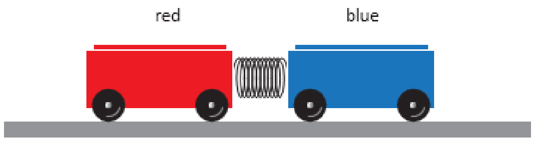
MECHANICS: NEWTONS LAWS, MOMENTUM AND ENERGY QUESTIONS

MOMENTUM AND IMPULSE (2022;2)

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.

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

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.

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

AROUND THE BEND (2021;2)

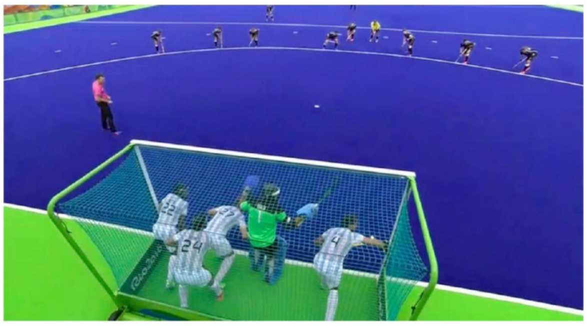
A rider rides around a circular bend of radius 7.0 m at a constant speed of 10 m s^{-1}.

(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.

OPEN ROAD (2020;2)

(a) 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.

THE SECOND HALF (2019;3)



Later in the hockey match, Nicole takes a penalty corner. She hits the stationary ball towards her teammates.

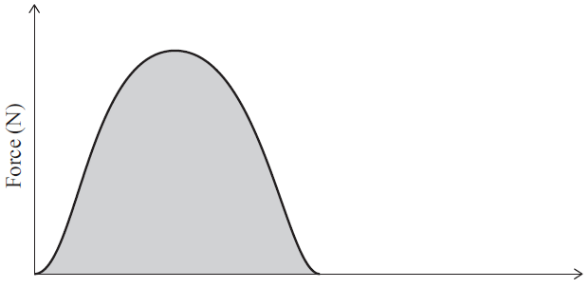
(a) State Newton's third law, which refers to the forces during the collision between the ball and Nicole's stick.

(b) When hitting the stationary ball for the penalty corner, Nicole hits with a stick-velocity of 18 m s^{-1}. After hitting the ball, the stick continues forward at 12 m s^{-1}. The mass of the stick is 600 g and the mass of the ball is 160 g. Calculate the velocity of the ball. What assumption(s) are made in your calculation?

Goalkeepers are heavily protected, including the use of leg guards as shown.

(c) The ball of mass 160 g is shot towards the goal but hits the goalkeeper's leg guards instead. The ball has an initial velocity of 30 m s^{-1} and the time of the impact is 0.02 s. It rebounds with a velocity of 10 m s^{-1}. Calculate the average force of the impact.

The graph below shows the force of impact over time when no leg guards are worn.



(i) Add a second graph to the diagram to show the effect that leg guards would have on the graph shape.

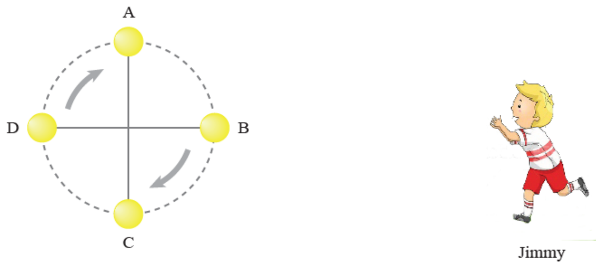
(ii) Justify your answer by using physics principles to explain how the leg guards benefit the goalkeeper.

ALTERNATIVE LAUNCHERS (2018;2)

Jimmy wanted to launch water balloons. He made a launcher using a long wooden beam. He placed his water balloon in a holder on the far left-hand end of the beam *(NB2S editor's note: the brick was there for a previous part of the question).*

(c) Jimmy decides to launch his balloon by jumping on the right-hand end of the wooden beam. It takes a time of 0.140 s to launch a 0.180 kg water balloon. The average force the balloon experiences is 20.0 N. By first showing the change of momentum (impulse) of the balloon is 2.8 kg m s^{-1}, calculate the speed of the balloon the instant it leaves the launcher.

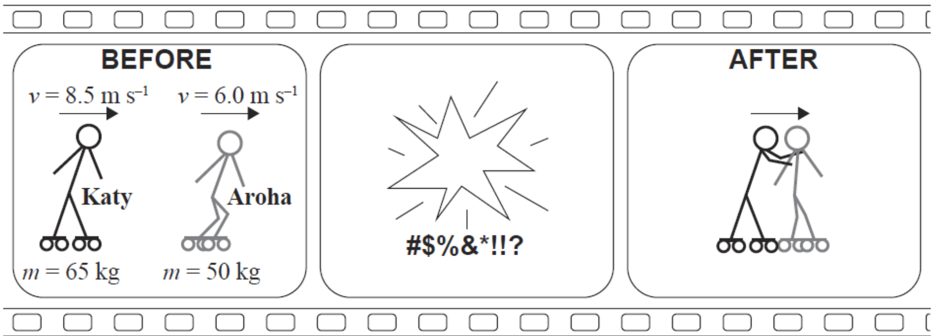
(d) Oliver tried launching a water balloon by connecting it to a string and swinging it around his head in a horizontal circle at a constant speed and releasing it.



(ii) Jimmy, who is standing to the right of the circle, wants to catch the fast-moving water balloon without it bursting. Explain, using physics principles, why Jimmy pulls his hand back in the process of catching the water balloon.

ROLLER SKATING (2017;1)

Katy, 65.0 kg, and Aroha, 50.0 kg, are roller skating. Aroha is moving to the right at a constant velocity of 6.0 m s^{-1} and Katy is also moving to the right, behind Aroha, at a constant velocity of 8.5 m s^{-1}. Katy collides with Aroha, holds her shoulders, and they move together to the right at a constant velocity.



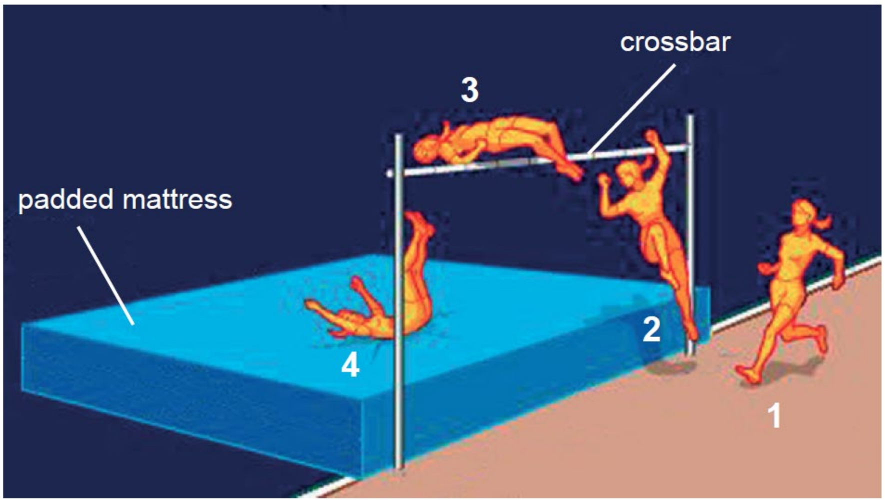
(a) What physical quantity is conserved during the above inelastic collision between Katy and Aroha? State any assumptions you have made.

(b) Calculate the combined velocity of Katy and Aroha as they skate together after the collision.

(c) As Katy collides with Aroha, they both experience a force due to the collision. The duration of the collision is 2.5 s. Calculate the size of the force experienced by Aroha.

High Jump (2017;2)

Sarah, a 55.0 kg athlete, is competing in the high jump where she needs to get her body over the crossbar successfully without hitting it. Where she lands, a padded mattress cushions her fall.

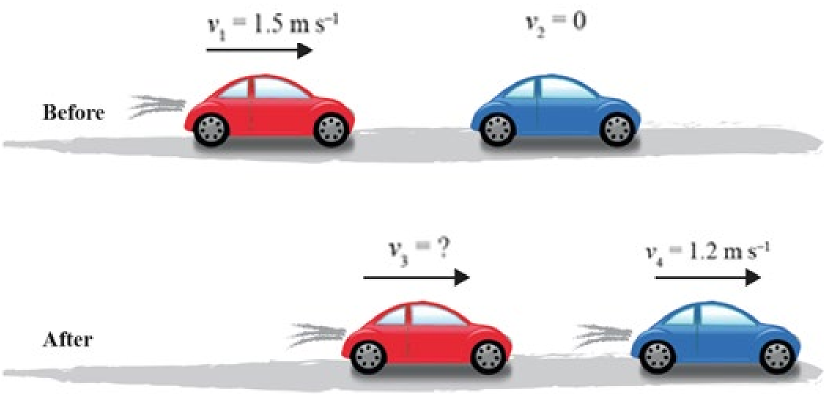


After Sarah has jumped, she lies motionless in position 4, as shown in the diagram. There are 20 springs evenly spaced in the area of the mattress where she lands. The average compression of each spring is 4.5 cm. Sarah's mass is 55.0 kg.

(d) When Sarah lands on the mattress after the jump, the force on her body is quite large. Discuss TWO changes that could be made to the springs of the mattress to make Sarah's landing more comfortable. Explain any physics principles that should be considered to make these changes.

Motion (2016;1)

At the bottom of the slope, the track is flat. The red car, moving with the speed of 1.5 m s^{-1}, collides with a stationary blue car. The mass of the red car is 0.050 kg, and the mass of the blue car is 0.040 kg.



(b) If the velocity of the blue car after the collision is 1.2 m s^{-1}, calculate the velocity of the red car after the collision.

(c) If the duration of the collision was 0.08 seconds, calculate the average force that the red car exerts on the blue car.

Ice Skating (2015;2)

Janet and Roy are ice skating.

(a) At one point, Roy is standing still, and Janet glides up to him from behind and grabs him by the shoulders. Janet's velocity as she glides up to Roy is 5.0 m s^{-1}, and together they glide off at a velocity of 2.2 m s^{-1} in the same direction as Janet was gliding (assume that both Janet's and Roy's skates are pointing in the direction of travel). Roy has a mass of 65 kg.

- State the law of physics that applies to this situation.
- Calculate Janet's mass.
- Explain why you can use the assumptions you made when calculating Janet's mass.

After removing her skates, Janet jumps down to the ground from a high bench.

(b) Write a comprehensive explanation of what Janet needs to do while landing, so that she does not hurt herself. Use a formula to explain your answer.

(c) When Janet jumps down, is her momentum conserved? Explain.

Basketball (2014;1)

(a) Rachel is on her way to basketball practice. Her ball has a mass of 0.60 kg. Rachel drops the ball from a balcony. It takes the ball 1.2 seconds to reach the ground. Calculate the size of the impulse on the ball during the time it takes to fall.

(b) Is the momentum of the ball conserved as it falls? Explain your answer with reference to the conditions required for momentum conservation.

At the Gym (2014;2)

(a) Jamie is doing a workout. He is using a barbell with weights on it. The total mass of the bar with the weights on it is 120 kg. Calculate the work done on the bar if Jamie lifts it 0.55 m vertically at constant speed.

After doing some weights, Jamie goes across to the punch-bag, which is a large bag hanging from a chain.

(d) Jamie punches the bag horizontally. He then puts on a glove with thick padding and punches the bag again with the same velocity. Discuss the difference between the two punches in terms of:

- the stopping time of his fist
- the force on the bag

State any assumptions you make.

Shamilla drives to the Gym (2014;3)

(a) Shamilla and her car have a combined mass of 1100 kg. She is driving at constant velocity. Calculate the size of the vertical force the road produces on the car.

(b) Shamilla says that 'even though the car is moving, it is in equilibrium'. Explain what this statement means.

Shamilla drives home (2014;4)

Shamilla and her car have a combined mass of 1100 kg.

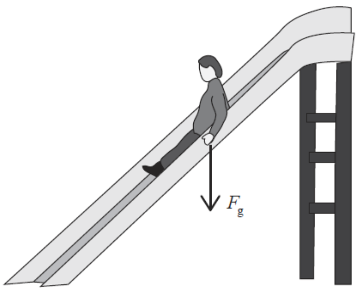
(a) Calculate the total momentum of the car and Shamilla when the car has a velocity of 18 m s^{-1}. Include the correct unit with your answer.

(b) Calculate the size and the direction of the momentum change of the car as it slows from a velocity of 18 m s^{-1} to a velocity of 11 m s^{-1}.

(c) Shamilla puts her foot on the brake, and the car slows down. Explain the principle of energy conservation in this situation and identify the transfer of energy caused by braking.

(d) Calculate the average rate at which the brakes transfer energy as the car slows from a velocity of 18 m s^{-1} to a velocity of 11 m s^{-1} in a time of 6.0 s.

Motion (2013;1)



Jason sits on a slide, as shown in the diagram. He is sliding down at constant speed. State the size of the net force on Jason.

Forces and motion (2013;2)

Hillary attempts to throw a basketball into a hoop.

(c) Explain the effect of the force(s) acting on the ball, once it has left Hilary's hand until it reaches maximum height. You may ignore the effects of air resistance.

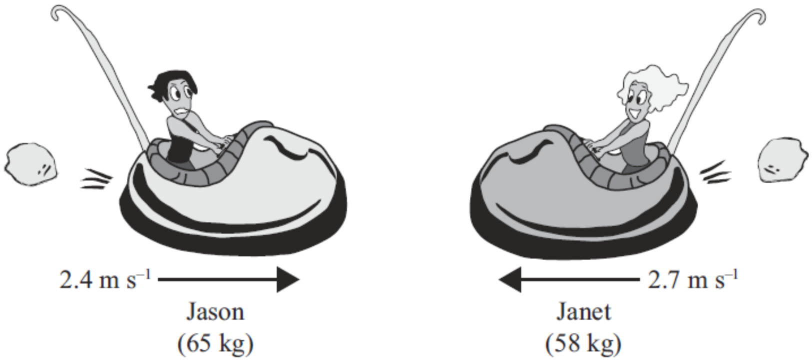
Momentum and energy (2013;2)

Each bumper car has a rubber bumper all round it.

(a) The mass of a bumper car is 240 kg. Jason has a mass of 65 kg and is travelling at a speed of 2.4 m s^{-1}. Calculate the size of the momentum of Jason and his bumper car.

(b) The bumper cars are designed to minimise injury. Discuss the reasons for the bumper cars having rubber bumpers all round them. Assume cars with and without bumpers have the same mass. Assume change in velocity is the same with and without bumpers.

(c) Jason collides head-on with Janet who is in another bumper car. The bumpers don't work properly and after collision both cars lock together.



The mass of each bumper car is 240 kg. Jason has a mass of 65 kg and Janet has a mass of 58 kg. They are travelling towards each other in opposite directions, Jason with a speed of 2.4 m s^{-1} to the right and Janet with a speed of 2.7 m s^{-1} to the left. Calculate their combined velocity after collision. Include a direction with your answer.

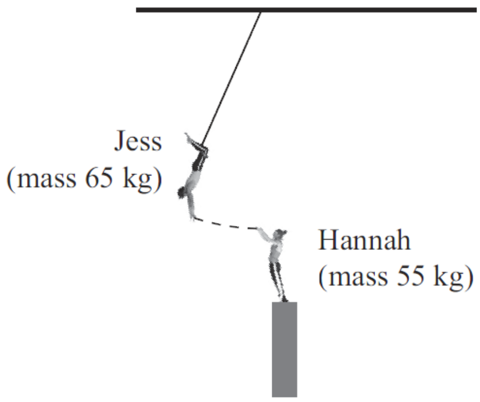
(d) The rubber bumper in Jason's bumper car has a spring constant of 78 000 N m^{-1}. On one occasion he collides with the wall, causing a compression of 15 cm. Determine the impulse if the collision lasted for 0.80 s. Include a unit with your answer.

THE TRAPEZE (2012;1)

Jess is a trapeze artist at the circus. As part of her act she hangs on a long rope and swings downwards. When she gets to the lowest point she grabs onto Hannah and they keep moving together.

Jess has a mass of 65 kg.

Hannah has a mass of 55 kg.



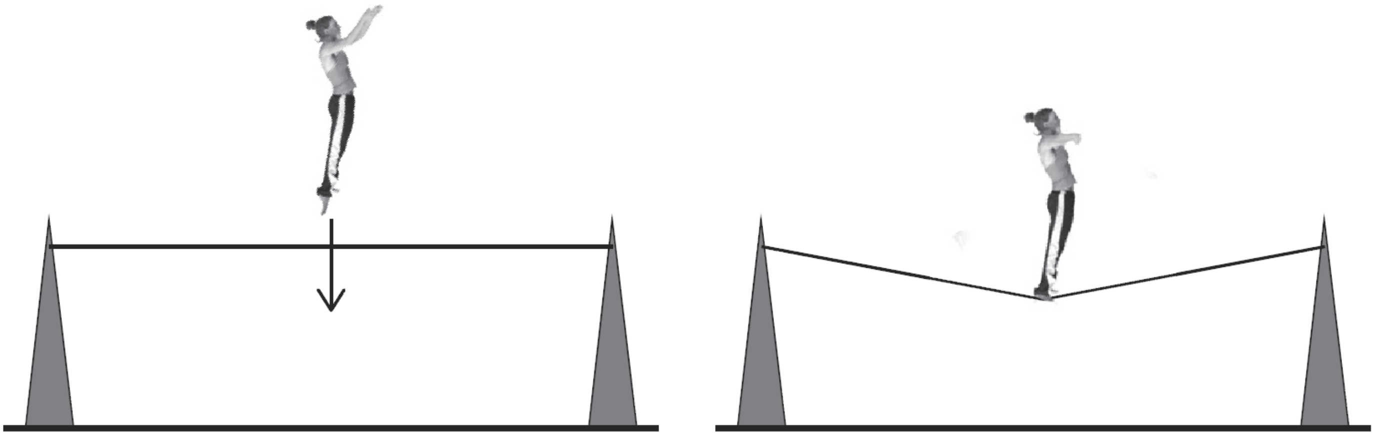
(a) Name the important quantity that is conserved as Jess swings down.

(b) Name the important quantity that is conserved as Jess grabs onto Hannah and they move together.

(c) Immediately after Jess grabs Hannah, they move together at a speed of 5.5 m s^{-1}. Calculate the **vertical height** that Jess dropped down.

THE ELASTIC ROPE (2012;3)

In the second part of her act, Hannah flies through the air and lands on an elastic rope, which is held under tension between two supports, as shown in the diagram below.

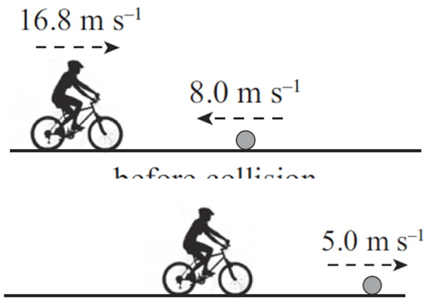


(a) Name the main energy changes that occur as Hannah is falling AND as she is coming to a stop.

(b) Hannah doesn't like the rope to be too tight when she lands on it. State the direction of the force on her from the rope. Explain, in terms of the force acting on Hannah, why the rope should not be too tight when she lands on it.

THE BRIDGE (2011;2)

(c) While Jacquie is cycling at a speed of 16.8 m s^{-1}, she collides with a soccer ball that is rolling towards her at a speed of 8.0 m s^{-1}. The soccer ball bounces off in the opposite direction with a speed of 5.0 m s^{-1}.



after collision

Calculate Jacquie's velocity (size and direction) after the collision.

You may ignore any effects of friction.

Mass of Jacquie and her bike = 72.0 kg

Mass of soccer ball = 0.430 kg.

(d) Explain what is meant by an **elastic collision** and an **inelastic collision**. Describe what you would need to do in order to determine whether this collision between the bike and the soccer ball is **elastic** or **inelastic**. *You are not required to carry out any calculations.*

(e) Explain how the force exerted by the ball on Jacquie and her bike is dependent on the duration of the time on impact, AND explain how the force exerted by the ball on Jacquie and her bike is related to the force exerted by Jacquie and her bike on the ball.

ENERGY AND PROJECTILE MOTION (2011;3)

(b) Ernie is pushing a lawn mower with a horizontal force of 22 N, as shown. Calculate the power produced by Ernie when he accelerates the mower through a distance of 4.0 m in 3.0 seconds. Give the correct **units** for your answer.

THE HIGH JUMP (2010;3)

Lucy is competing in a high jump event. She runs up to the bar, jumps over it and lands on the mat.

(a) She starts her run-up by accelerating from rest at 2.21 m s^{-2} for 2.0 s. Calculate the **distance** she travels in this time. Write your answer to the correct number of **significant figures**.

(b) Explain why you have used this number of significant figures.

(c) Use physics principles to explain why it is better for Lucy to land on the padded mat than it is to land on grass.

THE SHOT PUT (2010;4)

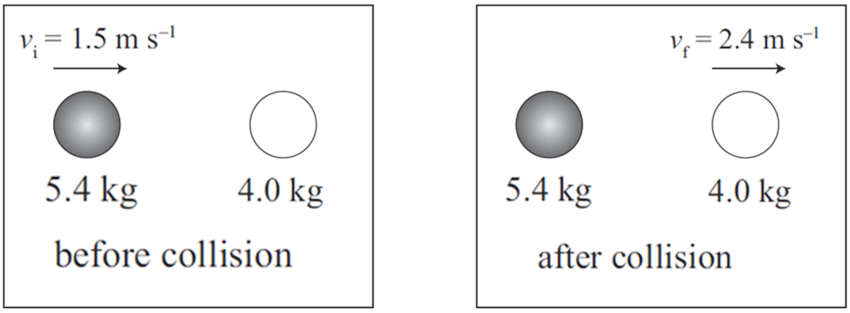
Hamish is competing in the shot put. This involves throwing a 5.4 kg iron ball (the shot) as far as possible.

(a) The shot starts from rest and accelerates for 0.25 s. Calculate the average force that Hamish exerts on the shot if it leaves his hand at 11 ms^{-1}.

When the shot lands, it rolls along the ground at 1.5 ms^{-1} and collides head-on with a stationary shot which has a mass of 4.0 kg. The friction force is negligible during the collision. After the collision, the 4.0 kg shot rolls forward at 2.4 ms^{-1} in the same direction that the 5.4 kg shot was initially rolling.

(b) Without doing any calculations, what can you say about the **total momentum** and the **momentum of the 4.0 kg shot** during the collision? Discuss your answer.

(c) Calculate the velocity (size and direction) of the 5.4 kg shot after the collision.



CIRCULAR MOTION (2009;1)

(d) Jordan drops a ball to the floor. The ball bounces up and down a few times. Explain using energy considerations, why the height of bounce of the ball, changes with time.

EQUILIBRIUM, MOMENTUM AND SPRINGS (2009;3)

One of the games that Harry plays is cricket.

(d) The ball approaches the batsman with a speed of 21 ms^{-1}. The ball has a mass of 0.161 kg. The batsman hits the ball hard with an average force of 2560 N, and the ball moves away in the opposite direction at 30.0 ms^{-1}. Calculate the time the ball was in contact with the bat.

(e) Express your answer to (d) to the correct number of significant figures. State the reason for your choice of significant figures for your final answer.

(f) Harry is a fielder near the batsman. Explain, using physics principles, why Harry usually pulls back his hand while catching a ball.

THE SOCCER MATCH (2008;1)

Louise is playing soccer for her 1st XI soccer team. Louise has a mass of 65 kg.

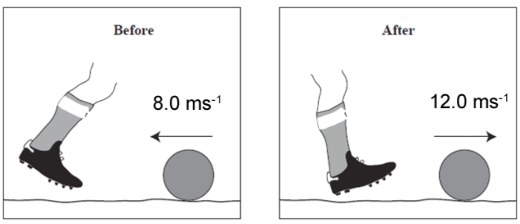
(a) Calculate the size of Louise's momentum while she is running at 8.0 ms^{-1}. Write your answer with the correct units.

(f) Determine the size of the average net force acting on her when she is running at constant speed. Explain your answer.

Louise kicks the ball vertically up, as shown in the diagram. It rises and then falls. You may assume air resistance is negligible.

(g) Describe and explain what happens to (i) the force on the ball (ii) the ball's acceleration (iii) the ball's velocity after the ball is kicked and as it rises and falls.

Later, the ball is rolling towards Louise at a speed of 8.0 ms^{-1} as shown in the diagram. She kicks it and it rolls in the opposite direction with a speed of 12.0 ms^{-1}. The ball's mass is 450 g. Her foot is in contact with the ball for 0.10 s.

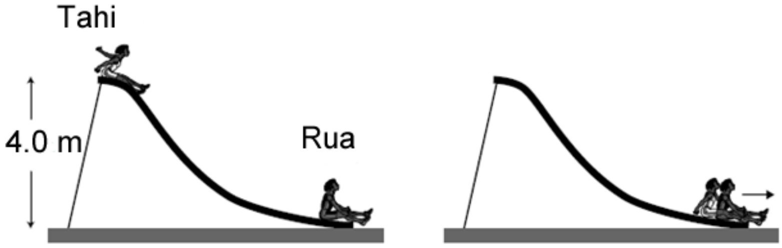


(h) Calculate the size of the unbalanced force on the ball.

(i) State the size and direction of the force of the ball on her foot.

GOING TO THE PLAYGROUND (2008;2)

Tahi then climbs to the top of a slide. The slide is 4.0 m high. He slides down. Assume all the gravitational potential energy is converted into kinetic energy. At the bottom he collides with Rua, who is initially stationary. Tahi's mass is 55 kg and Rua's mass is 65 kg.



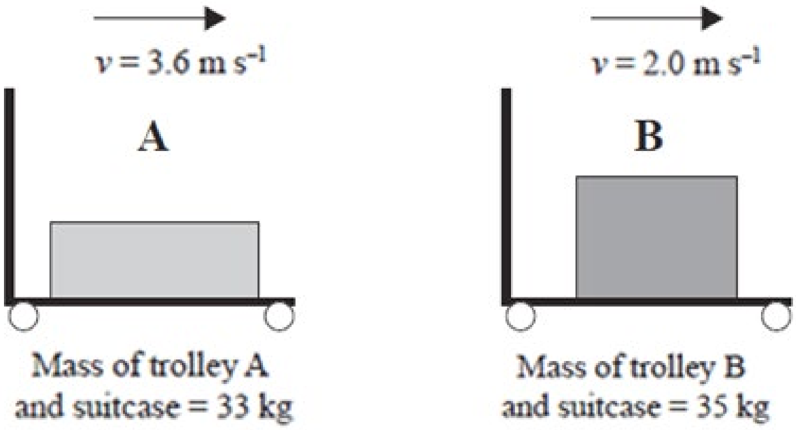
(j) This collision is inelastic. State what this means.

(k) Calculate their combined speed if they stick together after the collision.

(l) Is Tahi's momentum conserved as he moves down the slide? Explain your answer.

THE BAGGAGE SECTION (2007;3)

(e) A suitcase is put on trolley A. The total mass of trolley A and the suitcase is 33 kg. Trolley A with the suitcase is moving with a speed of 3.6 ms^{-1} when it collides inelastically with trolley B moving in the same direction with a speed of 2.0 ms^{-1}. The total mass of trolley B and its suitcase is 35 kg.



After the collision, trolley A is moving with a speed of 2.4 ms^{-1} in the same direction. Calculate the kinetic energy of trolley B and its suitcase after the collision.

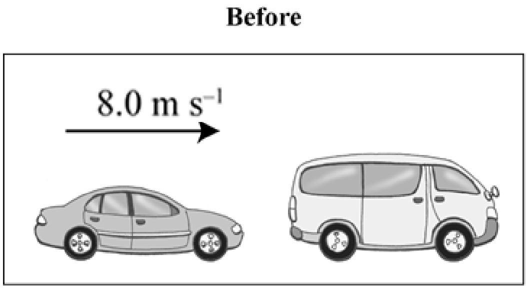
(f) What assumptions did you make in order to answer the above question?

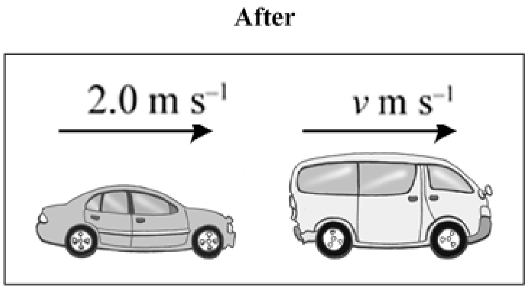
(g) This collision is described as inelastic. Explain clearly what happens to momentum and kinetic energy in both elastic and inelastic collisions.

MOMENTUM (2006;4)

Marama is driving her car home after her event, when she collides with a stationary van. Assume there are no outside horizontal forces acting during the collision.

(a) Name the physical quantity that is conserved in this collision.





The mass of the car is 950 kg and the mass of the van 1700 kg.

The car is travelling at 8.0 ms^{-1} before the collision and 2.0 ms^{-1} immediately after the collision, as shown in the diagram.

(b) Calculate the size and direction of the car's momentum change.

(c) Calculate the speed of the van immediately after the collision.

(d) If the average force that the van exerts on the car is 3800 N, calculate how long the collision lasts.

(e) Marama had a bag resting on the front seat. Use relevant physics concepts to explain why the bag fell onto the floor during the collision.

(f) The front of modern cars is designed to crumple or gradually compress during a collision. Use the idea of impulse to explain why this is an advantage for the people in the car.

A COLLISION (2005;2)

A car and its driver have a combined mass of 1200 kg. The car collided with a stationary van of mass 1500 kg.

The car and van locked together after impact and from the marks on the road the police were able to deduce that the wreckage moved at 4.0 ms^{-1} immediately after the collision.

(a) Calculate the speed of the car just before it collided with the van.

(b) State what physical quantity is conserved in the collision.

(c) State the condition necessary for the quantity you have named in (b) to be conserved.

(d) The impact lasted for 0.50 seconds. Calculate the average force that the car exerted on the van during the collision.

(e) Explain TWO features that a car has in order to reduce injury to the driver during a collision.

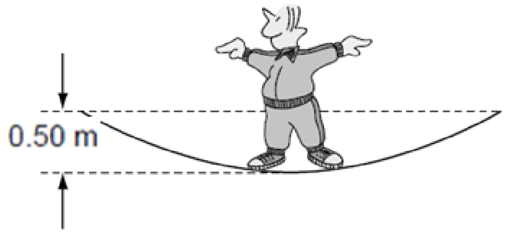
(f) Use calculations to explain whether the collision was elastic or inelastic.

SCHOOL GYM (2004;3)

Where needed, use g = 10.0 ms^{-2}.

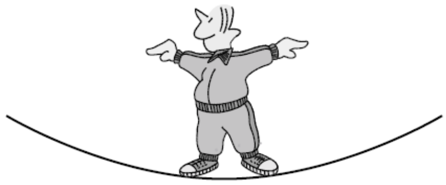
Henry is bouncing on the elastic mat of a trampoline.

In order to gain the necessary height to perform a certain move, Henry has stretched the mat downwards by 0.50 m. The spring constant of the mat is 3500 Nm^{-1}.



(i) Calculate the size of the force supplied by the mat when stretched by this amount.

(ii) On the diagram, draw labelled arrow(s) to show the force(s) acting on Henry when he is at the lowest point of his bounce.



Henry has a mass of 75 kg.

(ii) Calculate the value of the net force acting on Henry when the trampoline mat is stretched downwards by 0.50 m.

(iii) State the direction of this net force.

(iv) Calculate Henry's initial acceleration when the mat is stretched downwards by 0.50 m.

(v) Calculate the vertical height to which Henry will rise above his lowest position.

(vi) Explain the physics involved in finding the answer to (vi), including a statement of any assumptions made.

SCHOOL TRIP - ICE SKATING (2004;4)

Ana and Jon are now practising ice skating routines.

Jon (mass 75 kg) skates at 6.0 ms^{-1} towards Ana (mass 55 kg) who is standing still on the frictionless ice. Jon collides with Ana and they move off together in the same straight line that Jon was moving before the collision.

(a) Calculate the speed of the skaters after the collision.

(b) Explain the physics involved in finding the answer to (a), including a statement of any assumption made.