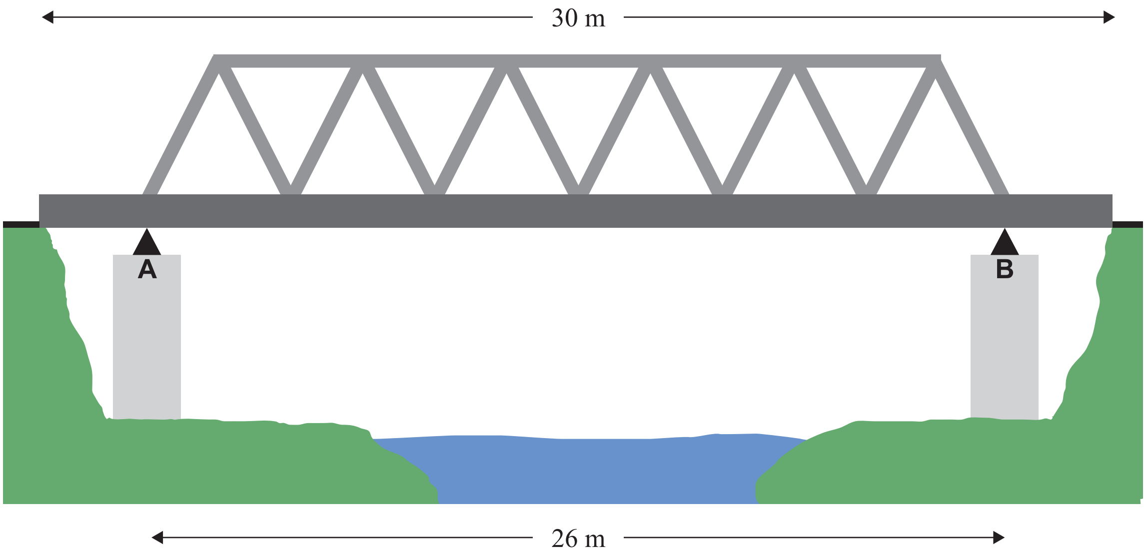
$$|F_{\text{crumple}}| < |F_{\text{no crumple}}|$$

Force on occupants is smaller when collision time is larger, so it is safer.

QUESTION THREE: THE BRIDGE

Jo and Alex need to cross a bridge to reach their destination.

www.flickr.com/photos/21663749@N03/5225413303



The bridge is 30 m long, and has a mass of 30 000 kg.

The supports are 26 m apart, and equal distance from the centre of the bridge.

(a) State the two requirements for an object to be in equilibrium.

$$F_{\text{up}} = F_{\text{down}}$$

$$\tau_{acw} = \tau_{cw}$$

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(b) The road is closed as the bridge is under repair. The support column at end B can supply a maximum support force of 160 000 N.

By finding torques about support A, calculate the furthest distance from support A that a 1600 kg mass could be placed before the support at B became overloaded.

$$\tau_{cw} = \tau_{acw}$$

$$(30000 \times 9.8)(13) + (1600 \times 9.8)(x) = (160000)(26)$$

$$3822000 + (15680)x = 4160000$$

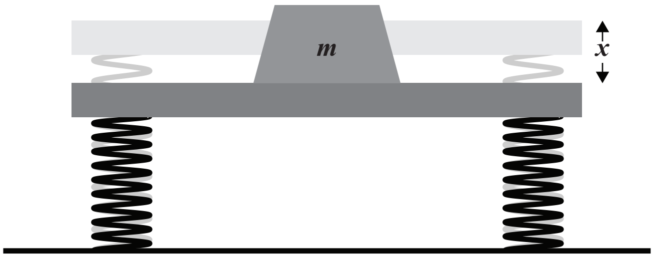
$$15680x = 4160000 - 3822000$$

$$15680x = 338000$$

$$x = \frac{338000}{15680}$$

$$x = 21.6 \text{ m}$$

(c) The bridge has an earthquake-protection system made up of springs. Before being put in place on the bridge, the springs are tested by being loaded with a mass *m*. When loaded with a mass *m* the springs compress by a distance *x*.



Explain, in depth, how the size of the mass on the springs needs to change in order to compress the springs a distance 2*x* from the original length.

$$F = kx$$

$$F = mg$$

$$kx = m(9.8)$$

$$x = \frac{m(9.8)}{k}$$

$$x \propto m$$

To compress to $2x$, the mass must be $2m$.

Question Three continues on the following page.

(d) Jo and Alex wonder whether a compressed spring from the bridge could accelerate their car once the spring is released, as in the diagram below. They decide to determine the effect of the spring on the car's motion. They estimate that for this spring, a force of 50 000 N would compress the spring length from 6.0 m to 4.2 m. The total mass of the car and occupants is 1600 kg.

(i) Calculate the maximum speed to which this spring could accelerate the car and its occupants if it was compressed to 4.2 m.

You should start your answer by first determining the spring constant, k.

$x = 6.0 - 4.2 = 1.8$ m

$F = kx$

$k = \frac{F}{x}$

$k = \frac{50000}{1.8}$

$k = 27778$ N m^{-1}

$E = \frac{1}{2}kx^2$

$E = \frac{1}{2}(27778)(1.8)^2$

$E = 45000$ J

$v = \sqrt{\frac{2E}{m}}$

$v = \sqrt{\frac{2(45000)}{1600}}$

$v = 7.5$ m s^{-1}

(ii) What assumption(s) have you made in this calculation?

Assumption(s):

- Energy is conserved: all spring energy transfers to the car (no losses).
- No energy lost to accelerating the spring / friction / sound / heat.

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SPARE DIAGRAMS

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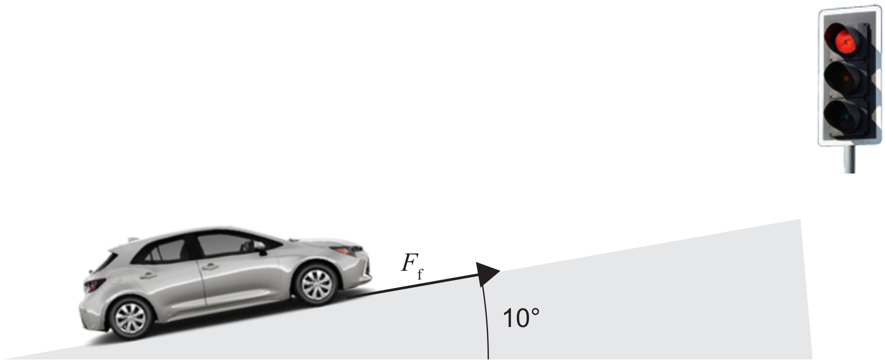
If you need to redraw your labelled arrows for Question One (b)(i), use the diagram below. Make sure it is clear which diagram you want marked.



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www.luxreview.com/2016/08/17/smart-traffic-lights-to-talk-to-drivers/

If you need to redraw your vector diagram for Question One (b)(ii), use the diagram below. Make sure it is clear which diagram you want marked.

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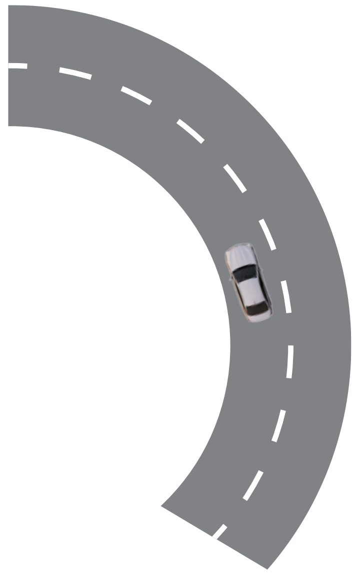
If you need to redraw your arrow for Question Two (a), use the diagram below. Make sure it is clear which diagram you want marked.



Extra space if required.
Write the question number(s) if applicable.

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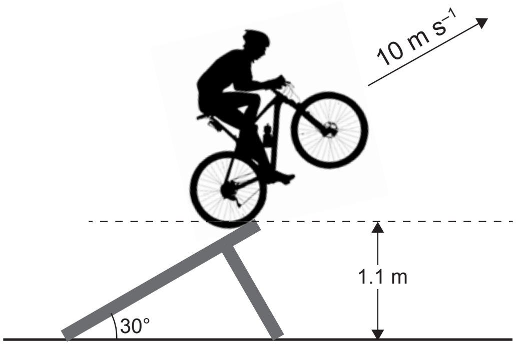
QUESTION ONE: THE RAMP

The picture on the right shows a bike rider going over a ramp.

The rider's speed at the top of the ramp is 10 m s^{-1}.

The angle between the ramp and the ground is 30°.

The top of the ramp is 1.1 m above the ground.



(a) Show that the vertical velocity of the rider just as they leave the top of the ramp is 5 m s^{-1}.

$$v_y = v \sin\theta$$

$$v_y = 10 \sin 30^\circ$$

$$v_y = 5.0 \text{ m s}^{-1}$$

(b) Calculate the maximum height that the rider will reach above the **ground**.

$$v_f^2 = v_i^2 + 2ad$$

$$d = \frac{v_f^2 - v_i^2}{2a}$$

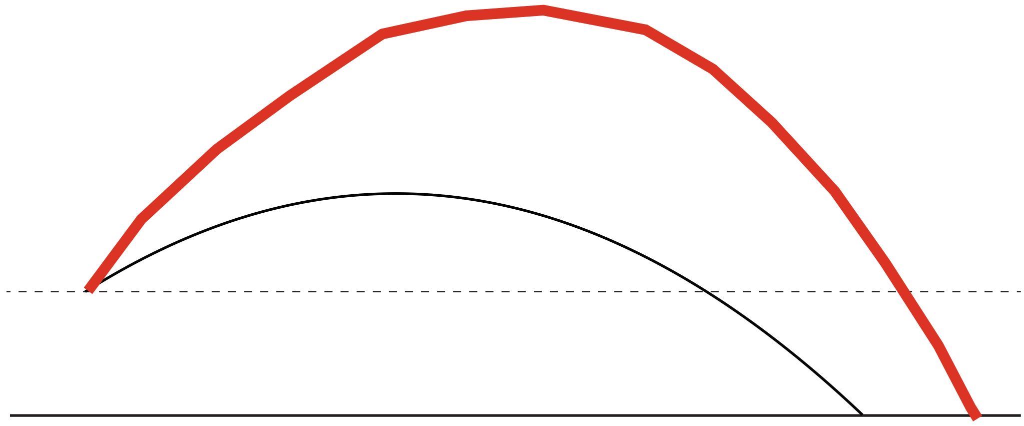
$$d = \frac{0^2 - 5.0^2}{2(-9.8)}$$

$$d = \frac{-25}{-19.6}$$

$$d = 1.28 \text{ m}$$

$$1.1 + 1.28 = 2.38 \text{ m}$$

(c) The diagram below shows the path of the rider when they leave the top of the 30° ramp at 10 m s⁻¹.



On the same diagram, and without further calculation, sketch the path of a rider who leaves the top of a 40° ramp at 10 m s⁻¹.

Assume the top of the ramps are in the same place.

If you need to redraw your response, use the diagram on page 8.

(d) For a rider leaving the top of a 30° ramp at 10 m s⁻¹:

(i) Calculate the **vertical** speed of the rider when they land on the ground.

$$v_f^2 = v_i^2 + 2ad$$

$$v_f = \sqrt{v_i^2 + 2ad}$$

$$v_f = \sqrt{5.0^2 + 2(9.8)(1.1)}$$

$$v_f = 6.8 \text{ m s}^{-1}$$

(ii) Calculate the horizontal distance travelled from the ramp to where the rider lands on the ground.

$$v_f = v_i + at$$

$$t = \frac{v_f - v_i}{a}$$

$$t = \frac{-6.82 - 5.0}{-9.8}$$

$$t = 1.21 \text{ s}$$

$$v_x = v\cos\theta$$

$$v_x = 10\cos 30^\circ$$

$$v_x = 8.66 \text{ m s}^{-1}$$

$$d = vt$$

$$d = 8.66(1.21)$$

$$d = 10.4 \text{ m}$$

QUESTION TWO: AROUND THE BEND

A rider rides around a circular bend of radius 7.0 m at a constant speed of 10 m s^{-1}.

ure-your-2006-

(a) If the combined mass of the rider and bike is 90 kg, calculate the centripetal force required.

$$F = m\frac{v^2}{r}$$

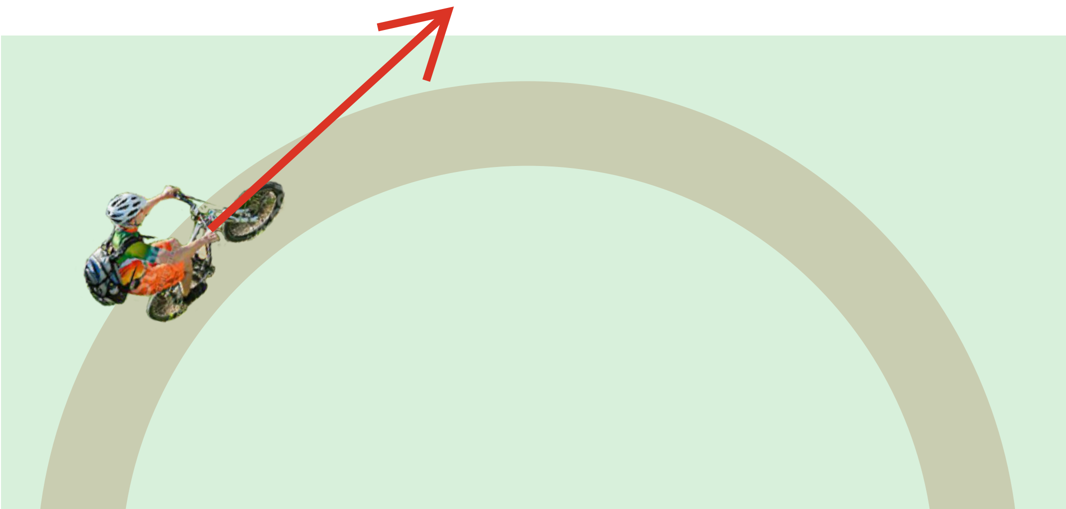
$$F = 90 \times \frac{10^2}{7.0}$$

$$F = 1286 \text{ N}$$

(b) When the rider is in the position below, they bike across a **very** slippery part of the track.

Use physics principles to explain the path the rider takes when they bike across the very slippery part of the track.

Show this path on the diagram with an arrow.



If you need to redraw your response, use the diagram on

Required centripetal force:

$$F = m\frac{v^2}{r}$$

On the slippery patch, friction is reduced, so the available friction force (which provides the centripetal force) **decreases**.

- m stays the same
- If v is the same and r is the same, the **required** F stays the same
- The **available** force decreases, so there is not enough inward force

So the rider cannot follow the curved path and moves in a straighter path (tangent), meaning the turning radius increases and they drift outward.

(c) Some trail bikes have a spring suspension system.

The spring constant is 40 000 N m^{-1}.

A rider of mass 80 kg sits on the bike, causing the spring to compress.

Source: www.bikeradar.com/features/shock-talk-the-coil-sprung-comeback/

Calculate how much energy is stored in the compressed spring.

$$F = kx$$

$$x = \frac{F}{k}$$

$$x = \frac{80 \times 9.8}{40000}$$

$$x = 0.0196 \text{ m}$$

$$E = \frac{1}{2}kx^2$$

$$E = 0.5(40000)(0.0196)^2$$

$$E = 7.68 \text{ J}$$

(d) When a rider lands after a jump, they essentially have a collision with the ground.

Use physics principles to explain fully how a suspension system makes a bike safer for landing.

Change in momentum:

$$\Delta p = F\Delta t$$

For the same rider and same before/after speeds:

- Δp stays the same

Suspension increases stopping time:

- Δt increases

So:

- F decreases (because $F = \frac{\Delta p}{\Delta t}$)

Smaller force means less damage / injury.

QUESTION THREE: ENERGY

A rider and bike with combined mass of 85 kg climb 4.0 m vertically in 3.0 s while biking up a track.

ingletracks.com/mtb-trails/keystone-something-for-everyone/

(a) Calculate the average power required.

$$E_p = mgh$$

$$E_p = 85 \times 9.8 \times 4.0$$

$$E_p = 3332 \text{ J}$$

$$P = \frac{E}{t}$$

$$P = \frac{3332}{3.0}$$

$$P = 1110 \text{ W}$$

The rider bikes over a 4.0 m-long bridge and stops 3.0 m from the end.

The bridge has a uniform mass of 700 kg.

The combined mass of the rider and bike is 85 kg.

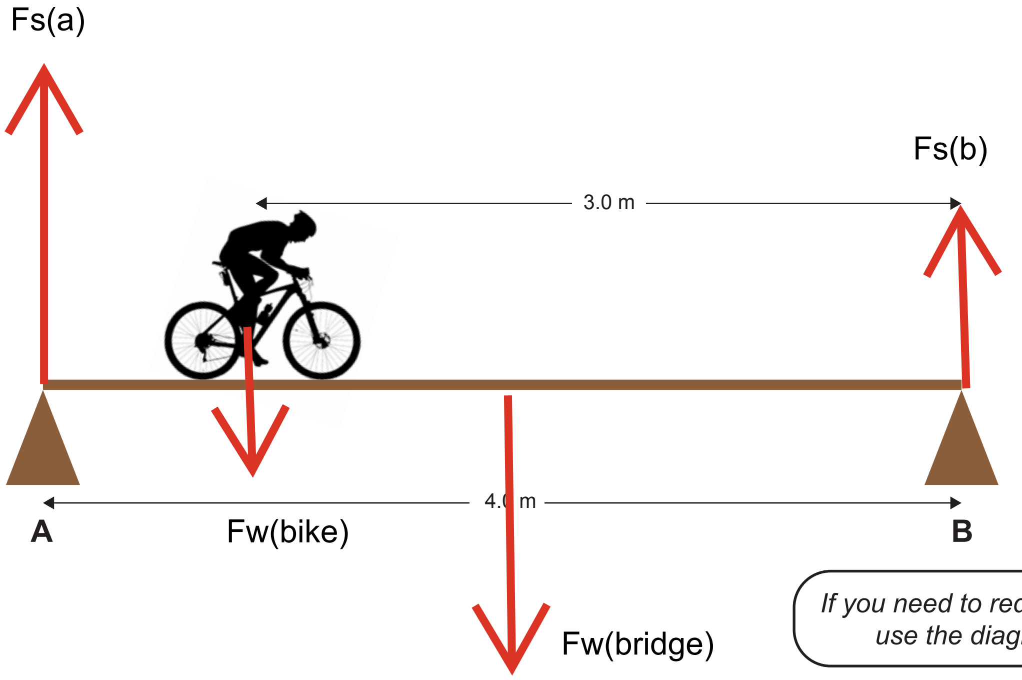
Source: www.visitnsw.com/destinations/hunter/barrington-tops/gloucester/attractions/the-steps-barrington-mountain-bike-park

(b) State the conditions required for the bridge to be in equilibrium.

$$F_{\text{up}} = F_{\text{down}}$$

$$\tau_{acw} = \tau_{cw}$$

(c) Draw labelled arrows to represent all the forces acting on the bridge.



If you need to redraw your response, use the diagram on page 9.

(d) Calculate the values of ALL the forces acting on the bridge.

$$\tau_{acw} = \tau_{cw}$$

$$F_A(4.0) = (85 \times 9.8)(3.0) + (700 \times 9.8)(2.0)$$

$$F_A(4.0) = 2499 + 13720$$

$$F_A(4.0) = 16219$$

$$F_A = \frac{16219}{4.0}$$

$$F_A = 4055 \text{ N}$$

$$F_{\text{up}} = F_{\text{down}}$$

$$F_A + F_B = (85 \times 9.8) + (700 \times 9.8)$$

$$F_A + F_B = 833 + 6860$$

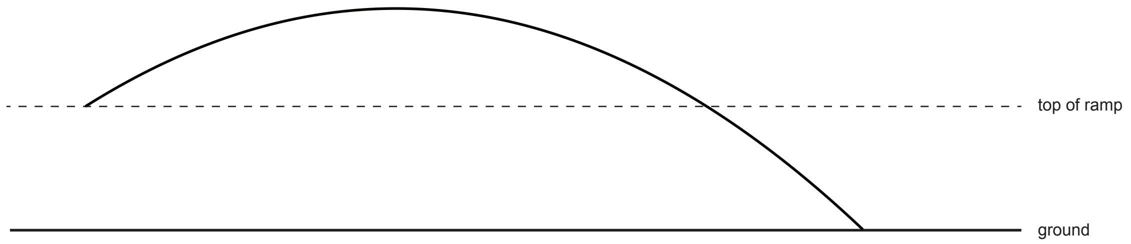
$$F_A + F_B = 7693$$

$$F_B = 7693 - 4055$$

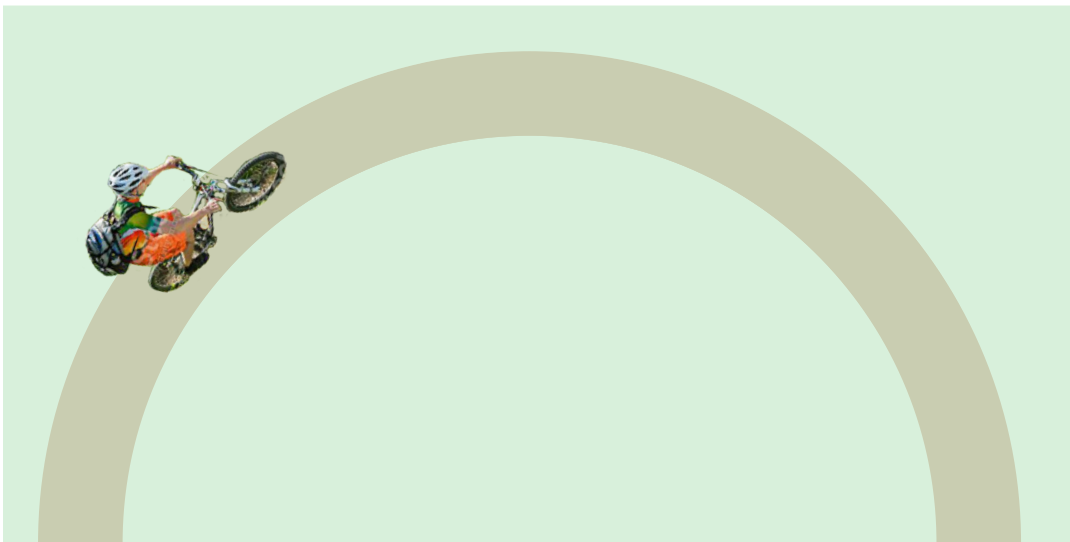
$$F_B = 3638 \text{ N}$$

SPARE DIAGRAMS

If you need to redraw your response to Question One (c), use the diagram below. Make sure it is clear which answer you want marked.



If you need to redraw your response to Question Two (b), use the diagram below. Make sure it is clear which answer you want marked.



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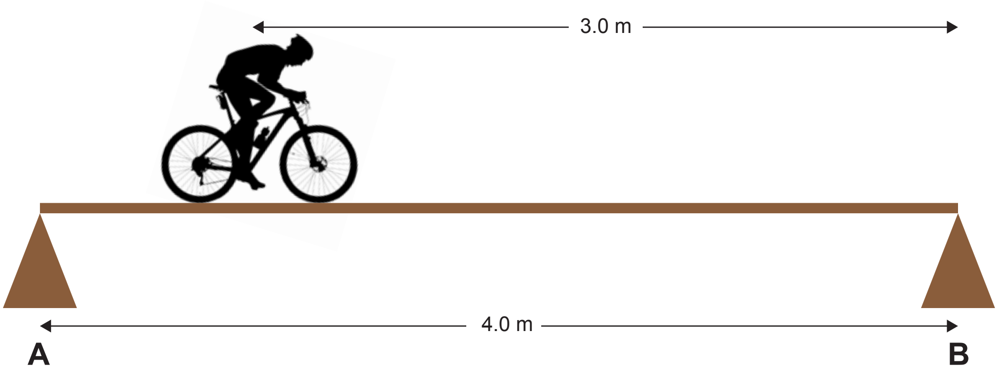

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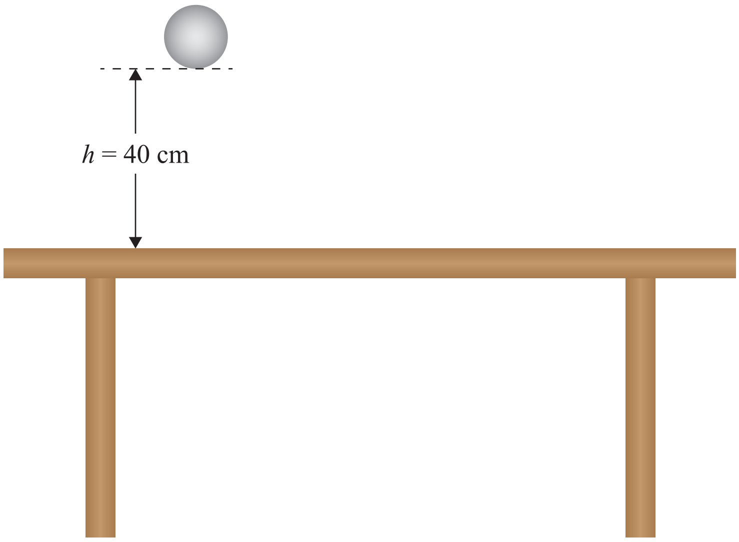
QUESTION ONE: KINEMATICS AND PROJECTILE MOTION

A steel ball is held 40 cm above a table. The ball is released, and the time for it to fall to the table is measured.



(a) Calculate the time it takes for the ball to fall to the table.

$$d = v_i t + \frac{1}{2}at^2 \qquad t = \sqrt{\frac{2d}{a}} \qquad t = \sqrt{\frac{2(0.40)}{9.8}} = 0.29\text{ s}$$

(b) The experiment was repeated with another ball of the same size, but half the mass.

Ignoring any effects of air resistance, use physics principles to explain how the time for this second ball to fall compares to the time for the first ball to fall.

Ignoring air resistance, both balls have the same acceleration:

$$F = ma$$

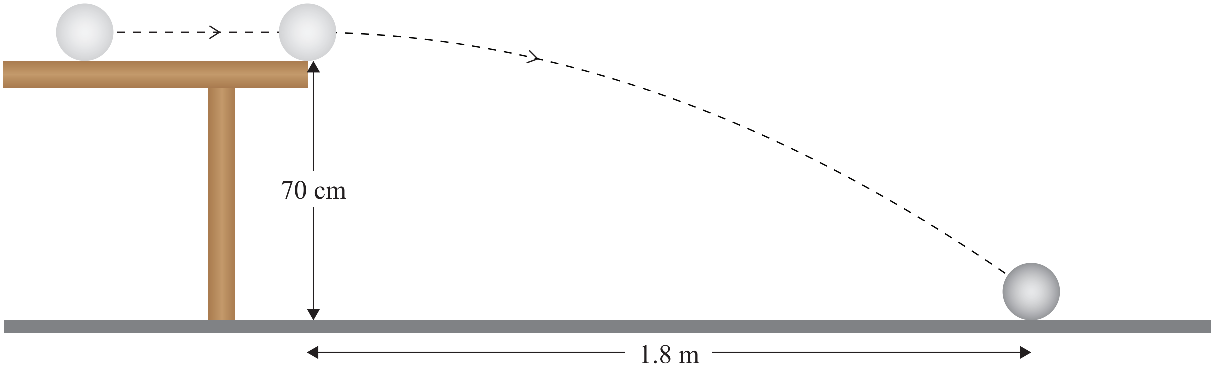
Weight force is mg, so:

$$mg = ma \Rightarrow a = 9.8$$

Mass cancels, so the acceleration is the same for both balls. Same height + same acceleration + same initial velocity means the **time is the same**.

(c) The steel ball is now rolled along the table and off the edge, as shown.

The height of the table is 70 cm, and the ball hits the ground 1.8 m past the edge of the table.



(i) Calculate the ball's final vertical velocity.

$d = 0.70\text{ m}, \quad v_{y,i} = 0, \quad a = 9.8$

$v_f^2 = v_i^2 + 2ad$

$v_{y,f}^2 = 0^2 + 2(9.8)(0.70) = 13.72$

$v_{y,f} = \sqrt{13.72} = 3.70\text{ m s}^{-1}$

(ii) What assumption have you made?

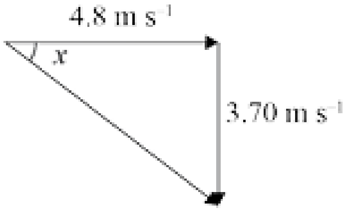
Air resistance is negligible (so $a = 9.8$ and horizontal velocity stays constant).

(d) Calculate the size and direction of the velocity of the ball just before it hits the ground.

You should start by showing the horizontal velocity of the ball is 4.8 m s^{-1}.

Time to fall $d = v_i t + \frac{1}{2}at^2 \Rightarrow 0.70 = 0 + 0.5(9.8)t^2$

$t = 0.377\text{ s}$



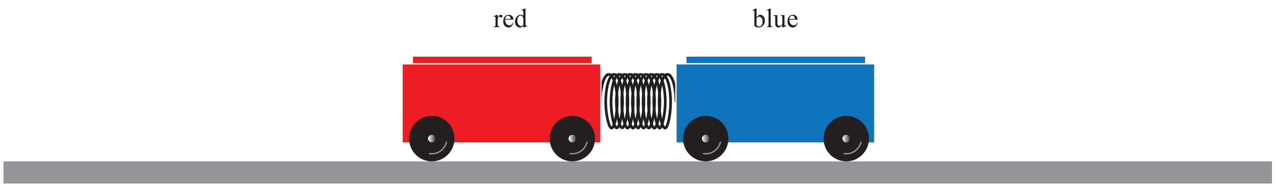
Horizontal speed $v_x = \frac{d}{t} = \frac{1.8}{0.377} = 4.8\text{ m s}^{-1}$

$\tan x = \frac{3.7}{4.8} \Rightarrow 37.6°$ (or 0.66 rad)

Speed $v = \sqrt{4.8^2 + 3.7^2} = 6.1\text{ m s}^{-1}$

QUESTION TWO: MOMENTUM AND IMPULSE

Two carts are set up with a spring between them. The spring is compressed by 10 cm. When the spring is released, the carts rapidly move apart in opposite directions.



(a) The spring has a spring constant of 250 N m^{-1}.

Calculate the total energy released from the spring.

$$k = 250\ \text{N m}^{-1}, \quad x = 0.10\ \text{m}$$

$$E = \frac{1}{2}kx^2$$

$$E = \frac{1}{2}(250)(0.10)^2 = \frac{1}{2}(250)(0.01) = 1.25\ \text{J}$$

(b) The mass of the red cart is 0.5 kg, and the mass of blue cart is 2 kg. The final velocity of the blue cart is 0.5 m s^{-1}.

(i) Calculate the final velocity of the red cart.

$$P_{\text{before}} = 0$$

$$P_{\text{after}} = P_{\text{red}} + P_{\text{blue}}$$

$$0 = (0.5)v_{\text{red}} + (2.0)(0.5)$$

$$0 = 0.5v_{\text{red}} + 1.0$$

$$0.5v_{\text{red}} = -1.0$$

$$v_{\text{red}} = -2.0\ \text{m s}^{-1}$$

(ii) What assumption, if any, have you made?

No external horizontal forces (so momentum is conserved), and friction/air resistance are negligible during the push.

In a different experiment, the red and blue carts are set moving in opposite directions with equal momentum. The blue cart is stopped at the end of the track by a solid board, and the red cart is stopped by a padded wall.

(c) Use physics principles to explain whether the blue cart or the red cart will suffer the most damage as they both stop.

They have equal momentum before stopping, so each has the same Δp to reach zero.

$$\Delta p = F\Delta t$$

The blue cart hits a solid board so Δt is very small, therefore F is large.

The red cart hits a padded wall so Δt is larger, therefore F is smaller.

Blue cart suffers more damage (larger force).

(d) The 2 kg blue cart, moving at 2 m s^{-1}, took 0.02 s to stop when it collided with the solid board.

(i) State Newton's third law of forces in the context of the collision of the blue cart and the solid board.

During the collision, the cart pushes on the board, and the board pushes on the cart with an **equal size force in the opposite direction**.

(ii) Calculate the size and direction of the average force experienced by the solid board during this impact.

First find Δp using $p = mv$:

$$p_i = (2.0)(2.0) = 4.0$$

$$p_f = (2.0)(0) = 0$$

$$\Delta p = p_f - p_i = 0 - 4.0 = -4.0 \text{ kg m s}^{-1}$$

$$\Delta p = F\Delta t$$

$$F = \frac{\Delta p}{\Delta t} = \frac{-4.0}{0.02} = -200 \text{ N}$$

That -200 N is the force on the **cart** (opposite its initial motion).

So the force on the **board** is equal and opposite:

Answer: 200 N in the direction the cart was moving (to the right).

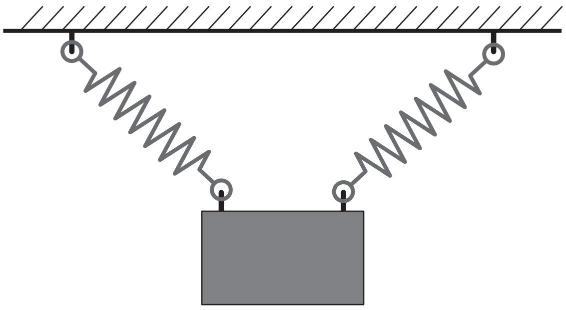
QUESTION THREE: FORCES

(a) Calculate the spring constant for a spring that extends 200 mm when a 2.94 N weight is hung on it.

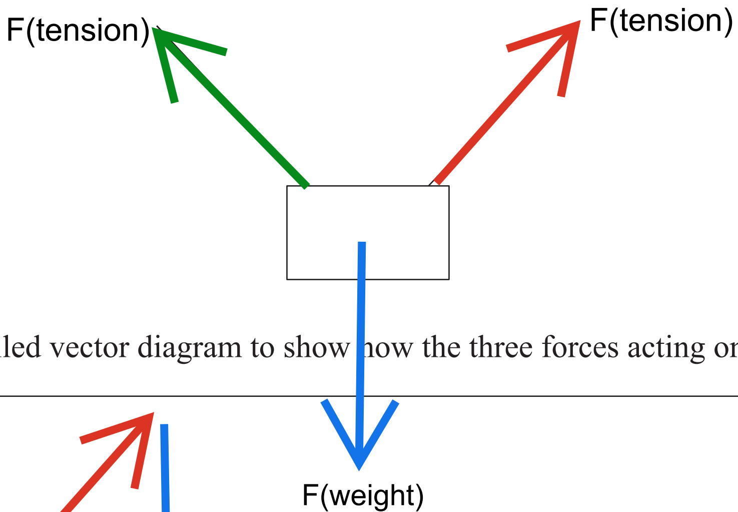
$$k = \frac{F}{x}$$

$$k = \frac{2.94}{0.200} = 14.7\ \mathrm{N\,m^{-1}}$$

(b) A block is attached to two identical springs and hung from the ceiling.

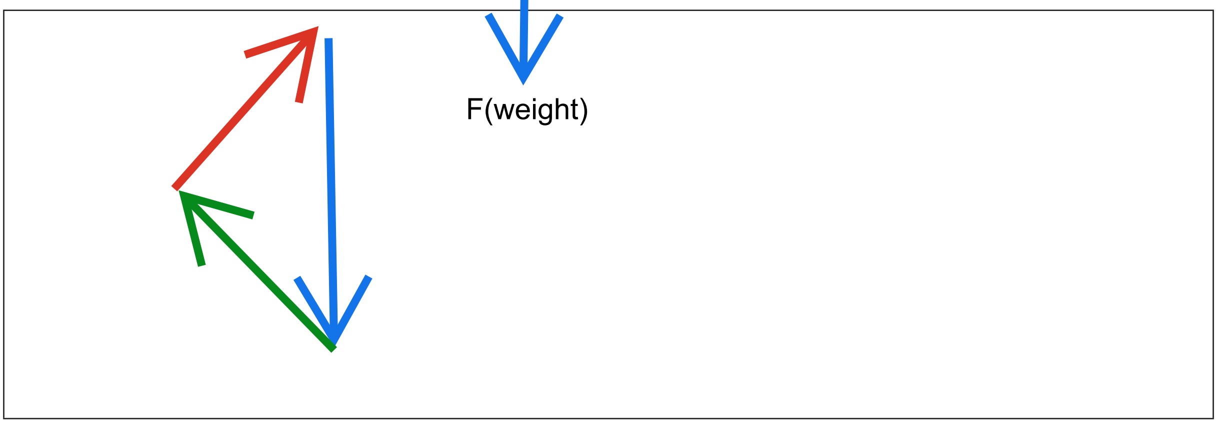


(i) On the diagram below, add labelled arrows to show all the forces acting on the block.



If you need to redraw your response, use the diagram on page 9.

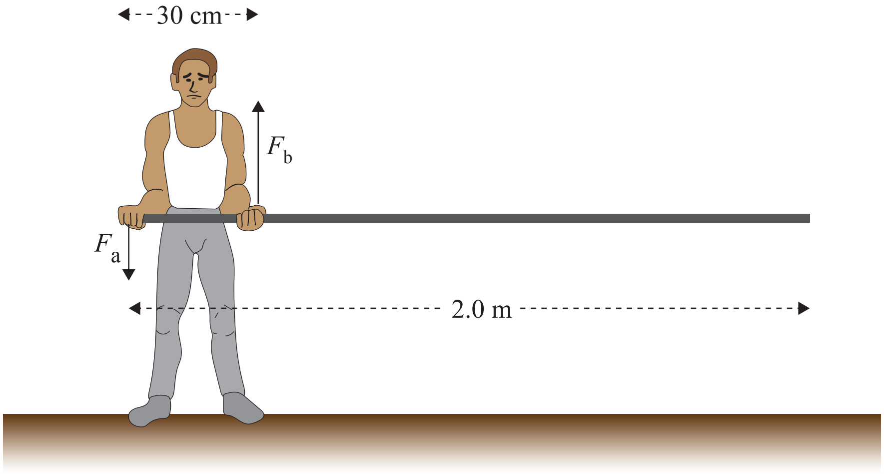
(ii) Draw a labelled vector diagram to show how the three forces acting on the block add together.



If you need to redraw your response, use the diagram on page 9.

(c) An athlete in training holds a uniform rod, 2.0 m long, stationary in a horizontal position.

The mass of the rod is 3.0 kg.



Calculate the forces F_a and F_b that are required by the athlete's hands to hold the rod in equilibrium, in the horizontal position.

$$\text{Torque}_{acw} = \text{Torque}_{cw}$$

$$F_b(0.30) = (3.0 \times 9.8)(1.0)$$

$$(3.0 \times 9.8)(1.0) = 29.4 \text{ Nm}$$

$$0.30F_b = 29.4$$

$$F_b = \frac{29.4}{0.30} = 98 \text{ N}$$

$$F_{\text{up}} = F_{\text{down}}$$

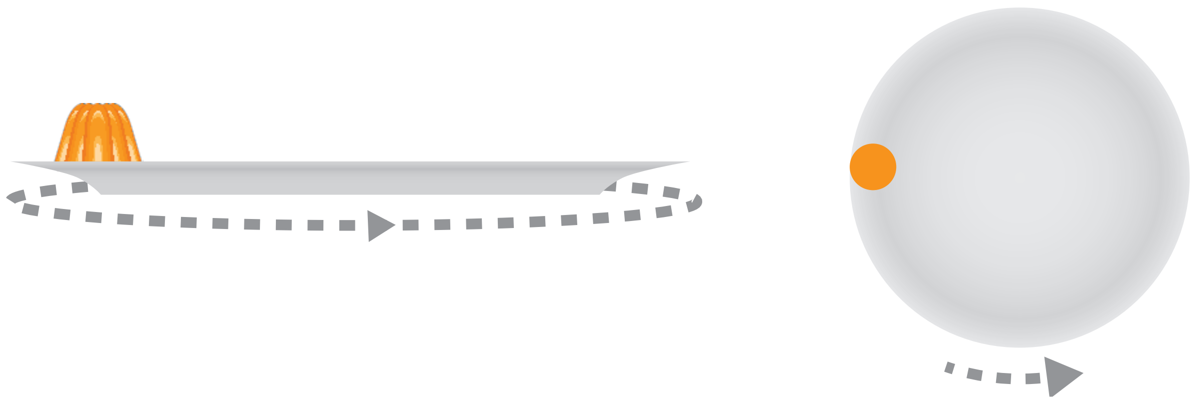
$$F_b = F_a + (3.0 \times 9.8)$$

$$98 = F_a + 29.4$$

$$F_a = 98 - 29.4 = 68.6 \text{ N}$$

Question Three continues on the next page.

(d) A jelly is placed on the edge of a plate, and the plate starts to spin so the jelly is moving in a circle. As the plate speed increases, the jelly initially maintains its position at the edge of the plate, until it eventually slides off.



Use physics principles to explain why the jelly initially stays on the plate, but as the speed increases, it slides off.

Your answer should include:

- naming of any relevant force(s) involved
- how increasing the velocity affects the situation
- a description of the path the jelly would take when it first slides off.

Relevant forces:

- Static friction provides the centripetal force while it does not slip.

As speed increases, required centripetal force increases:

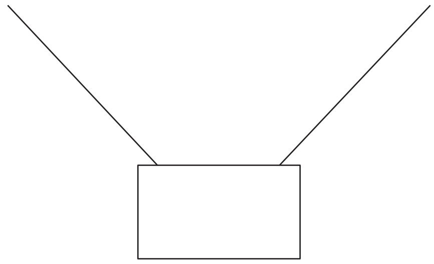
$$F = m\frac{v^2}{r}$$

Eventually the required centripetal force becomes larger than the maximum static friction available, so the jelly cannot keep moving in a circle and begins to slip.

When it first slides off, it moves in a straight line **tangent** to the circular path (because the centripetal force is no longer acting to change direction).

SPARE DIAGRAMS

If you need to redraw your response to Question Three (b)(i), use the diagram below. Make sure it is clear which answer you want marked.



If you need to redraw your response to Question One (b)(ii), use the diagram below. Make sure it is clear which answer you want marked.

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

91171

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2

91171

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Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 2 Physics 2023

91171 Demonstrate understanding of mechanics

Credits: Six

Achievement	Achievement with Merit	Achievement with Excellence
Demonstrate understanding of mechanics.	Demonstrate in-depth understanding of mechanics.	Demonstrate comprehensive understanding of mechanics.

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You should attempt ALL the questions in this booklet.

Make sure that you have Resource Sheet L2–PHYSR.

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Numerical answers should be given with an appropriate SI unit.

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Check that this booklet has pages 2–12 in the correct order and that none of these pages is blank.

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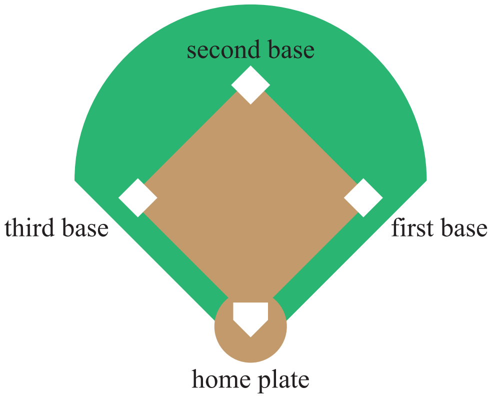
QUESTION ONE: SOFTBALL MATCH

The following diagram shows the layout of a softball game.



http://thesportdigest.com/2017/03/ten-ways-to-prevent-injuries-in-softball/

A stationary player accelerates from the home plate to first base.

The player takes 6.61 s to get to first base and arrives moving at 5.45 m s^{-1}.

(a) Show that the average acceleration is 0.825 m s^{-2}.

$V_i = 0$

$V_f = 5.45 \text{ m s}^{-1}$

$t = 6.61 \text{ s}$

$$a = \frac{V_f - V_i}{t}$$

$$a = \frac{5.45 - 0}{6.61} = 0.8245 \approx 0.825 \text{ m s}^{-2}$$

(b) (i) Calculate the maximum displacement between the home plate and first base.

$V_i = 0, \quad V_f = 5.45 \text{ m s}^{-1}, \quad t = 6.61 \text{ s}$

$$V_{\text{avg}} = \frac{V_i + V_f}{2}$$

$$V_{\text{avg}} = \frac{0 + 5.45}{2} = 2.725 \text{ m s}^{-1}$$

$$d = V_{\text{avg}} t$$

$$d = (2.725)(6.61) = 18.0 \text{ m}$$

(ii) Why might this displacement be different from the actual distance travelled by the player?

Displacement is the **straight-line change in position** from home plate to first base.

Actual distance travelled could be **longer** because the player may not run in a perfect straight line (they may curve, avoid defenders, step around the base, etc.).

(c) The softball has a mass of 0.180 kg, is thrown at 44.4 m s^{-1}, and is caught and brought to a stop at first base.

The catcher's arm is relaxed, and the ball and padded glove move backwards a little once the ball collides with the padded glove.

The ball takes 0.510 s to stop. This results in an impulse.

(i) What does the term impulse mean?

Change in momentum

(ii) Calculate the average force of the ball on the padded glove on impact.

$\Delta p = mv_f - mv_i$

$= 0.18 \times 0 - 0.18 \times 44.4$

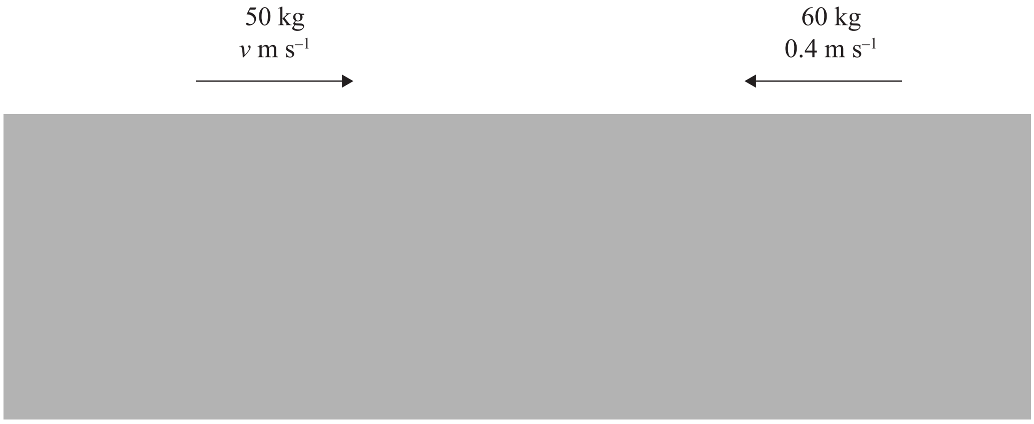
$= 7.99 \text{ kg m s}^{-1}$

$F = \frac{\Delta p}{t} = \frac{7.99}{0.51} = 15.7 \text{ N}$

(iii) Use physics principles to explain the advantages of catching a ball using a relaxed arm and a padded glove.

Having a relaxed arm increases the time it takes to stop the ball, or glove compresses when a ball is caught – this also increases the time to stop the ball. For the same momentum / impulse/ change in momentum, the increased time for the catcher will reduce the force of impact, (so less likely to cause injury or drop the catch).

(d) Later in the game, a 50 kg player moving to the right at speed *v* collides with a 60 kg player who is moving to the left at 0.4 m s^{-1}. The two players collide and stick together and move to the right at 2 m s^{-1} after the collision.



Adapted from: https://ggcathletics.com/news/2020/3/24/softball-grizzlies-scattered-across-naia-stats-school-records.aspx

(i) What physical quantity is assumed to be conserved during the collision?

Momentum

(ii) Calculate the initial speed, *v*, of the 50 kg player.

$$P_{\text{before}} = P_{\text{after}}$$

$$P_a + P_b = P_{\text{together}}$$

$$m_a v_a + m_b v_b = (m_a + m_b) v_{a+b}$$

$$50(v) + 60(-0.4) = 110(2.0)$$

$$50v - 24 = 220$$

$$50v = 244$$

$$v = 4.88 \text{ m s}^{-1}$$

QUESTION TWO: CORNERING

A player with a mass of 55.0 kg, moving at a constant speed of 7.00 m s^{-1}, follows a circular path as they round second base.

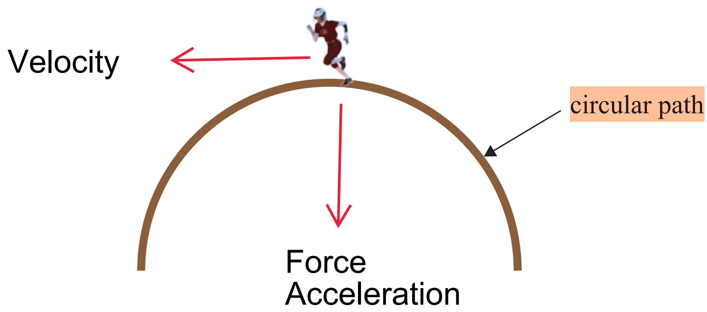
The radius of their circular path is 15.0 m.

(a) Calculate the centripetal force acting on the player as they round the base.

$$F_c = \frac{mv^2}{r} = \frac{55 \times 7^2}{15}$$

$$F_c = 179.7, \ F_c = 180 \text{ N}$$

(b) Add labelled arrows to the diagram below to show the direction of the force, acceleration, and velocity of the player.



If you need to redraw your response, use the diagram on page 10.

(c) (i) Name the force that supplies the centripetal force acting on the player as they move in a circle.

Friction

(ii) Explain why the player can be moving at a constant speed, and yet be accelerating at the same time.

Acceleration depends on **change in velocity**. Velocity includes **direction** as well as speed.

Even though the player's **speed is constant**, the player is moving in a circle so their **direction is continually changing**. Therefore their velocity is changing, so they are accelerating.

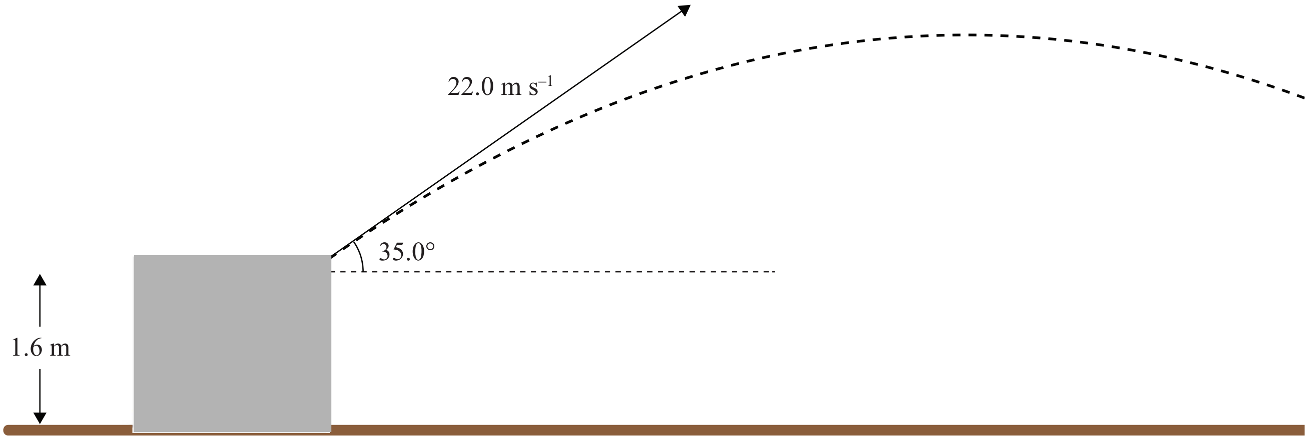
(d) The player runs onto a large slippery, muddy patch while rounding the base.

Describe and explain fully, using physics principles, the effect(s) the slippery mud will have on the player's motion.

- (F_c is provided by friction force created between shoes and the ground.)
- If the ground is muddy, this force will reduce.
- (If wet and slippery), the runner will no longer have enough F_c to move in a circle, and will move off at a tangent / move in a circle with a larger radius.

QUESTION THREE: PROJECTILES

The next batter hits the ball up in the air with an initial velocity of 22.0 m s^{-1} at an angle of 35.0°.



Adapted from: www.vectorstock.com/royalty-free-vectors/baseball-poses-vectors

(a) Show that the vertical component of the initial velocity of the ball is 12.6 m s^{-1}.

$$v_y = (22.0)\sin(35.0^\circ) = 12.6 \text{ m s}^{-1}$$

(b) Calculate the maximum height reached by the ball above the ground.

$$v_f = 0, \quad v_i = 12.6 \text{ m s}^{-1}, \quad a = -9.8 \text{ m s}^{-2}$$

$$v_f^2 = v_i^2 + 2ad$$

$$v_f^2 - v_i^2 = 2ad$$

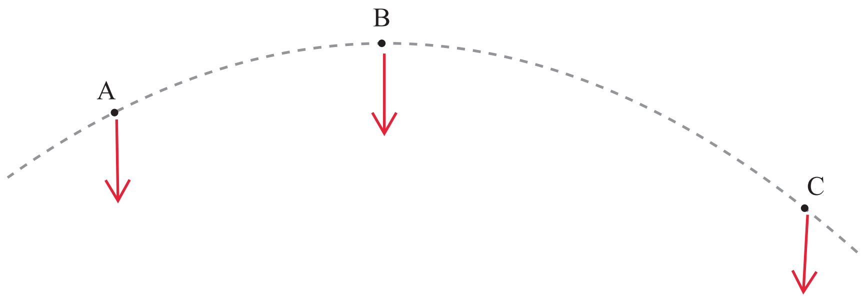
$$d = \frac{v_f^2 - v_i^2}{2a}$$

$$d = \frac{0^2 - (12.6)^2}{2(-9.8)}$$

$$d = \frac{-158.76}{-19.6} = 8.10 \text{ m}$$

$$h_{\text{max}} = 1.6 + 8.10 = 9.70 \text{ m}$$

(c) The ball's motion can be tracked and can be shown as the parabola motion below.



If you need to redraw your response, use the diagram on page 10.

Use physics principles to fully explain the motion of the ball from the time it leaves the bat until it hits the ground.

(i) Add labelled arrows of appropriate length to show the force(s) on the ball at A (leaves the bat), B (maximum height), and C (just before it hits the ground).

(ii) Describe and explain how the forces, acceleration, and horizontal and vertical velocities of the ball change throughout its flight.

Forces:

Acceleration is constant downward due to gravity. no horizontal forces

Acceleration:

Down and always -9.8ms-2 due to rgravity

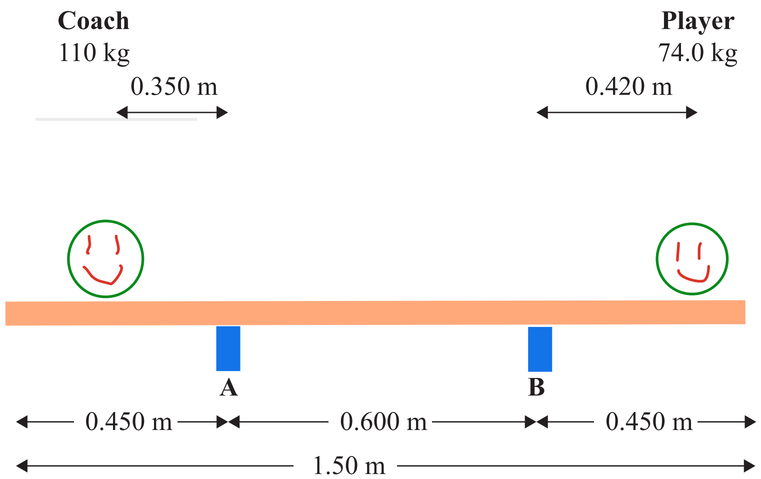
Horizontal velocity:

Constant assuming negligible force from friction

Vertical velocity:

Decreasing on the way up, stationary at the top and increasing on the way down

(d) The 110 kg coach and a substitute player of mass 74.0 kg sit on a uniform bench. The mass of the bench is 40.0 kg.



Source: https://www.alamy.com/stock-photo/

If you need to redraw your response, use the diagram on page 10.

(i) On the above diagram, add arrows to show all the forces acting on the bench.

(ii) By calculating torques about support B or otherwise, determine the values of the support forces at A and B.

$$\tau_{acw} = \tau_{cw}$$

$$T_{\text{coach}} + T_{\text{bench}} = T_{\text{player}} + T_A$$

$$(m_{\text{coach}} 9.8) d_{\text{coach}} + (m_{\text{bench}} 9.8) d_{\text{bench}} = (m_{\text{player}} 9.8) d_{\text{player}} + F_A d_A$$

$$(110 \times 9.8)(0.950) + (40.0 \times 9.8)(0.300) = (74.0 \times 9.8)(0.420) + F_A(0.600)$$

$$1024.1 + 117.6 = 304.5 + 0.600 F_A$$

$$1141.7 - 304.5 = 0.600 F_A$$

$$837.2 = 0.600 F_A$$

$$F_A = \frac{837.2}{0.600} = 1.40 \times 10^3 \text{ N}$$

$$F_{\text{up}} = F_{\text{down}}$$

$$F_A + F_B = F_{\text{coach}} + F_{\text{player}} + F_{\text{bench}}$$

$$F_A + F_B = (110 \times 9.8) + (40.0 \times 9.8) + (74.0 \times 9.8)$$

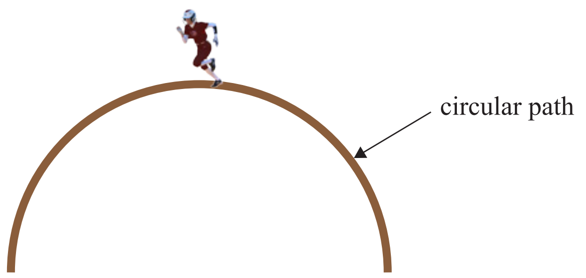
$$F_A + F_B = 1078 + 392 + 725 = 2195$$

$$F_B = 2195 - 1395 = 800 \text{ N}$$

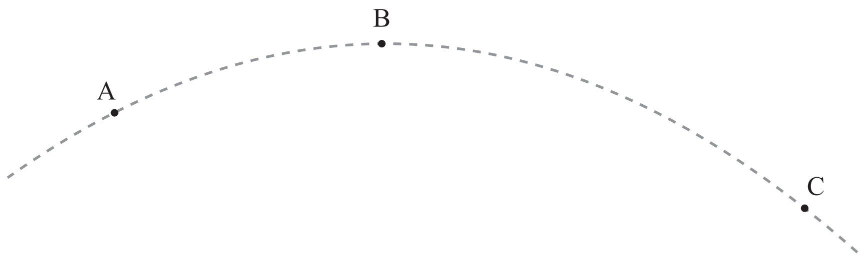
$$F_A = 1400 \text{ N}, \quad F_B = 800 \text{ N}$$

SPARE DIAGRAMS

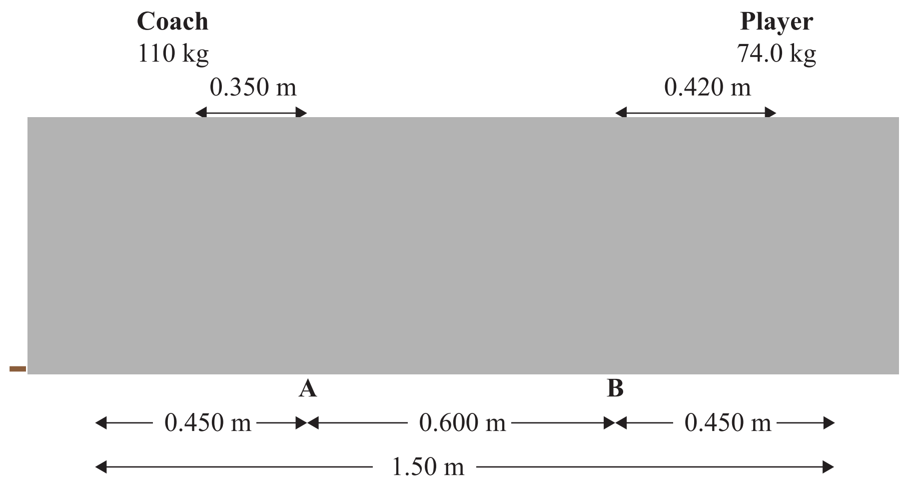
If you need to redraw your response to Question Two (b), use the diagram below. Make sure it is clear which answer you want marked.



If you need to redraw your response to Question Three (c), use the space below. Make sure it is clear which answer you want marked.



If you need to redraw your response to Question Three (d), use the space below. Make sure it is clear which answer you want marked.



Extra space if required.
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QUESTION ONE: MOMENTUM AND CIRCULAR MOTION

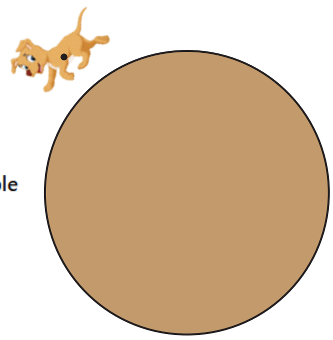
Jono and Tony are in the kitchen. Their dog is sitting on the floor next to them when the neighbour's dog comes in and playfully chases it around the table.

Source: https://www.hgtv.com/design/rooms/kitchens/round-kitchen-island

(a) The dog runs in a circle on the floor around the table.

Add a labelled arrow to the diagram below to show the force acting on the dog as it runs in a circle at a constant speed.

- Arrow pointing from the dog **towards the centre of the table**
- Label: **Centripetal force**



Source (adapted): www.shutterstock.com/search/dog-happy-dog-angry

If you need to redraw your response, use the diagram on page 11.

(b) The mass of the dog is 10 kg.
The dog is moving at 0.87 m s^{-1}.
The centripetal force is 15 N.

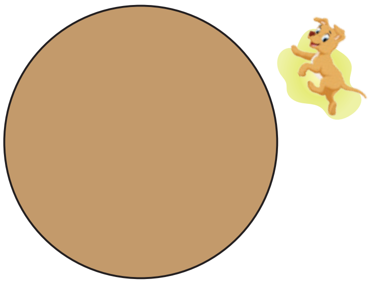
(i) Calculate the radius of the dog's path.

$$F = \frac{mv^2}{r} \qquad r = \frac{10 \times (0.87)^2}{15}$$

$$r = \frac{mv^2}{F} \qquad r = 0.50 \text{ m}$$

(ii) On the other side of the table, the dog hits a slippery patch of the floor and slides off at a tangent.

Use physics principles to explain the dog's velocity immediately after it starts moving off at a tangent.



The dog continues moving in a straight line tangent to the circular path at the same speed and in the same direction as it had at the instant it left the circle.

(c) The dog slides along the floor towards Jono. Jono reaches down and cushions the dog as it slides into him by putting out his arms and then gradually bringing them in towards him. The dog takes 2.0 seconds to come to rest, unharmed.

Use physics principles to explain why Jono put out his arms to cushion the dog rather then let the dog stop quickly in 0.10 seconds.

Start by calculating the force experienced by the dog in the cushioned collision (2.0 s).

Force during cushioned stop (2.0 s)

Initial speed $u = 0.87$ m s^{-1}

Final speed $v = 0$

Time $t = 2.0$ s

Mass $m = 10$ kg

Acceleration:

$$a = \frac{v-u}{t} = \frac{0-0.87}{2.0} = -0.435\ \text{m s}^{-2}$$

Force:

$$F = ma = 10 \times 0.435 = 4.35\ \text{N}$$

Explanation (Excellence level)

Impulse:

$$Ft = m\Delta v$$

For the same change in momentum, increasing the stopping time **reduces the force**.

If the dog stopped in 0.10 s:

$$a = \frac{0.87}{0.10} = 8.7\ \text{m s}^{-2}$$

$$F = 10 \times 8.7 = 87\ \text{N}$$

So stopping in 0.10 s would cause a much larger force.

Answer:

Jono extends the stopping time, reducing the acceleration and therefore reducing the force on the dog. This prevents injury.

(d) Jono releases his 10 kg dog and it runs directly towards the neighbour's dog at 1.1 m s^{-1}. The neighbour's dog, mass 12 kg, runs directly towards Jono's dog. They collide, stick together, and slide across the floor at 0.30 m s^{-1}.

Source (adapted): www.tiktok.com/@nervousmonkey88

Calculate the speed that the neighbour's dog was moving at before the collision.

Jono's dog:

- Mass $m_1 = 10$ kg
- Velocity $u_1 = -1.1$ m s^{-1}

Neighbour's dog:

- Mass $m_2 = 12$ kg
- Velocity $u_2 = ?$

After collision:

- They stick together
- Final velocity $v = +0.30$ m s^{-1}
- Combined mass $= 22$ kg

$$\text{Total momentum before} = \text{Total momentum after}$$

$$m_1u_1 + m_2u_2 = (m_1 + m_2)v$$

$$10(-1.1) + 12u_2 = 22(0.30)$$

$$-11 + 12u_2 = 6.6$$

$$12u_2 = 17.6$$

$$u_2 = 1.47 \text{ m s}^{-1}$$

The neighbour's dog was moving at **1.47 m s^{-1} towards Jono's dog** before the collision.

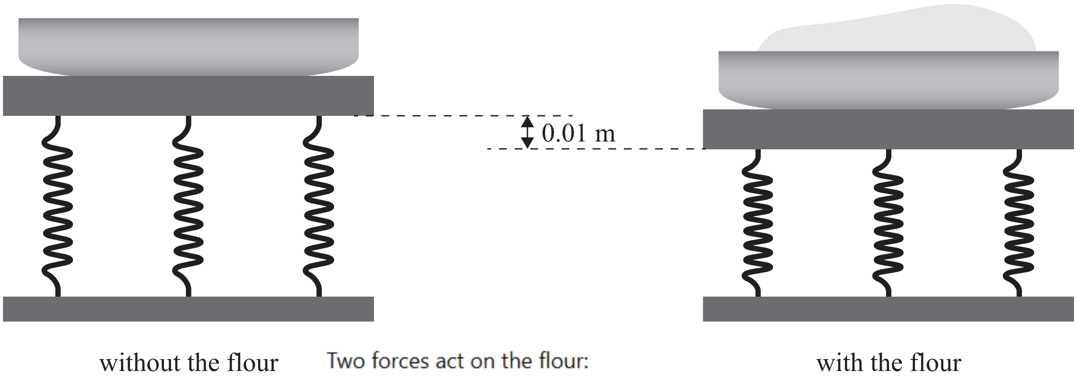
QUESTION TWO: SPRINGS AND EQUILIBRIUM

Tony decides to make a cake. Tony and Jono measure 0.11 kg of flour using a kitchen balance as shown below.

Source: www.farmers.co.nz/home/kitchen/food-preparation/cinemon-vincent-vintage-kitchen-scale-6338445

There are three springs in the balance. Each gets compressed 0.01 m when the flour is added.

The simplified diagram shows the springs in the balance.



Two forces act on the flour:

- Weight mg downward
- Support force (spring force) upward

(a) Add labelled arrows to the diagram above right (with the flour) to show the two forces acting on the flour.

If you need to redraw your response, use the diagram on page 11.

(b) Calculate the spring constant for one spring.

$$F = mg = 0.11 \times 9.8 = 1.078\ \text{N}$$

Given:

- Mass $m = 0.11$ kg
- Compression per spring = 0.01 m
- Number of springs = 3

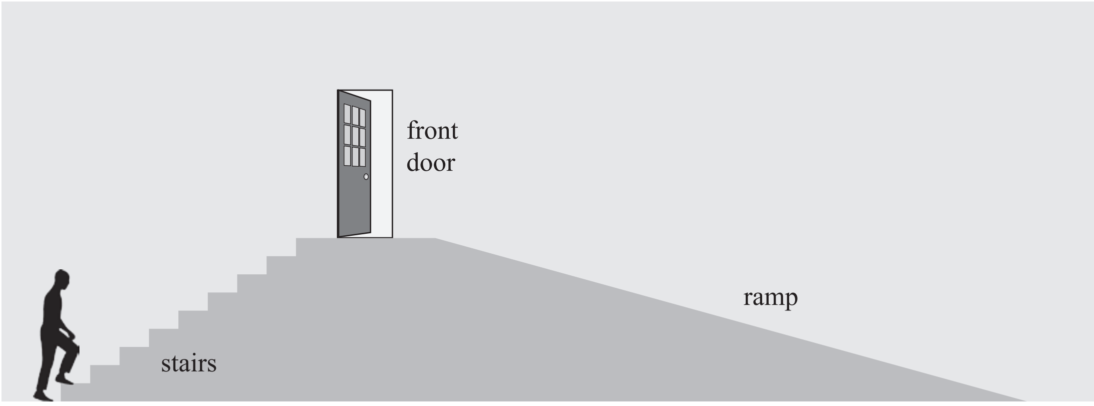
$$F = \frac{1.078}{3} = 0.359\ \text{N}$$

$$F = kx$$

$$k = \frac{F}{x} = \frac{0.359}{0.01}$$

$$k = 35.9\ \text{N m}^{-1}$$

(c) When Jono brings the groceries to the front door, he has a choice of climbing the stairs or using the ramp. He has found that it takes less time to go up the ramp than the stairs.



Compare both routes by considering:

- work done
- force required
- power.

Same for both routes. $W = mgh$

Ramp: smaller force over longer distance

Stairs: larger force over shorter distance

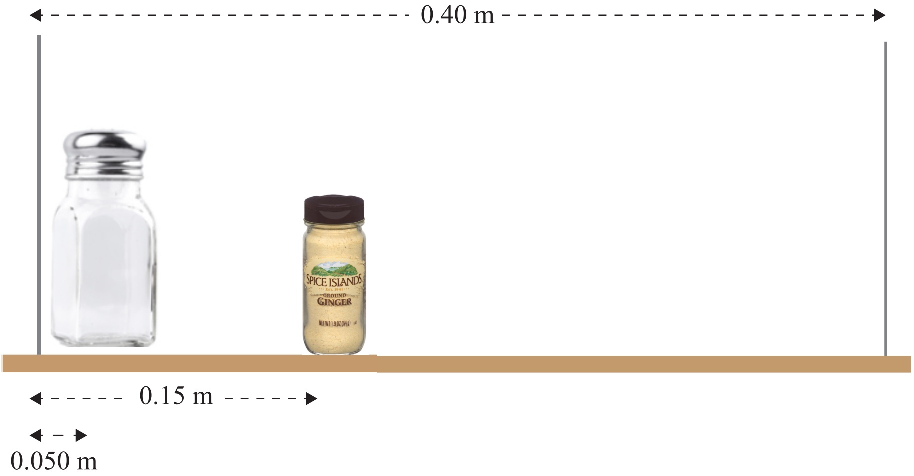
$$P = \frac{W}{t}$$

Ramp takes less time → higher power output.

(d) Tony is using a spice rack hanging by wires above the work bench, as shown below. The ginger spice has a mass of 0.030 kg, the salt 0.50 kg, and the uniform rack has a mass of 0.37 kg and is 0.40 m long.

The ginger spice is placed 0.15 m and the salt is placed 0.050 m from the left-hand wire, as shown below.

The maximum tension force that each wire can provide is 5.0 N.



https://mrsrogers.co.nz/product/coarse-iodised-sea-salt-bag/

(i) State the conditions required for the spice rack to be in equilibrium.

Net force is zero
No external forces acting on system

(ii) By performing suitable calculations, decide if the wires can hold the spice rack with the ginger and bag of salt.

Calculation assumes pivot about right wire connection

Distances are all to the right hand wire

$$F_{\text{ginger}} = 0.030g = 0.294 \text{ N}$$

$$F_{\text{salt}} = 0.50g = 4.9 \text{ N}$$

$$F_{\text{rack}} = 0.37g = 3.63 \text{ N}$$

$$F_{\text{Left wire}}(0.40) = F_{\text{ginger}}(0.25) + F_{\text{salt}}(0.35) + F_{\text{rack}}(0.20)$$

$$F_{\text{Left wire}}(0.40) = (0.294)(0.25) + (4.9)(0.35) + (3.63)(0.20)$$

$$F_{\text{Left wire}}(0.40) = 0.0735 + 1.715 + 0.726$$

$$F_{\text{Left wire}}(0.40) = 2.515$$

$$F_{\text{Left wire}} = \frac{2.515}{0.40}$$

$$F_{\text{Left wire}} = 6.29 \text{ N}$$

Conclusion

Maximum wire tension = 5.0 N

$$F_{\text{Left wire}} = 6.29 \text{ N} > 5.0 \text{ N}$$

Therefore the left wire cannot hold the rack.

QUESTION THREE: MOTION

Tony is going to add apples to the cake. His friend Jono rolls an apple along the table. The apple leaves his hand at 0.56 m s^{-1}, and stops in front of Tony. It takes 4.0 seconds to roll along the table top.

Source (adapted): https://www.homesweetwhare.co.nz/products/salisbury-ext-dining-table-1200x850

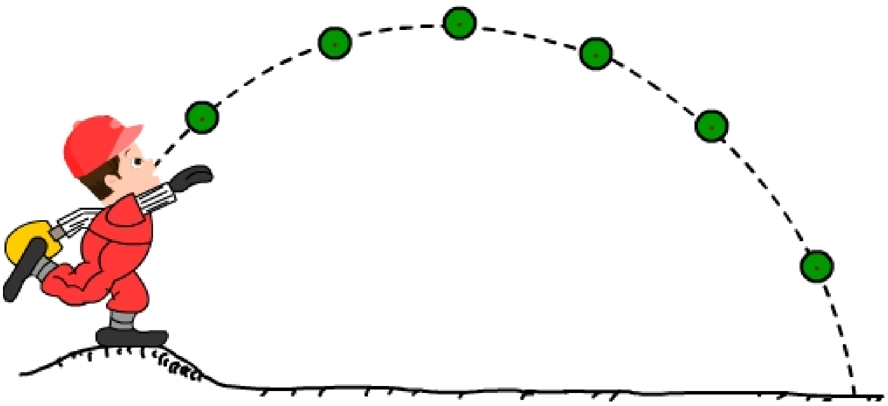
(a) Calculate the acceleration of the apple.

$$a = \frac{V_f - V_i}{t}$$

$$a = \frac{0 - 0.56}{4.0} = -0.14\ \text{m s}^{-2}$$

Tony now throws the apple to Jono.

The angle of the throw is 40° and the initial velocity is 5 m s^{-1}, as shown in the diagram below.



(b) Calculate the vertical and horizontal components of the initial velocity.

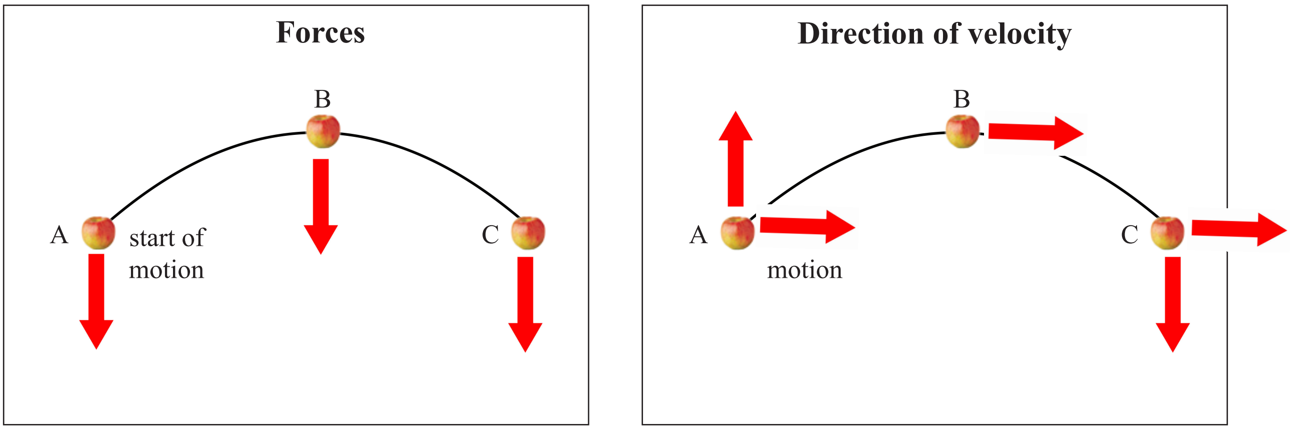
Vertical:

$$V_{y,i} = V\sin\theta = 5.0\sin 40^\circ = 3.21 \text{ m s}^{-1}$$

Horizontal:

$$V_{x,i} = V\cos\theta = 5.0\cos 40^\circ = 3.83 \text{ m s}^{-1}$$

(c) Explain the motion of the apple shown below:



(i) Identify the type of motion.

Projectile Motion

(ii) For the points A , B, and C on the appropriate diagram above, add labelled arrows of appropriate length to show:

- the force(s), if any, acting on the apple
- the direction of the velocity of the apple.

If you need to redraw your responses, use the diagram on page 11.

(iii) Describe how the vertical velocity and horizontal velocity of the apple change throughout its flight.

- Horizontal velocity: **constant** (no horizontal force)
- Vertical velocity: **decreases** to zero at the top, then **increases downward** due to $a = -9.8 \text{ m s}^{-2}$

Question Three continues on the following page.

(d) The ceiling is 1.5 m above the table surface.

By calculating the maximum height reached by the apple, as well as the horizontal distance covered, determine whether the apple will reach Tony, 2.0 m away.

$v_x = 3.8\ \text{m s}^{-1}$ $v_y = 3.2\ \text{m s}^{-1}$

Time to maximum

$v_f = v_i + at \Rightarrow 0 = 3.2 - 9.8t \Rightarrow t = 0.33\ \text{s}$

Maximum height calculated using:

$d = v_i + \frac{1}{2}at^2 = 3.2 \times 0.33 - \frac{1}{2} \times 9.8 \times 0.33^2 = 0.52\ \text{m}$

or $v_f{}^2 = v_i{}^2 + 2ad \Rightarrow 0 = 3.2^2 - 2 \times 9.8d \Rightarrow d = 0.52\ \text{m}$

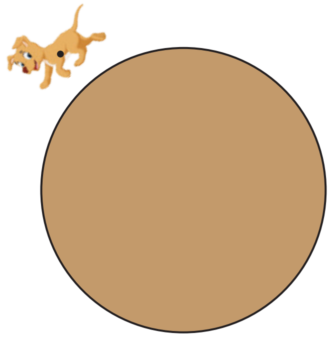
So height is 0.52 m

total $t = 2 \times 0.33 = 0.66$, therefore horizontal $d = 0.66 \times 3.8 = 2.5\ \text{m}$

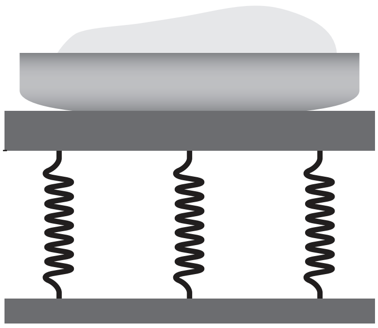
So the apple will make the distance without hitting the roof.

SPARE DIAGRAMS

If you need to redraw your response to Question One (a), use the diagram below. Make sure it is clear which answer you want marked.

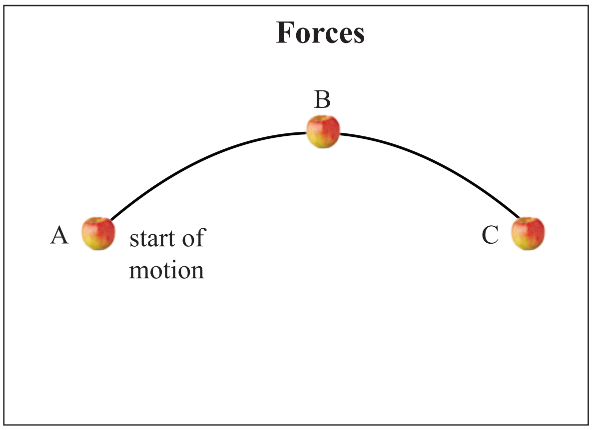


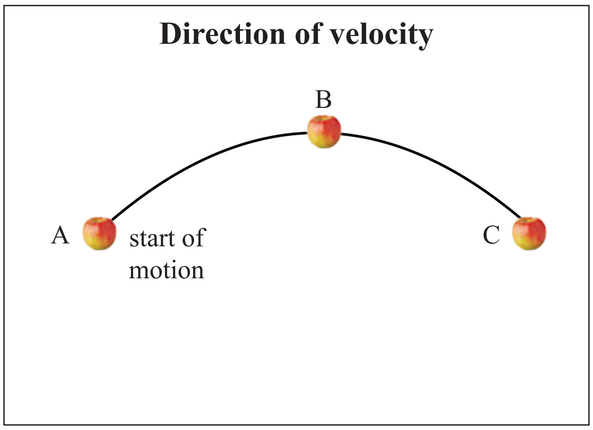
If you need to redraw your response to Question Two (a), use the space below. Make sure it is clear which answer you want marked.



with the flour

If you need to redraw your response to Question Three (c)(ii), use the space below. Make sure it is clear which answer you want marked.





Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

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