Newton's 1st Law

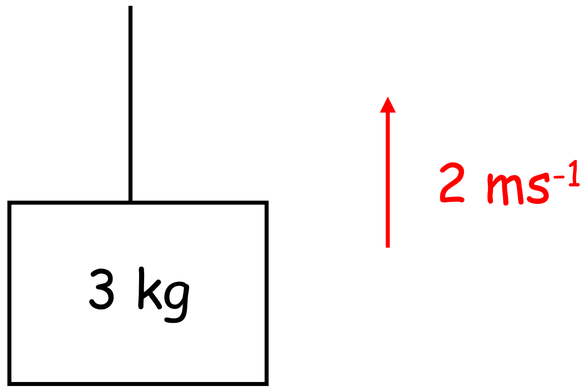
Newton's 1st Law of motion states:

"an object will remain at rest or continue to travel at a constant speed in the same direction unless acted upon by a net or unbalanced force."

- If NO FORCES act on an object – at rest.
- If BALANCED FORCES act on an object – remains at rest, or continues travelling at constant speed.
- If UNBALANCED FORCES act on an object – accelerates or decelerates.

Example 1

A 3 kg mass suspended by a rope is moving upwards with a steady speed of 2 ms^{-1}.



Calculate the tension (force) in the rope.

steady speed => forces are balanced

$$W = m g$$

$$= 3 \times (-9.8)$$

$$\underline{\underline{W = -29.4\,N}}$$

<u>Tension in rope is 29.4 N</u>

(Since $F\uparrow = F\downarrow$)

Newton's 2nd Law

Unbalanced forces will cause an object to accelerate or decelerate.

$$\boxed{F = m\,a}$$

KEY:

$F =$ unbalanced force (N)

$m =$ mass (kg)

$a =$ acceleration (ms^{-2})

Definition of a Newton

One Newton is the size of the unbalanced force which will cause an object of mass 1 kg to accelerate at 1 ms^{-2}.

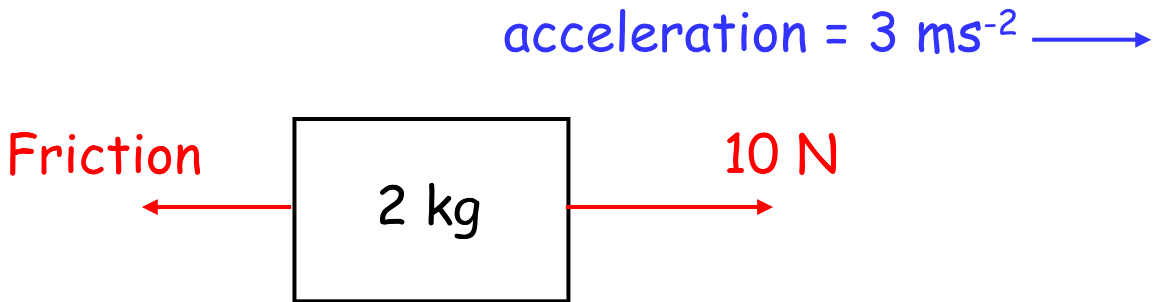
The unbalanced force is the sum of all the forces acting on the object.

Example 1

A 2 kg mass accelerates horizontally at 3 ms^{-2}.

The mass is pulled by a force of 10 N.

Calculate the force of friction acting against the block.



$m = 2\ kg$

$a = 3\ ms^{-2}$

$F = ?$

$$F_{unbalanced} = m\,a$$
$$= 2 \times 3$$
$$\underline{\underline{F_{unbalanced} = 6\ N \text{ to the right}}}$$

$$\therefore\ 10 - friction = 6$$
$$friction = 10 - 6$$
$$\underline{\underline{friction = 4\ N}}$$

Example 2

A 1000 kg car accelerates to the right at 4 ms^{-2}. The force of friction acting on the car is 600 N. Calculate the force exerted by the car's engine.

acceleration = 4 ms^{-2} $\longrightarrow$

Friction = 600 N $\longleftarrow$

$\longrightarrow$ F_{ENGINE}

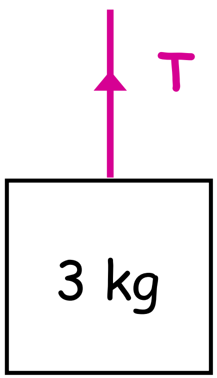
$$m = 1000\ \text{kg}$$
$$a = 4\ \text{ms}^{-2}$$
$$F = ?$$

$$F_{unb} = m\,a$$
$$= 1000 \times 4$$
$$F_{unb} = 4000\ \text{N}$$

$$\therefore\ F_{engine} - \text{friction} = 4000$$
$$F_{engine} = 4000 + 600$$
$$F_{engine} = 4600\ \text{N}$$

Example 3

A 3 kg mass is pulled vertically upwards by a rope. The mass accelerates at 2 ms^{-2}. Calculate the tension in the rope.



acceleration = 2 ms^{-2}

$m = 3\ kg$

$a = 2\ ms^{-2}$

$F = ?$

$F_{unb} = m\,a$

$= 3 \times 2$

$\underline{\underline{F_{unb} = 6\ N}}$ (upwards ↑)

$W = m\,g$

$= 3 \times (-9.8)$

$\underline{\underline{W = -29.4\ N}}$ (down ↓)

$T - W = 6$

$T - (29.4) = 6$

$\underline{\underline{T = 35.4\ N}}$

<u>Worksheet – Dynamics Problems</u>

Q1 – Q5.

Rocket Motion

Example 1

A guided missile has a mass of 1,000 kg and is fired vertically into the air.

It's rockets provide a thrust of 20,000 N.

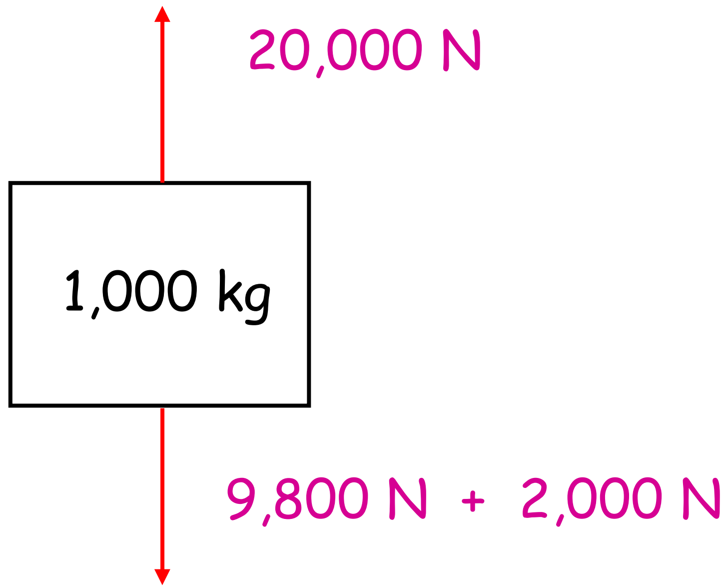
The drag force caused by air resistance is 2,000 N.

Calculate the acceleration of the rocket.

$$W = m\,g$$

$$= 1000 \times 9.8$$

$$\underline{\underline{W = 9800\,\text{N}}}$$



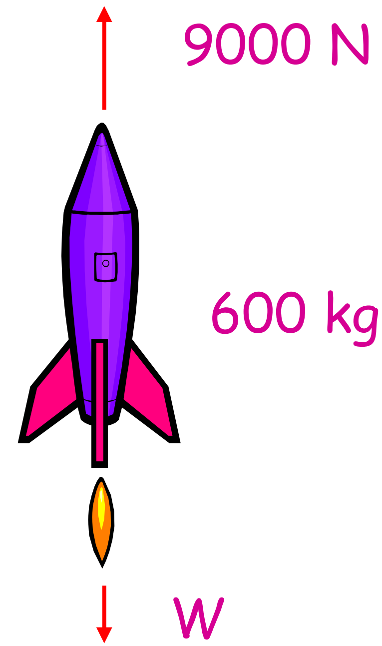
$$m = 1{,}000\ \text{kg}$$
$$F_{unb} = 20{,}000 - 11{,}800$$
$$= 8{,}200\ \text{N}$$
$$a = ?$$

$$a = \frac{F_{unb}}{m}$$
$$= \frac{8{,}200}{1{,}000}$$
$$a = 8.2\ \text{ms}^{-2}$$

Example 2

A rocket of mass 600 kg is launched from Cape Canaveral. The total engine thrust is 9000 N.

(a) Calculate the acceleration of the rocket.



$$W = mg$$
$$= 600 \times 9.8$$
$$\underline{\underline{W = 5880\,\text{N}}}$$

$$m = 600\,\text{kg}$$
$$F_{unb} = 9000 - 5880$$
$$= 3120\,\text{N}$$
$$a = ?$$

$$a = \frac{F_{unb}}{m}$$
$$= \frac{3120}{600}$$
$$\underline{\underline{a = 5.2\,\text{ms}^{-2}}}$$

(b) The acceleration of the rocket increases as the rocket gains altitude. Explain your answer fully.

The mass of the rocket decreases as fuel on board the rocket is used up, so weight decreases.

The size of the unbalanced force increases ($F_{unb} = 9000 - W$).

Considering equation; $\boxed{a = \frac{F_{unb}}{m}}$

as $F_{unb}\uparrow$ and mass $\downarrow$ the acceleration increases.

In addition, air resistance decreases at higher altitudes.

(c) The same rocket takes off from the moon where gravity is 1.6 N kg^{-1}. Calculate the new initial acceleration.

$$W = m\,g$$
$$= 600 \times 1.6$$
$$W = 960\,\mathrm{N}$$

$$m = 600\,\mathrm{kg}$$
$$F_{unb} = 9000 - 960$$
$$= 8040\,\mathrm{N}$$
$$a = ?$$

$$a = \frac{F_{unb}}{m}$$
$$= \frac{8040}{600}$$
$$a = 13.4\,\mathrm{ms}^{-2}$$

(d) On Jupiter, gravity is 26 N kg^{-1}. Explain fully whether this rocket would be able to take off or not.

$$W = mg$$
$$= 600 \times 26$$
$$\underline{\underline{W = 15600\,\text{N}}}$$

- weight > engine thrust
- no unbalanced force acting upwards
- rocket won't take off from Jupiter

Lift Motion

We will consider objects in lifts as they accelerate, travel at a constant speed and decelerate.

In a lift, your weight feels heavier than normal when:

- accelerating upwards
- decelerate downwards

In a lift, your weight feels lighter than normal when:

- accelerating downwards
- decelerate upwards

In a lift, your weight feels normal when:

- constant speed

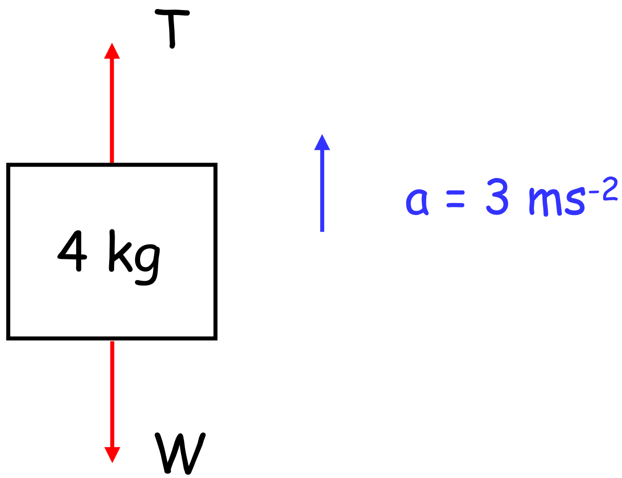
Example 1

A package of mass 4 kg is connected to a Newton balance which is attached to the ceiling of a lift.

Calculate the reading on the Newton balance at each stage of the following journey.

(a) accelerates at 3 ms-2 upwards.

The Newton balance measures the upward force produced by the tension (T) in the lift cable.

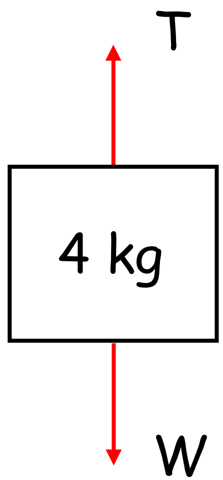


$$W = m\,g$$
$$= 4 \times 9.8$$
$$\underline{\underline{W = 39.2\,\text{N}}}$$

$$m = 4\,\text{kg}$$
$$a = 3\text{ms}^{-2}$$
$$F_{unb} = ?$$

$$F_{unb} = m\,a$$
$$T + W = m\,a$$
$$T + (-39.2) = 3 \times 4$$
$$T - 39.2 = 12$$
$$\underline{\underline{T = 51.2\,\text{N}}}$$

(b) travels with a constant velocity upwards.



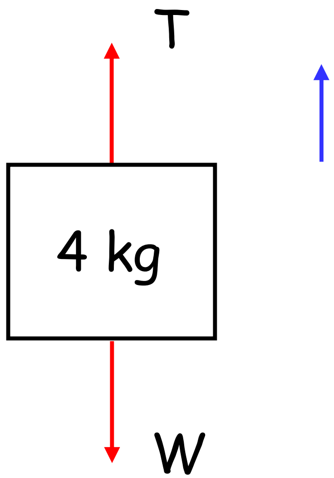
constant velocity => balanced forces

(tension in rope = weight of package)

tension = 39.2 N

$$F_{unb} = m\,a$$
$$T + W = m\,a$$
$$T + (-39.2) = 4 \times 0$$
$$T - 39.2 = 0$$
$$\underline{\underline{T = 39.2\,N}}$$

(c) decelerates at 3 ms^{-2} upwards.

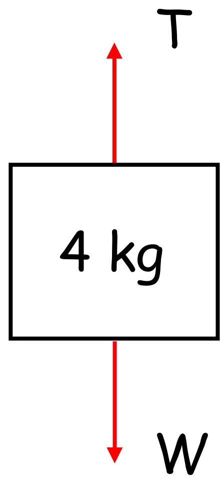


$a = -3\ ms^{-2}$

(decelerating so - ve)

$$F_{unb} = m\,a$$
$$T + W = m\,a$$
$$T + (-39.2) = 4 \times (-3)$$
$$T - 39.2 = -12$$
$$T = -12 + 39.2$$
$$\underline{\underline{T = 27.2\,N}}$$

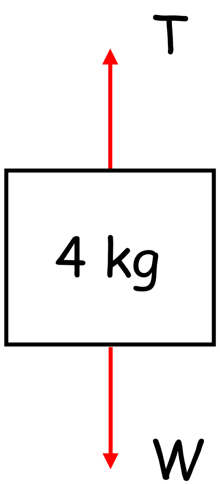
(d) stopped.



$a = 0\ ms^{-2}$

$$F_{unb} = m\,a$$
$$T + W = m\,a$$
$$T + (-39.2) = 4 \times 0$$
$$\underline{\underline{T = 39.2\,N}}$$

(e) accelerates downwards at 3 ms^{-2}.

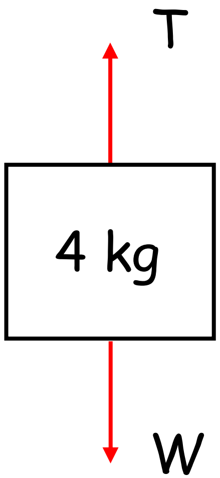


$a = -3\ ms^{-2}$

(- ve as travelling downwards)

$$F_{unb} = m\,a$$
$$T + W = m\,a$$
$$T + (-39.2) = 4 \times (-3)$$
$$T = -12 + 39.2$$
$$\underline{\underline{T = 27.2\,N}}$$

(f) decelerates downwards at 3 ms^{-2}.



$a = 3\ ms^{-2}$

(- ve as travelling downwards and – ve as decelerating)

[(-) x (-) = +]

$$\begin{aligned} F_{unb} &= m\,a \\ T + W &= m\,a \\ T + (-39.2) &= 4 \times 3 \\ T &= 12 + 39.2 \\ T &= 51.2\,\text{N} \end{aligned}$$

In a lift, your weight feels heavier than normal when:

- accelerating upwards
- decelerate downwards

In a lift, your weight feels lighter than normal when:

- accelerating downwards
- decelerate upwards

In a lift, your weight feels normal when:

- constant speed

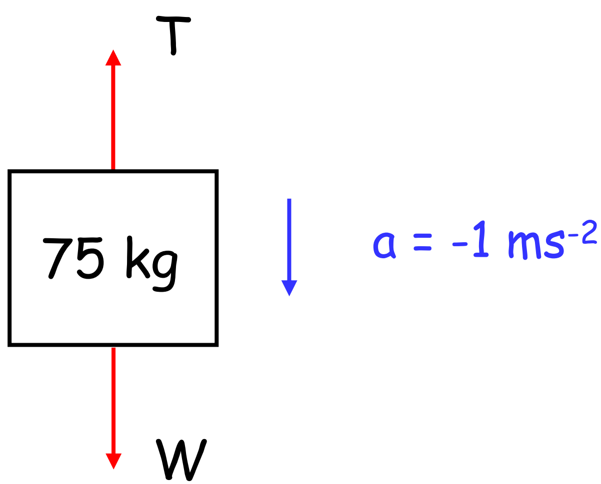
Example 2

A person of mass 75 kg enters a lift.

He presses the starting button and the lift descends with an acceleration of 1 ms^{-2}.

The lift then descends at a steady speed before coming to rest with a deceleration of 1 ms^{-2}.

(a) Calculate the force exerted on the person by the floor when the lift is accelerating.



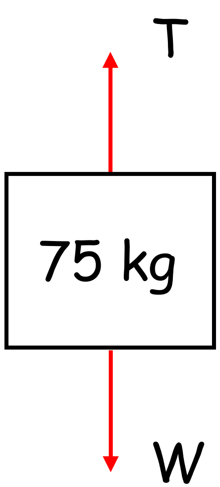
$$W = mg$$
$$= 75 \times 9.8$$
$$W = 735\,N$$

Force exerted on person by floor is equal to tension (T) in the cable.

$$m = 75\ \text{kg}$$
$$a = -1\ \text{ms}^{-2}$$
$$F_{unb} = ?$$

$$F_{unb} = m\,a$$
$$T + W = m\,a$$
$$T + (-735) = 75 \times (-1)$$
$$T = -75 + 735$$
$$T = 660\ \text{N}$$

(b) Calculate the force exerted on the person by the floor when the lift is decelerating.



$\downarrow$ $a = 1\ \text{ms}^{-2}$

decelerating downwards

[(-) x (-) = +]

$$F_{unb} = m\,a$$
$$T + W = m\,a$$
$$T + (-735) = 75 \times 1$$
$$T = 75 + 735$$
$$T = 810\ \text{N}$$

Q1. A 70 kg man stands on scales in a lift.

For the first 2 seconds of the journey, the scales read 651 N.

(a) (i) Is the lift travelling up or down?

downward

since F↓ is greater than F↑

(ii) Calculate the acceleration of the lift.

$- 0.5\ ms^{-2}$

(b) The lift then moves at a steady speed. What is the reading on the scales now.

686 N

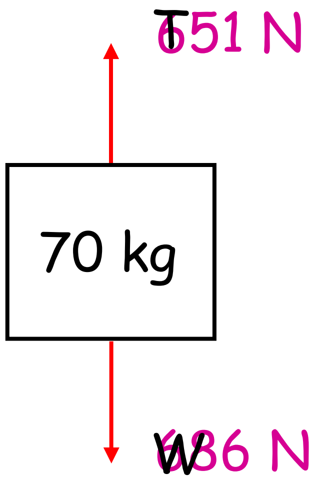
(man's weight)

(c) Calculate the steady speed of the lift.

$- 1\ ms^{-1}$

(- ve as downwards)

(a) i)



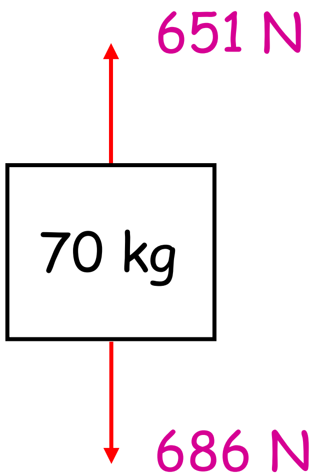
$$W = mg$$
$$= 70 \times 9.8$$
$$\underline{\underline{W = 686\,\text{N}}}$$

lighter than actual weight => accelerating down / decelerating up

Since at start of journey (first 2s), must be accelerating.

<u>Lift is travelling downwards.</u>

(a) ii)



$$m = 70\ \text{kg}$$

$$F_{unb} = -35\ \text{N}$$ **(downwards)**

$$a = ?$$

$$F_{unb} = m\,a$$

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

$$a = \frac{-35}{70}$$

$$\underline{\underline{a = -0.5\ \text{ms}^{-2}}}$$

(-ve indicates downwards)

(b)

constant velocity => balanced forces

$$\text{reading on scales} = \text{weight of man}$$
$$= 686\,\text{N}$$

(c)

$a = -0.5\text{ms}^{-2}$

$t = 2\text{ s}$

$u = 0\text{ ms}^{-1}$

$v = ?$

$$v = u + at$$
$$= 0 + (-0.5 \times 2)$$
$$v = -1\text{ ms}^{-2}$$

Worksheet – Dynamics Problems

Q6 – Q11

Towing Objects

Can be asked to calculate many things, but common questions are to find the acceleration of the system, the tension in the tow ropes or the force pulling system.

Example 1

A car of mass 1000 kg tows a caravan of mass 500 kg along a straight and level road.

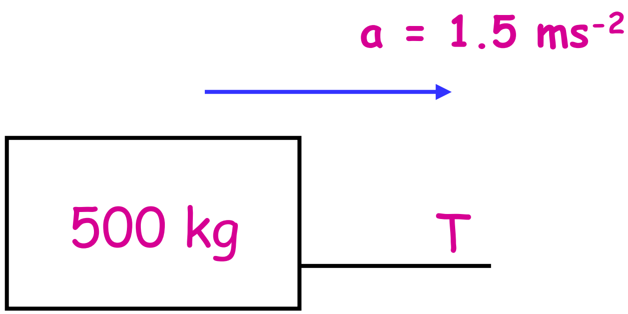
The car and caravan accelerate at 1.5 ms^{-2}.

The effects of friction are ignored.

(a) Calculate the tension in the towbar between the car and the caravan.

(b) Calculate the engine force.

(a) Tension in the towbar is caused by the trailer, NOT by the engine pulling it!



$$m_{car} = 1000\,\text{kg}$$
$$m_{caravan} = 500\,\text{kg}$$
$$a = 1.5\,\text{ms}^{-2}$$
$$F_{bar} = ?$$

$$F_{bar} = m_{caravan} \times a$$
$$= 500 \times 1.5$$
$$\underline{\underline{F_{bar} = 750\,\text{N}}}$$

(b)

$$F_{engine} = ?$$

$$m_{system} = m_{car} + m_{caravan}$$
$$= 500 + 1000\ kg$$
$$= 1500\ kg$$

$$a = 1.5\ ms^{-2}$$

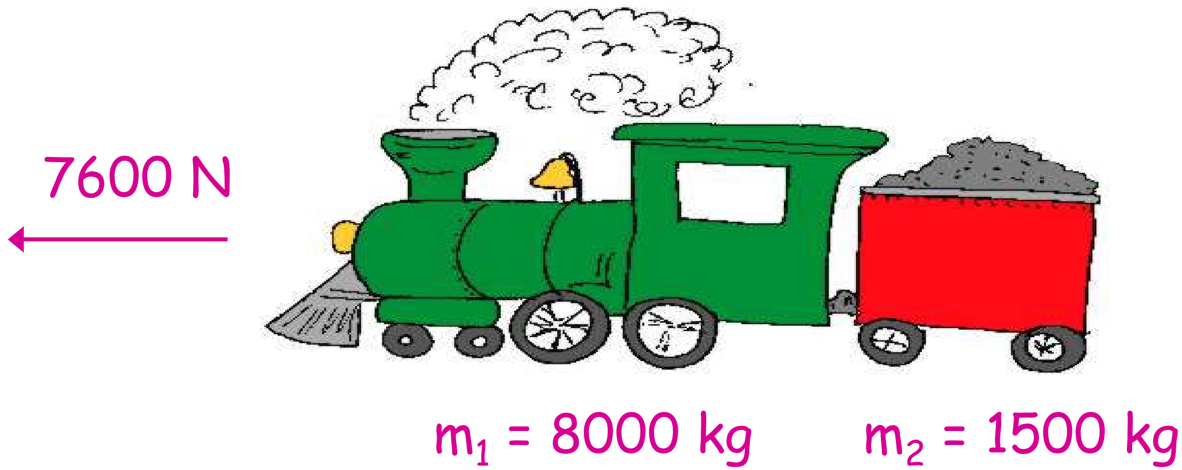
$$F_{engine} = m_{system} \times a$$
$$= 1500 \times 1.5$$
$$\underline{\underline{F_{engine} = 2{,}250\ N}}$$

Example 2

A train of mass 8000 kg tows a wagon of mass 1500 kg along a straight and level track.

The resultant force causing the train to accelerate is 7600 N.

Calculate the tension in the coupling.



Firstly, calculate the acceleration of the system.

$$a = ?$$

$$m_{system} = m_{engine} + m_{wagon}$$
$$= 8000\,kg + 1500\,kg$$
$$= 9500\,kg$$
$$F = 7600\,N$$

$$F = m\,a$$
$$7600 = 9500\,a$$
$$\underline{\underline{a = 0.8\,ms^{-2}}}$$

Now, using the acceleration, calculate the tension in the coupling.

$$m_{wagon} = 1500\,kg$$
$$a = 0.8\,ms^{-2}$$
$$F_{coupling} = ?$$

$$F_{coupling} = m_{wagon} \times a$$
$$= 1500 \times 0.8$$
$$\underline{\underline{F_{coupling} = 1200\,N}}$$

Worksheet – Mechanics & Properties of Matter Tutorial

Q66, Q67 and Q68

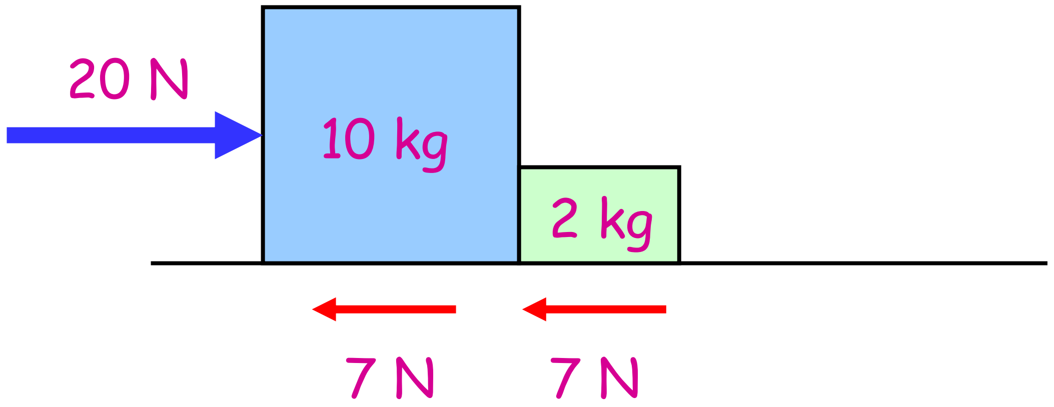
Touching Objects

Example 1

Two objects are placed next to each other.

The mass of the objects are 10 kg and 2 kg.

They are pushed by a 20 N force, whilst a frictional force of 7 N acts on each object.



(a) Calculate the acceleration of the blocks.

$$m = 10 + 2$$
$$= 12\ \text{kg}$$

$$F_{unb} = 20 - 14$$
$$= 6\ \text{N}$$

$$a = ?$$

$$F_{unb} = m\,a$$
$$6 = 12\,a$$
$$\underline{\underline{a = 0.5\ \text{ms}^{-2}}}$$

(b) Calculate force exerted on the 2kg block, by the 10 kg block.

$$a = 0.5\ \text{ms}^{-2}$$
$$m = 2\ \text{kg}$$
$$F_{unb} = ?$$

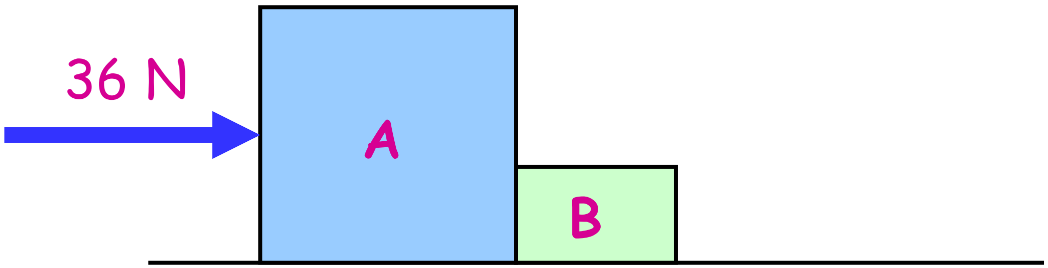
$$F_{unb} = m\,a$$
$$= 2 \times 0.5$$
$$\underline{\underline{F_{unb} = 1\ \text{N}}}$$

$$F_{2kg} = 1 + 7$$
$$\underline{\underline{= 8\ \text{N}}}$$

Example 2

A force of 36 N acts on two blocks, A and B.

Block A has a mass of 8 kg and block B, 4 kg.



(a) Calculate the acceleration of the blocks.

$$m = 8 + 4$$
$$= 12\ \text{kg}$$
$$F_{unb} = 36\ \text{N}$$
$$a = ?$$

$$F_{unb} = m\,a$$
$$36 = 12\,a$$
$$\underline{\underline{a = 3\ \text{ms}^{-2}}}$$

(b) Calculate the net force acting on block A.

$$m_a = 8\,\text{kg}$$
$$a_a = 3\,\text{ms}^{-2}$$
$$F_{unb} = ?$$

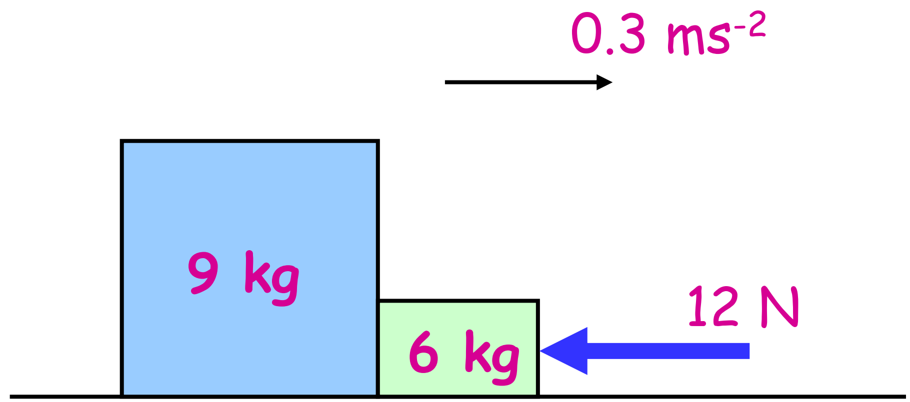
$$F_{unb} = m_a\, a_a$$
$$= 8 \times 3$$
$$F_{unb} = 24\,\text{N}$$

(c) Calculate the force that block A exerts on block B..

$$m_b = 4\,\text{kg}$$
$$a_b = 3\,\text{ms}^{-2}$$
$$F_{unb} = ?$$

$$F_{unb} = m_b \times a_b$$
$$= 4 \times 3$$
$$F_{unb} = 12\,\text{N}$$

Q1. Two blocks are pushed across a carpet with a constant acceleration of 0.3 ms^{-2}.



If there is a frictional force of 12N acting against the blocks, what is the size of the force exerted by the 9kg block on the 6 kg block?

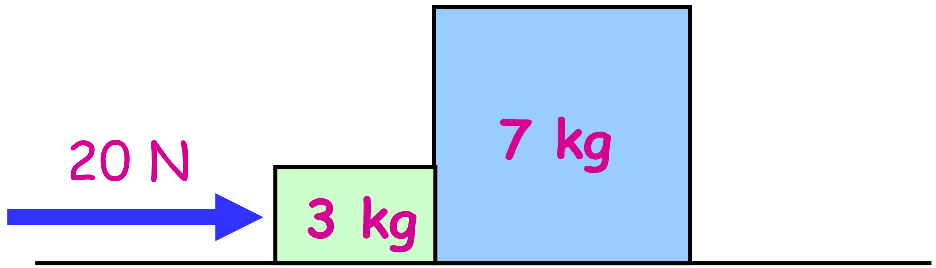
(You may assume that the frictional force is shared by the blocks in proportion to their mass).

$F_{9kg\ on\ 6kg} = 6.6\ N$

Q2. (1996 – Paper I – Higher Physics)

A horizontal force of 20N is applied as shown to two wooden blocks of masses 3 kg and 7 kg.

The blocks are in contact with each other on a frictionless surface.



What is the size of the horizontal force acting on the 7 kg block?

A 20 N

B 14 N

C 10 N

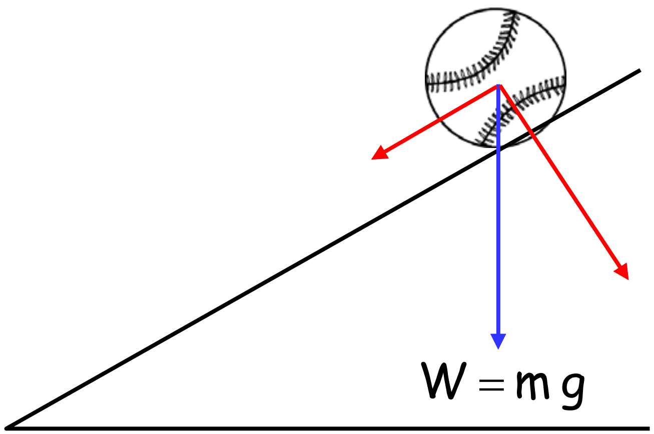
D 8 N

E 6 N

Worksheet – Mechanics & Properties of Matter Tutorial

Q69

Components of Force on a Slope



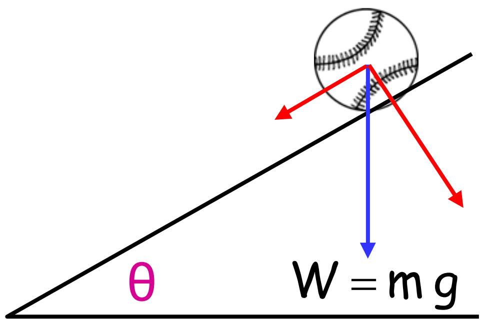
A ball will fall freely towards the earth due to its weight (W = mg).

The weight of a ball placed on a slope is split into two components.

One component is PARALLEL to the slope, the other is PERPENDICULAR to the slope.

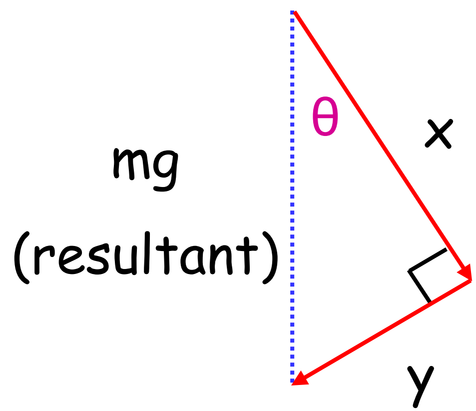
The parallel component makes the ball run down the slope.

The perpendicular component holds the ball against the slope.



Redraw vectors as a vector diagram, remembering

Vectors are joined
“ **tip-to-tail** ”



Perpendicular Component

$$\cos\theta = \frac{adj}{hyp}$$

$$\cos\theta = \frac{x}{mg}$$

$$x = m\,g\ \cos\theta$$

Parallel Component

$$\sin\theta = \frac{opp}{hyp}$$

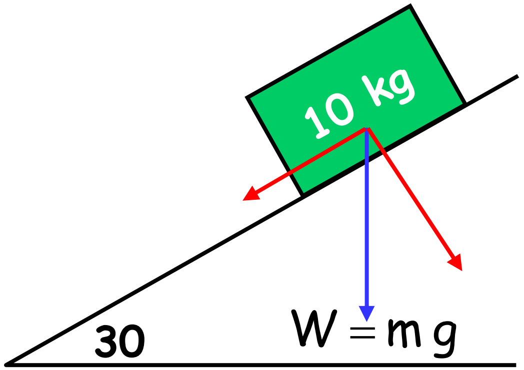
$$\sin\theta = \frac{y}{mg}$$

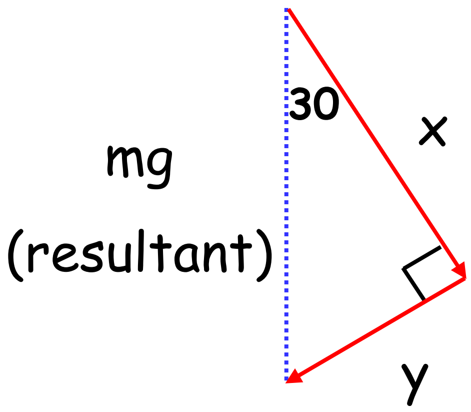
$$y = m\,g\ \sin\theta$$

Example 1

A 10 kg mass sits on a 30° slope.

Calculate the component of weight acting down the slope.





$$\sin\theta = \frac{opp}{hyp}$$

$$\sin 30 = \frac{y}{mg}$$

$$\sin 30 = \frac{y}{10 \times 9.8}$$

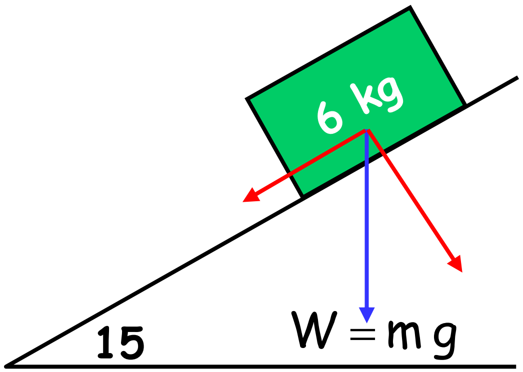
$$y = 98 \times \sin 30$$

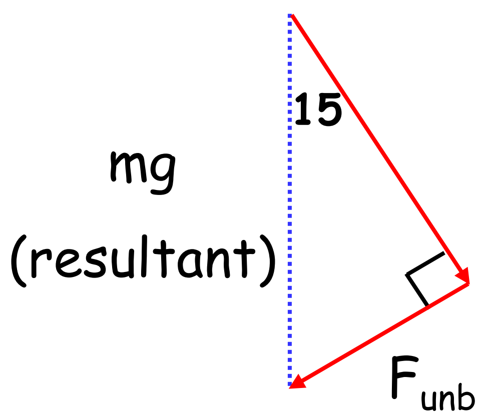
$$y = 49\,\text{N}$$

Example 2

A 6 kg block sits on a 15° frictionless slope.

Calculate the acceleration of the block.





$$\sin\theta = \frac{opp}{hyp}$$

$$\sin 15 = \frac{F_{unb}}{mg}$$

$$\sin 15 = \frac{F_{unb}}{6 \times 9.8}$$

$$F_{unb} = 58.8 \times \sin 15$$

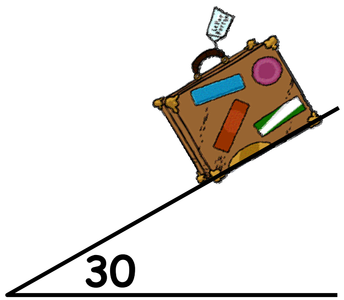
$$\underline{\underline{F_{unb} = 15.2\,\text{N}}}$$

$$F_{unb} = 15.2\text{ N}$$
$$m = 6\text{ kg}$$
$$a = ?$$

$$F_{unb} = m\,a$$
$$15.2 = 6\,a$$
$$\underline{\underline{a = 2.54\text{ ms}^{-2}}}$$

Questions

1. A 20 kg suitcase slides at a steady speed down a 30° slope.



Calculate:

(a) the component of weight down the slope 98 N

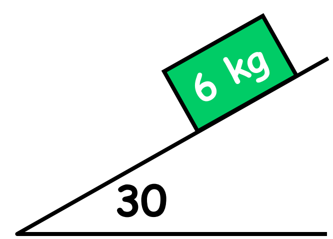
(b) the resultant unbalanced force acting on the suitcase 0 N

(c) the frictional force acting on the suitcase 98 N

2. A 6 kg block slides down a 30° slope.

The force of friction acting on the block is 8 N.

Calculate the acceleration of the block down the slope.



F down slope = 29.4 N

F unbalanced = 29.4 – 8 = 21.4 N

$a = 3.6\ ms^{-2}$

Worksheet – Mechanics & Properties of Matter Tutorial

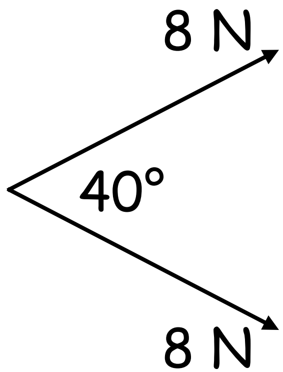
Q73, Q74 & Q75

Resultant of Two Forces

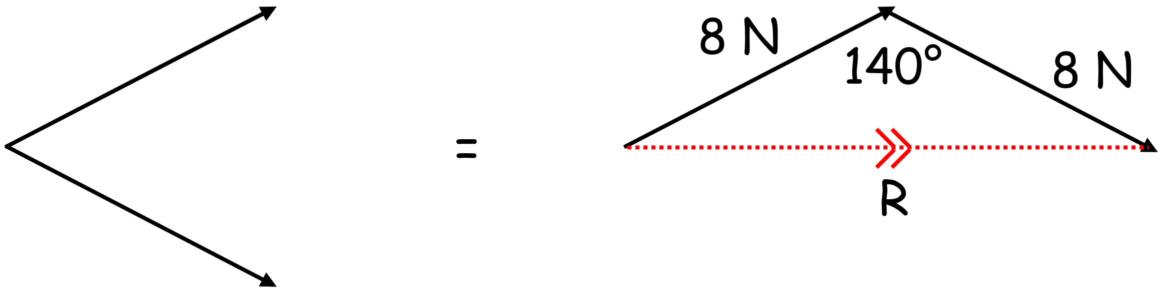
Example

Two forces act on an object as shown.

Calculate the resultant of these forces.



Method 1 (Complete Vector Diagram)



Cosine rule:

$$a^2 = b^2 + c^2 - 2bc\cos A$$

$$R^2 = 8^2 + 8^2 - (2 \times 8 \times 8\ )\cos(140^\circ)$$

$$= 64 + 64 - 128\cos(140^\circ)$$

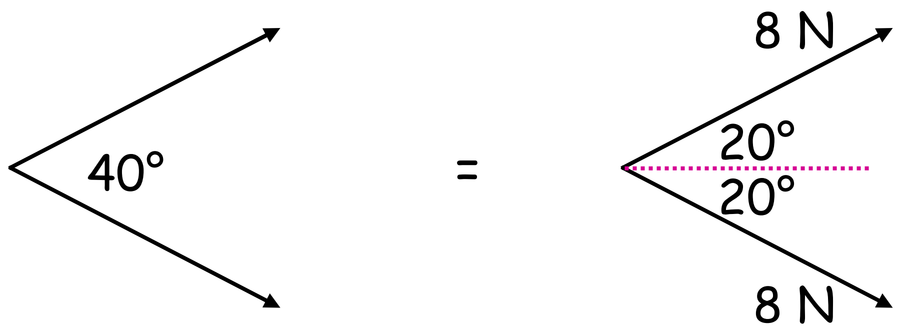
$$= 128 - 128 \times (-0.766)$$

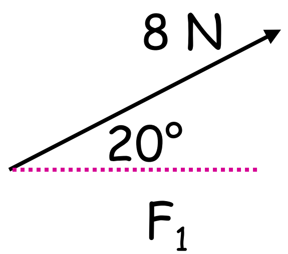
$$R^2 = 226$$

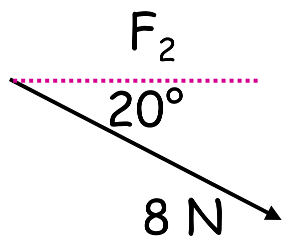
$$R = 15\,\mathrm{N}$$

Resultant force is 15 N horizontally, to the right.

Method 2 (Components)







$$\cos 20 = \frac{F_1}{8}$$

$$F_1 = 8 \times \cos 20$$

$$\underline{\underline{F_1 = 7.5\,\text{N}}}$$

$$\cos 20 = \frac{F_2}{8}$$

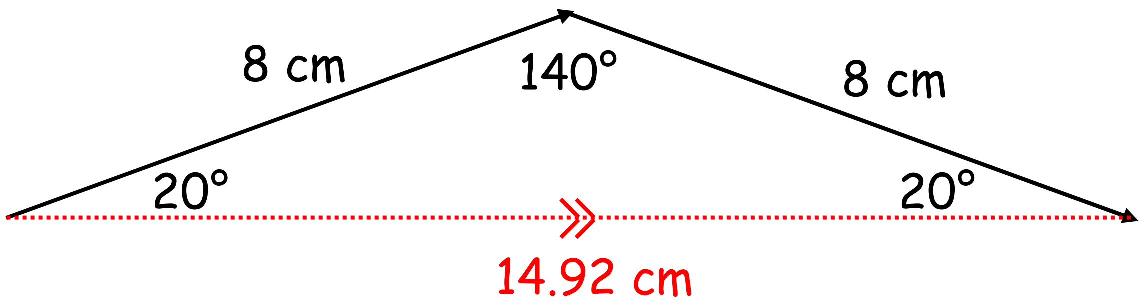
$$F_2 = 8 \times \cos 20$$

$$\underline{\underline{F_2 = 7.5\,\text{N}}}$$

Resultant force is 15 N horizontally, to the right.

Method 3 (Scale Drawing)

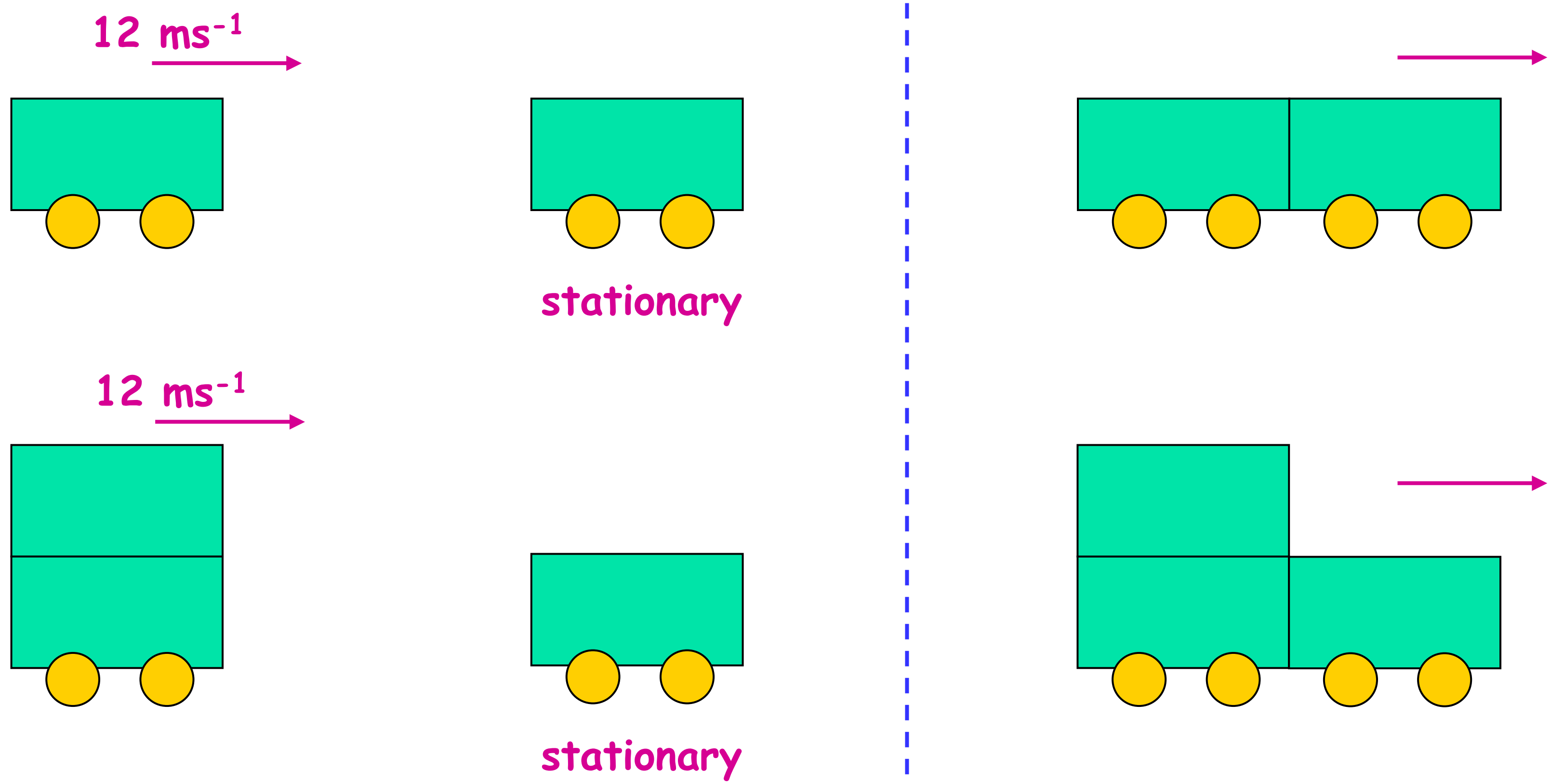
Let 1 cm represent 1 N.



Resultant force is 14.92 N horizontally, to the right.

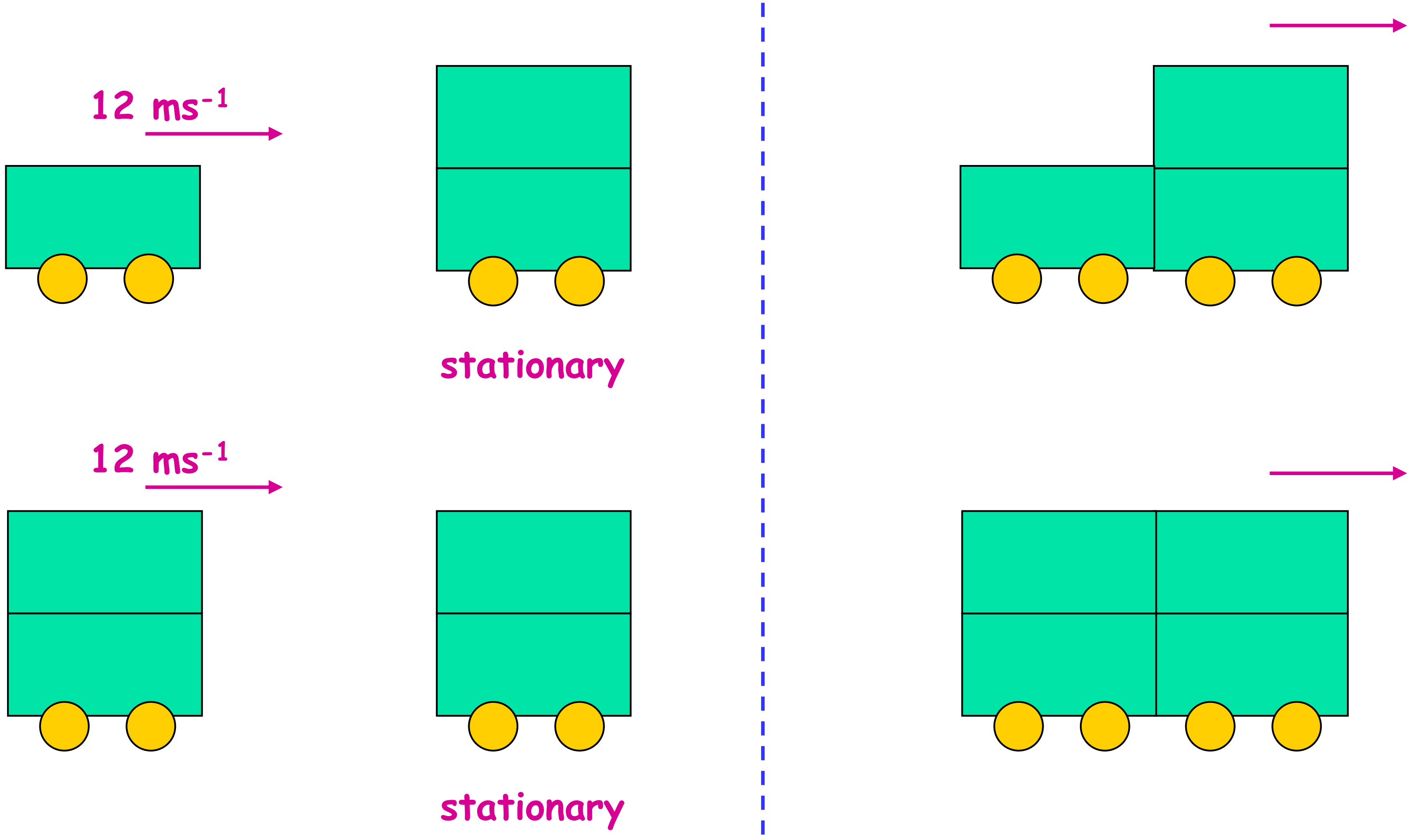
Collisions

Before Collision | **After Collision**



Before Collision

After Collision



Results

Before Collision

Mass	Velocity
1	12
2	12
1	12
2	12

After Collision

Mass	Velocity
2	6
3	8
3	4
4	6

Conclusion

BEFORE **AFTER**

mass × velocity = mass × velocity

Momentum

The MOMENTUM of an object is calculated by:

$$\boxed{p = m\,v}$$

momentum
(kg ms^{-1})

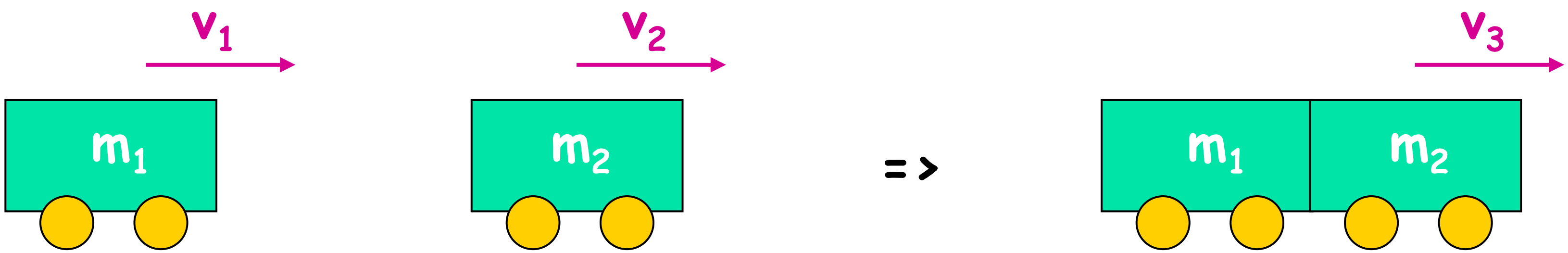
mass
(kg)

velocity
(ms^{-1})

Momentum is a vector (has both magnitude and direction).

Momentum and Collisions

The total momentum is CONSERVED in collisions provided there are no external forces (e.g. friction).



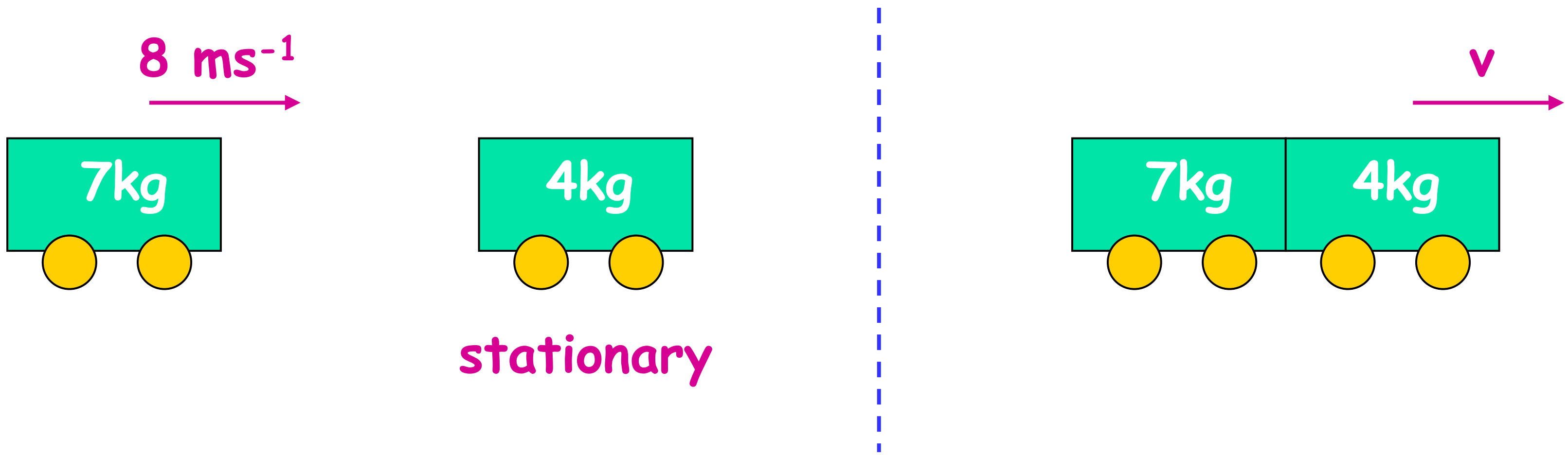
total momentum before = total momentum after

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_3$$

Example 1

A 7kg mass travelling at 8 ms^{-1} collides and sticks to a stationary 4 kg mass.

Calculate the velocity just after impact.



total momentum before = total momentum after

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_3$$

$$(7 \times 8) + (4 \times 0) = 11 v$$

$$11 v = 56$$

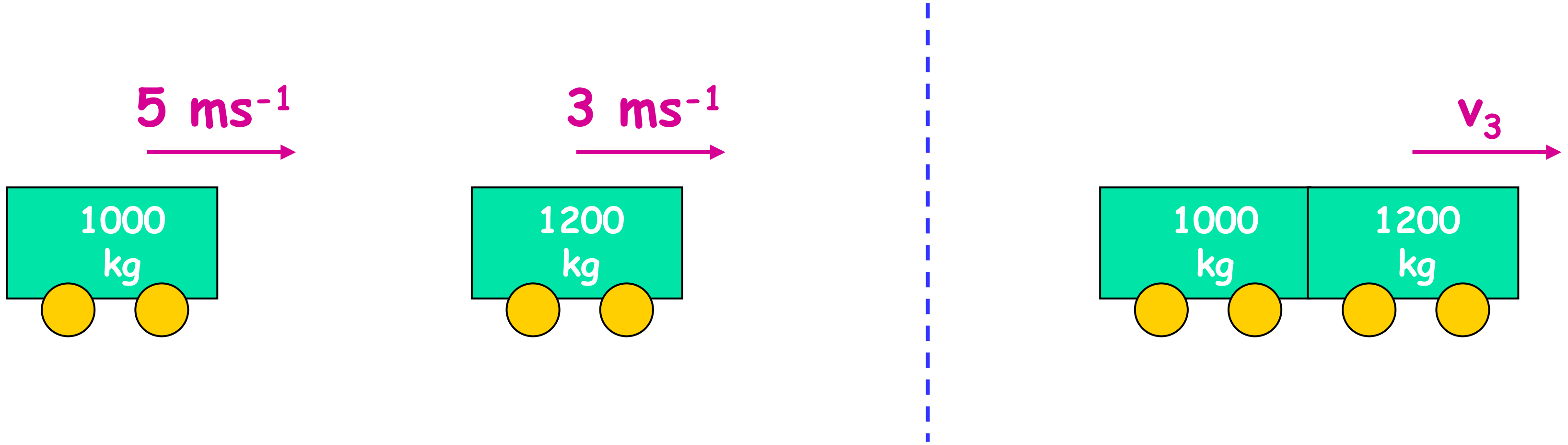
$$v = 5.1 \, ms^{-1} \text{ to the right}$$

Example 2

A car of mass 1,000 kg is travelling at 5 ms^{-1}.

It collides and joins with a 1,200 kg car travelling at 3 ms^{-1}.

Calculate the velocity of the cars just after impact.



total momentum before = total momentum after

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_3$$

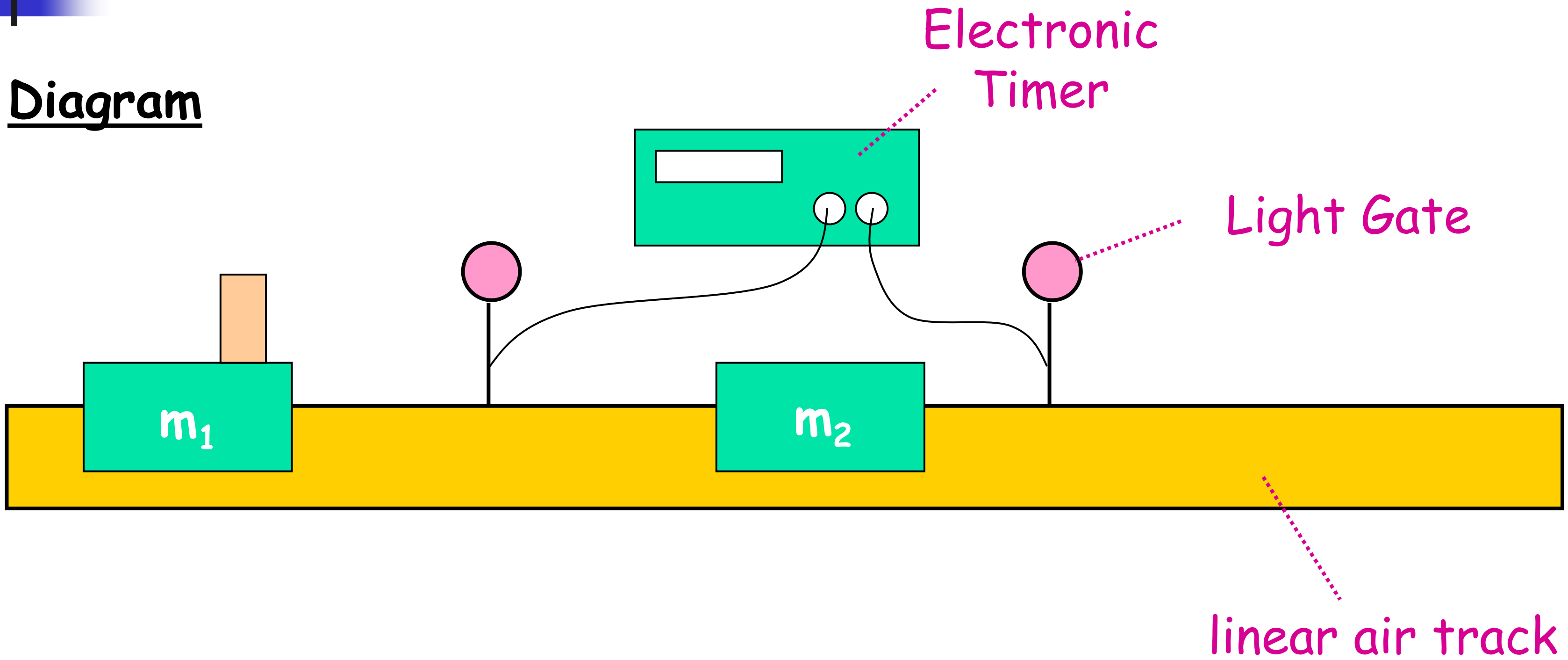
$$(1000 \times 5) + (1200 \times 3) = 2200\,v$$

$$2200\,v = 8600$$

$$v = 3.9\,ms^{-1} \text{ to the right}$$

Is Momentum Conserved?

Diagram



Procedure

Vehicle 1 is sprung along the air track.

It breaks the first light gate and a velocity is given.

It collides and sticks to the second vehicle.

They both move together and break the second light gate, giving a second velocity.

Results

$m_1 = \_\_\_\_$ kg $\qquad m_2 = \_\_\_\_$ kg $\qquad m_3 = \_\_\_\_$ kg

$v_1 = \_\_\_\_\_$ ms^{-1} $\qquad v_2 = \_\_\_\_\_$ ms^{-1} $\qquad v_3 = \_\_\_\_\_$ ms^{-1}

total momentum before $= m_1 v_1 + m_2 v_2$

$= \_\_\_\_\_\_\_\_\_\_ + \_\_\_\_\_\_\_\_\_\_$

$= \_\_\_\_\_\_\_\_\_\_$ kg ms^{-1}

total momentum after $= m_3 v_3$

$= \_\_\_\_\_\_\_\_\_\_ + \_\_\_\_\_\_\_\_\_\_$

$= \_\_\_\_\_\_\_\_\_\_$ kg ms^{-1}

Conclusion

Momentum is CONSERVED.

total momentum before = total momentum after

Elastic Collisions

KINETIC ENERGY CONSERVED

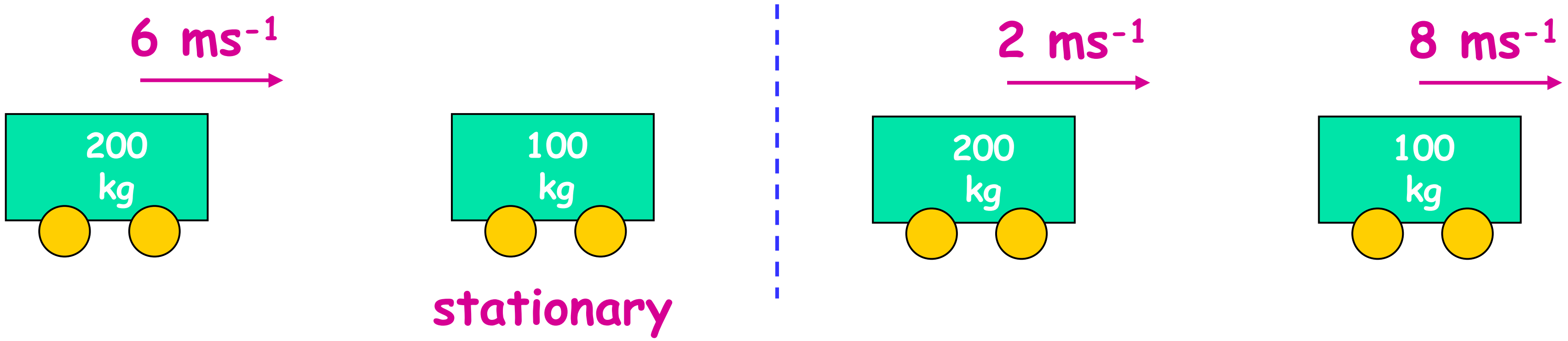
MOMENTUM CONSERVED

<u>Example 1</u>

A 200 kg vehicle is travelling at 6 ms^{-1} when it collides with a stationary 100 kg vehicle.

After the collision, the 200 kg vehicle moves off at 2 ms^{-1} and the 100 kg vehicle at 8 ms^{-1}.

Show the collision is elastic.



Momentum

Before

$$m_1 v_1 + m_2 v_2$$

$$(200 \times 6) + (100 \times 0)$$

$$1200 \text{ kg ms}^{-1}$$

After

$$m_1 v_3 + m_2 v_4$$

$$(200 \times 2) + (100 \times 8)$$

$$1200 \text{ kg ms}^{-1}$$

Momentum has been conserved.

Kinetic Energy

Before

$$E_K = \frac{1}{2} m v^2$$

$$= \left(\frac{1}{2} \times 200 \times 6^2\right) + \left(\frac{1}{2} \times 100 \times 0^2\right)$$

$$E_K = 3600 \text{ J}$$

After

$$E_K = \frac{1}{2} m v^2$$

$$= \left(\frac{1}{2} \times 200 \times 2^2\right) + \left(\frac{1}{2} \times 100 \times 8^2\right)$$

$$E_K = 3600 \text{ J}$$

Kinetic Energy has been conserved.

As momentum and kinetic energy are conserved, ELASTIC collision.

Inelastic Collisions

Kinetic Energy NOT Conserved

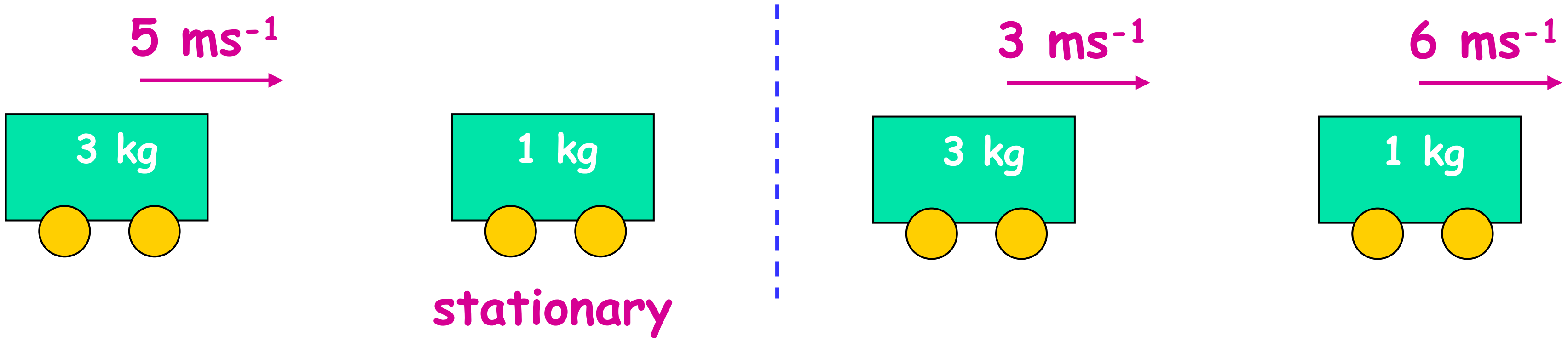
MOMENTUM CONSERVED

Example 1

A trolley of mass 3 kg is travelling at 5 ms^{-1} when it collides with a stationary 1 kg trolley.

Afterwards, they move off at 3 ms^{-1} and 6 ms^{-1} respectively.

Show that this collision is inelastic.



Momentum

Before

$m_1 v_1 + m_2 v_2$

$(3 \times 5) + (1 \times 0)$

15 kg ms^{-1}

After

$m_1 v_3 + m_2 v_4$

$(3 \times 3) + (1 \times 6)$

15 kg ms^{-1}

Momentum has been conserved.

Kinetic Energy

Before

$$E_K = \frac{1}{2} m v^2$$

$$= \left(\frac{1}{2} \times 3 \times 5^2\right) + \left(\frac{1}{2} \times 1 \times 0^2\right)$$

$$E_K = 37.5 \text{ J}$$

After

$$E_K = \frac{1}{2} m v^2$$

$$= \left(\frac{1}{2} \times 3 \times 3^2\right) + \left(\frac{1}{2} \times 1 \times 6^2\right)$$

$$E_K = 31.5 \text{ J}$$

Kinetic Energy has NOT been conserved.

As momentum is conserved and kinetic is not, INELASTIC collision.

TOTAL ENERGY is always CONSERVED

total energy = kinetic energy + heat energy + sound energy

Note

In reality, most collisions are inelastic.

Some of the kinetic energy is converted to heat and sound energy on impact.

Head On Collisions

Head on collisions involve objects travelling in opposite directions.

One direction is POSITIVE, the other then has to be NEGATIVE.

Example 1

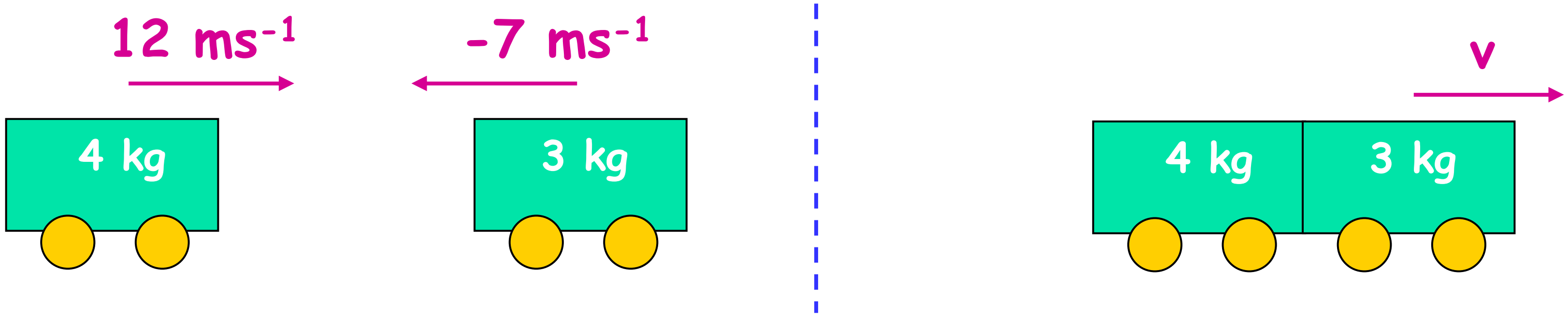
A 4 kg object travels at 12 ms^{-1} and collides head on with a 3 kg object travelling with a speed of 7 ms^{-1}.

After the collision, they both move off together.

(a) calculate the velocity of the objects just after impact.

(b) determine whether the collision is elastic or inelastic.

(a)



total momentum before = total momentum after

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v$$

$$(4 \times 12) + (3 \times (-7)) = (4 + 3) v$$

$$7v = 48 - 21$$

$$7v = 27$$

$$\underline{\underline{v = 3.86 \text{ ms}^{-1} \text{ to the right}}}$$

(b) **Kinetic Energy**

Before

$$E_K = \frac{1}{2} m v^2$$

$$= \left(\frac{1}{2} \times 4 \times 12^2\right) + \left(\frac{1}{2} \times 3 \times (-7)^2\right)$$

$$= 288 + 73.5$$

$$E_K = 361.5\ J$$

After

$$E_K = \frac{1}{2} m v^2$$

$$= \left(\frac{1}{2} \times 7 \times 3.86^2\right)$$

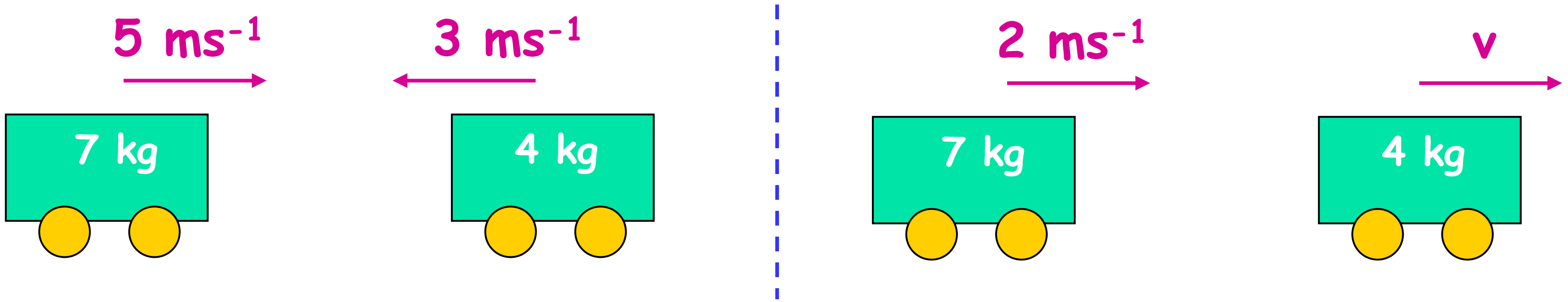
$$E_K = 52.1\ J$$

Kinetic Energy has NOT been conserved.

INELASTIC collision.

Example 2

Two objects collide as shown.



(a) Calculate the velocity at which the 4 kg object moves, just after impact.

(b) Determine whether the collision is elastic or inelastic.

(a)

total momentum before = total momentum after

$$m_1 v_1 + m_2 v_2 = m_1 v_3 + m_2 v_4$$

$$(7 \times 5) + (4 \times (-3)) = (7 \times 2) + (4 \times v)$$

$$35 - 12 = 14 + 4v$$

$$23 - 14 = 4v$$

$$4v = 9$$

$$v = 2.25\ ms^{-1} \text{ to the right}$$

(b) **Kinetic Energy**

Before

$$E_K = \frac{1}{2} m v^2$$

$$= \left(\frac{1}{2} \times 7 \times 5^2\right) + \left(\frac{1}{2} \times 4 \times (-3)^2\right)$$

$$= 87.5 + 18$$

$$E_K = 105.5 \text{ J}$$

After

$$E_K = \frac{1}{2} m v^2$$

$$= \left(\frac{1}{2} \times 7 \times 2^2\right) + \left(\frac{1}{2} \times 4 \times 2.25^2\right)$$

$$= 14 + 10.13$$

$$E_K = 24.13 \text{ J}$$

Kinetic Energy has NOT been conserved.

INELASTIC collision.

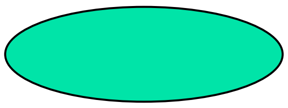
Explosions

In all explosions:

MOMENTUM CONSERVED

BEFORE

AFTER



$$\boxed{\text{total momentum before} = \text{total momentum after}}$$

$$m\,v = m_1 v_1 + m_2 v_2$$

$$0 = m_1 (-v_1) + m_2 v_2$$

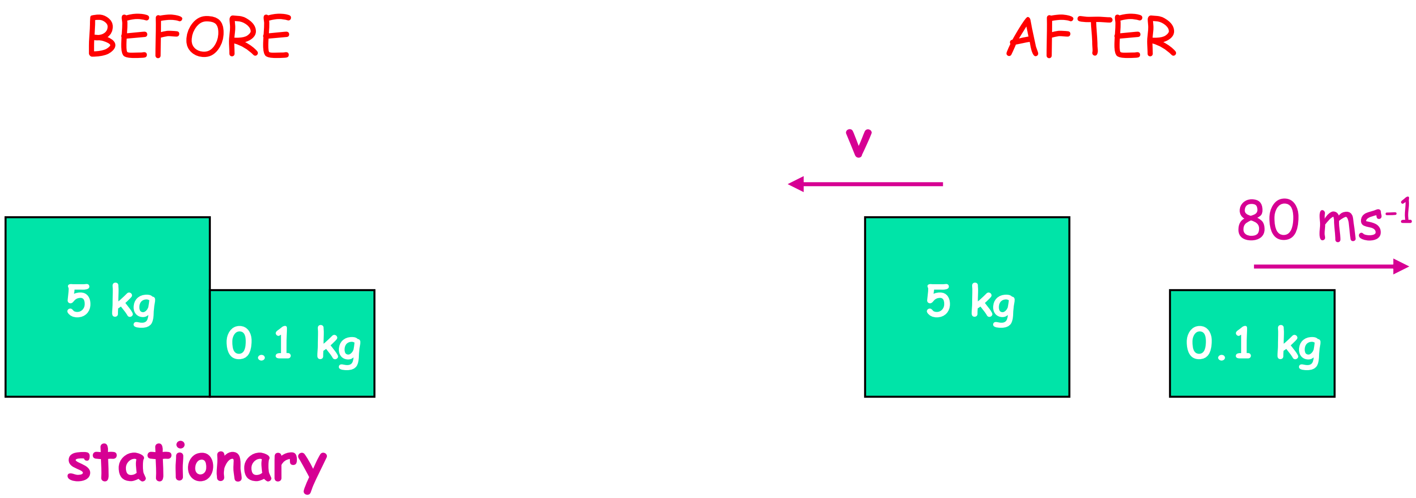
$$0 = -m_1 v_1 + m_2 v_2$$

Example 1

A 5 kg gun fires a 0.1 kg shell at 80 ms^{-1}.

The gun recoils after firing the shell.

Calculate the recoil speed of the gun.



total momentum before = total momentum after

$$m\,v = m_1\,v_1 + m_2\,v_2$$

$$0 = 5(-v) + (0.1 \times 80)$$

$$5v = 8$$

$$v = 1.6\ \text{ms}^{-1} \quad \text{backwards}$$

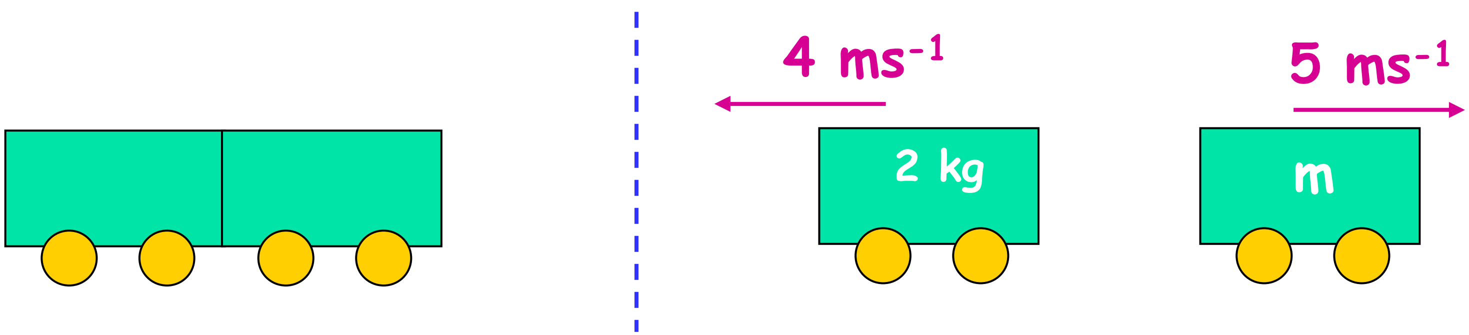
Example 2

Two trolleys initially at rest and touching, fly apart when the plunger is released.

One trolley with a mass of 2 kg moves off with a speed of 4 ms^{-1}.

The other trolley moves off in the opposite direction with a speed of 5 ms^{-1}.

Calculate the mass of this trolley.



total momentum before = total momentum after

$$m\,v = m_1 v_1 + m_2 v_2$$

$$0 = 2 \times (-4) + (m \times 5)$$

$$5m = 8$$

$$\underline{\underline{m = 1.6\,\text{kg}}}$$

Impulse 1

Consider the following equations:

$$\boxed{F = m\,a}$$

$$\boxed{a = \frac{v-u}{t}}$$

Combining these equations:

$$F = m\,a$$

$$F = \frac{m\,(v-u)}{t}$$

$$F\,t = mv - mu$$

IMPULSE (F t) = CHANGE IN MOMENTUM (mv – mu)

$$\boxed{F\,t = mv - mu}$$

force (N)

time (s)

mass (kg)

final velocity (ms^{-1})

initial velocity (ms^{-1})

IMPULSE is the product of the FORCE and TIME during which it acts.

The units of impulse are N s (Newton Seconds).

Impulse is a vector quantity.

The unit of change in momentum is kg ms^{-1}.

Example 1

A golf ball of mass 50 g is hit off the tee at 30 ms^{-1}.

The time of contact between club and ball is 25 ms (milliseconds).

Calculate the average force exerted on the ball.

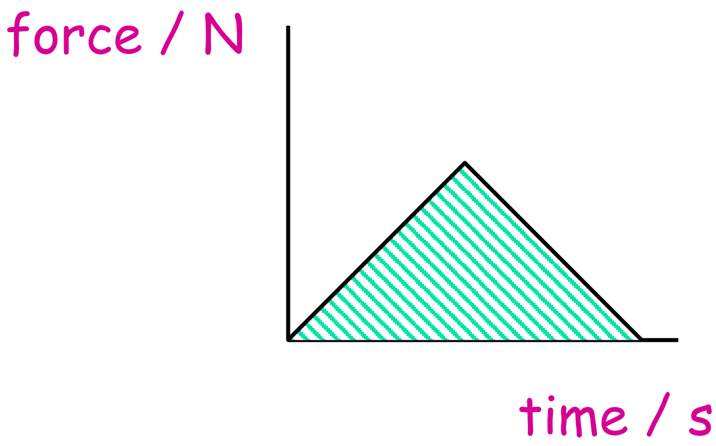
$$m = 50\ g$$
$$= 0.05\ kg$$
$$u = 0\ ms^{-1}$$
$$v = 30\ ms^{-1}$$
$$t = 25\ ms$$
$$= 25 \times 10^{-3}\ s$$

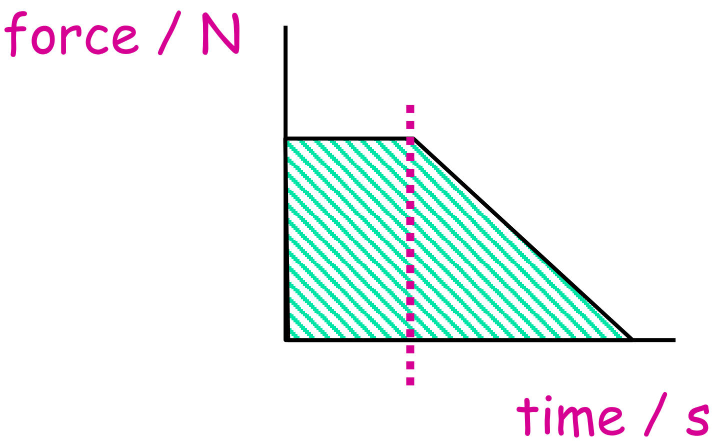
$$F\,t = mv - mu$$
$$F \times \left(25 \times 10^{-3}\right) = (0.05 \times 30) - (0.05 \times 0)$$
$$F = \frac{1.5}{25 \times 10^{-3}}$$
$$F = 60\ N$$

Worksheet - Impulse 1

Impulse 2

The area under a force time-graph is equal to the impulse.



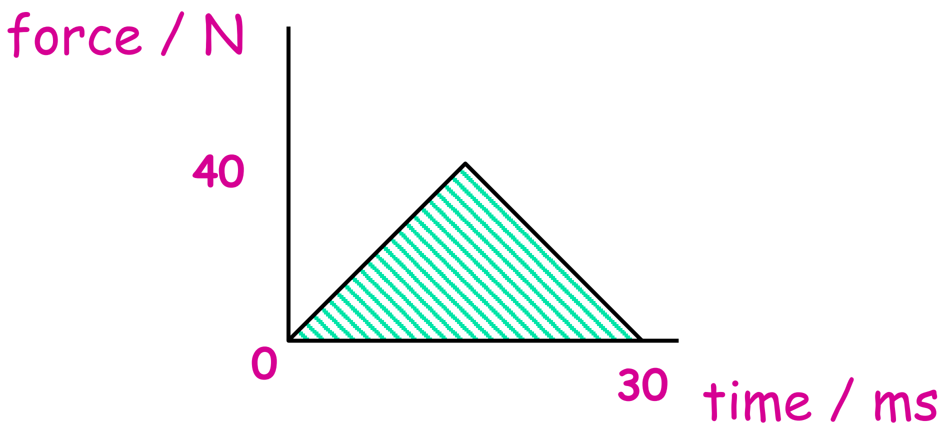


$$\text{impulse} = \text{area under graph} = \frac{1}{2} \times b \times h$$

$$\text{impulse} = \text{area under graph} = l \times b + \frac{1}{2} \times b \times h$$

Example 1

A 50 g golf ball is hit off the tee by a force which varies with time as shown.



Calculate the speed of the golf ball off the tee.

$$\text{impulse} = \text{area under graph}$$

$$= \frac{1}{2} \times b \times h$$

$$= \frac{1}{2} \times \left(30 \times 10^{-3}\right) \times 40$$

$$= 0.6 \text{ N s}$$

$$\text{impulse} = mv - mu$$

$$0.6 = 0.05v - 0.05 \times 0$$

$$0.05v = 0.6$$

$$v = \frac{0.6}{0.05}$$

$$v = 12 \text{ ms}^{-1}$$

Worksheet – Impulse 2

Change In Momentum

Air Bags

A passenger in a car involved in a collision will experience a force which will bring him to a stop.

NO Air Bag

- Head hits hard object eg. steering wheel
- In contact for a short time
- Large force involved
- Lots of Damage

AIR BAG

- Head hits air bag
- In contact for a longer time
- Smaller force involved
- Less damage

In both cases the change in momentum and therefore the impulse are the same.

However, the force-time graphs will differ in shape although the area under the line will be the same.

NO Air Bag

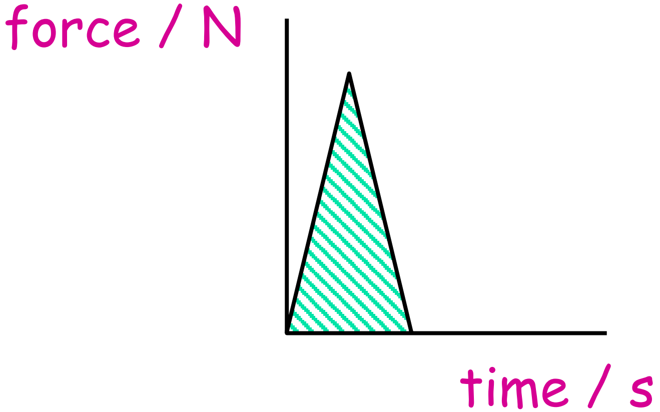
Large force.

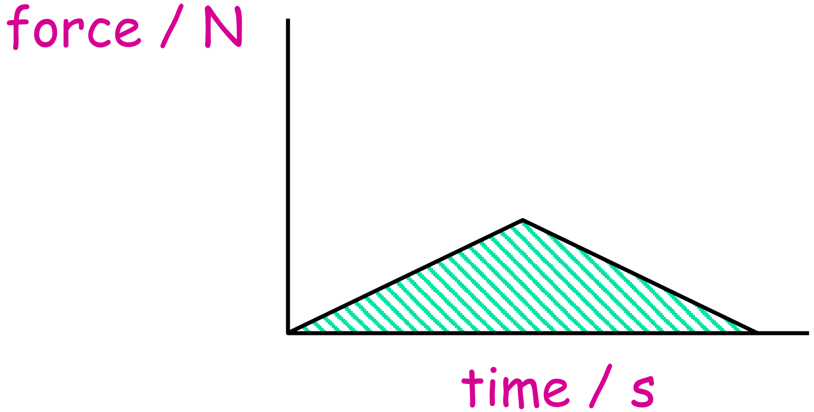
Short time.

AIR BAG

Small force.

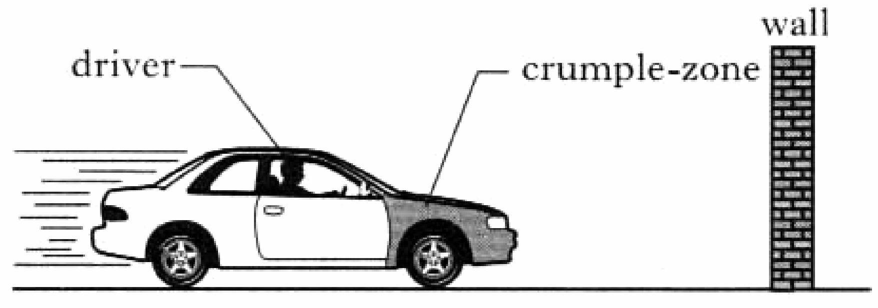
Long time.





Crumple Zone

A car is designed with a "crumple zone" so that the front of the car collapses during impact.



The purpose of the crumple-zone is to

A decrease the driver's change in momentum per second

B increase the driver's change in momentum per second

C decrease the driver's final velocity

D increase the driver's total change in momentum

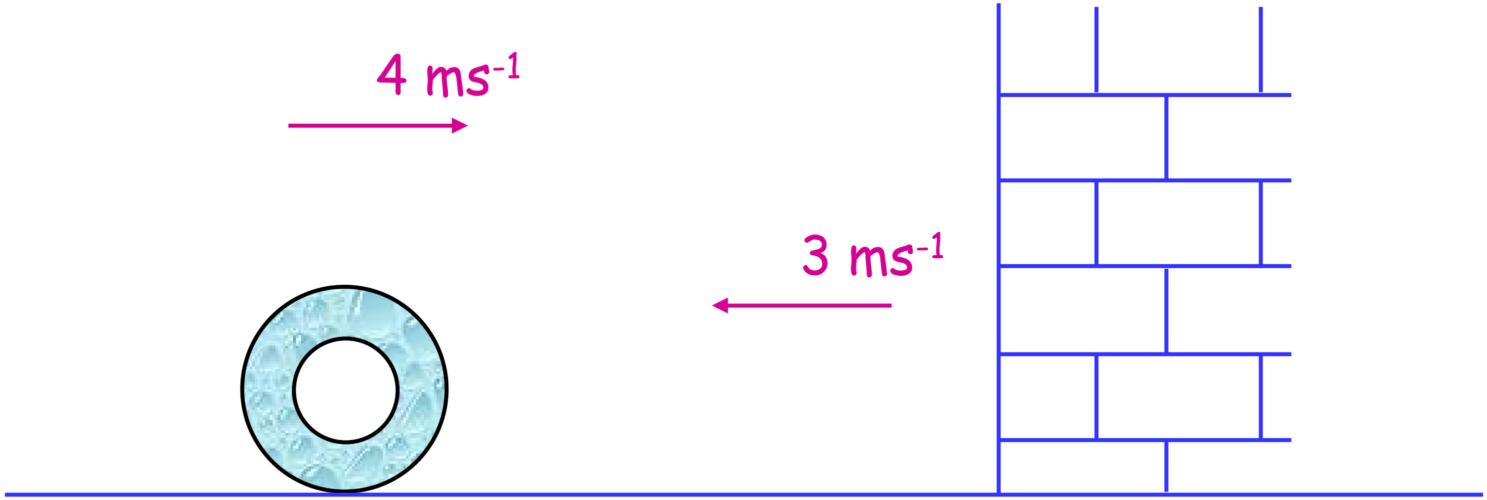
E decrease the driver's total change in momentum.

Less damage is caused if the change in momentum is over a long period of time.

Rebounds

Example 1

A 5 kg tyre hits a wall at 4 ms^{-1} and rebounds at 3 ms^{-1}.

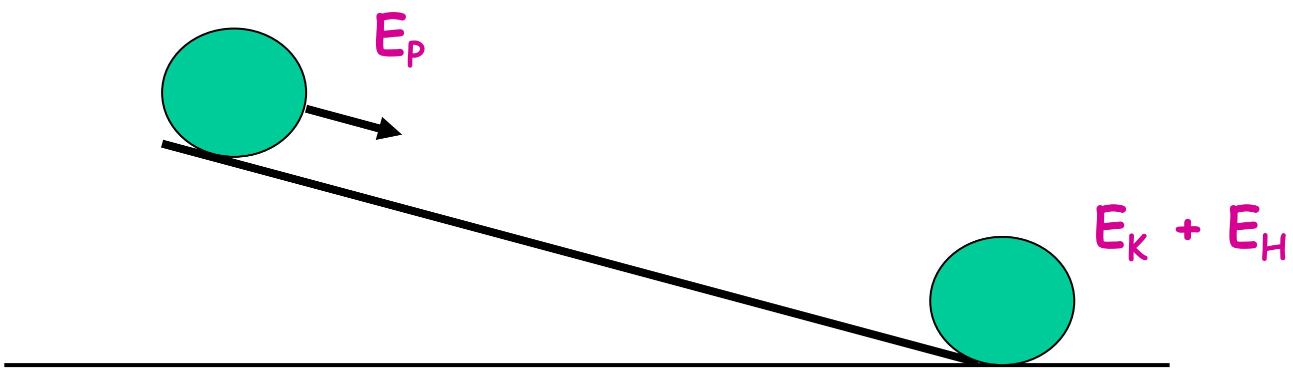


Calculate the change in momentum of the tyre.

$$\begin{aligned}\text{change in momentum} &= mv - mu \\ &= 5\times(-3) - 5\times 4 \\ &= -15 - 20 \\ &= -35\ \text{kg ms}^{-1}\end{aligned}$$

Conservation of Energy

Energy cannot be created or destroyed.



TOTAL ENERGY is CONSERVED

$$E_P = E_K + E_H$$

Equations Needed (Standard Grade)

work done (J)

$$\boxed{E_W = F\,d}$$

distance (m)

force (N)

power (W)

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

energy (J)

time (s)

$$\boxed{E_P = m\,g\,h}$$

potential energy (J)

height (m)

mass (kg)

gravitational field strength ($N\,kg^{-1}$)

$$\boxed{E_K = \frac{1}{2} m\,v^2}$$

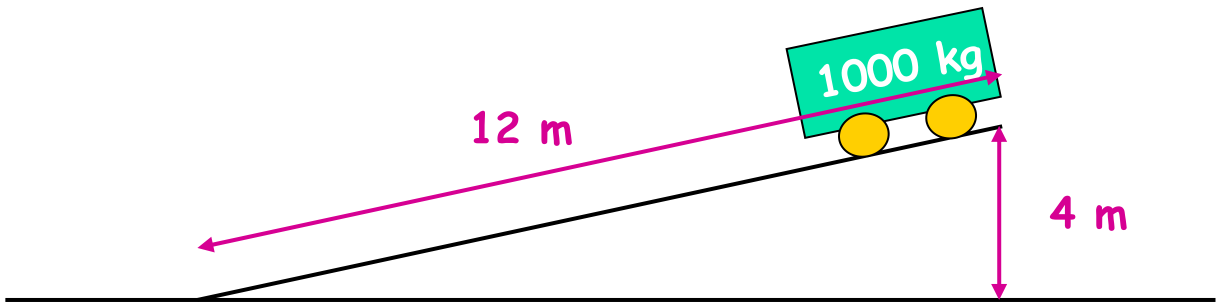
kinetic energy (J)

velocity (ms^{-1})

mass (kg)

Example 1

A car of mass 1000 kg sits at the top of a hill as shown.



The car rolls down the slope with a speed of 5 ms^{-1} to the bottom of the slope.

(a) Calculate the potential energy of the car at the top of the slope.

$$m = 1000\ kg$$
$$h = 4\ m$$
$$g = 9.8\ N\,kg^{-1}$$
$$E_P = ?$$

$$E_P = m\,g\,h$$
$$= 1000 \times 9.8 \times 4$$
$$E_P = 39{,}200\ J$$

(b) Calculate car's kinetic energy at the bottom of the slope.

$$m = 1000 \text{ kg}$$
$$v = 5 \text{ ms}^{-1}$$
$$E_K = ?$$

$$E_K = \frac{1}{2} m v^2$$
$$= \frac{1}{2} \times 1000 \times 5^2$$
$$\underline{\underline{E_K = 12{,}500 \text{ J}}}$$

(c) Calculate how much work has been done against friction as the car runs down the slope.

$$\text{work against friction} = 39{,}200 - 12{,}500$$
$$\underline{\underline{= 26{,}700 \text{ J}}}$$

(d) Calculate the average force of friction on the car as it runs down the slope.

$$E_W = 26{,}700\ \text{J}$$
$$d = 12\ \text{m}$$
$$F = ?$$

$$E_W = F\,d$$
$$26{,}700 = 12\,F$$
$$\underline{\underline{F = 2{,}225\ \text{N}}}$$

(e) Explain what happens to the 26,700 J of energy as the car runs down the slope.

The 26,700 J of energy is changed to **HEAT ENERGY** in overcoming friction.

Pulley Systems

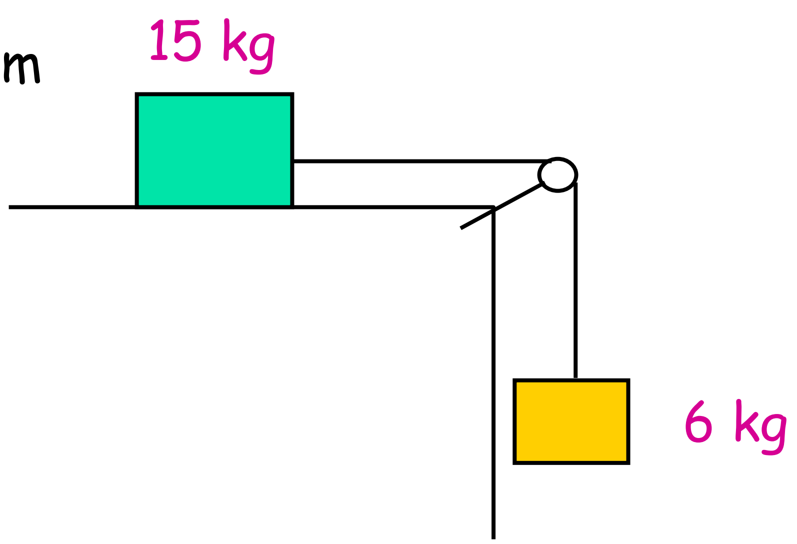
Example 1

A 15 kg mass and a 6 kg mass are linked by a light string and connected via a frictionless pulley.

Assuming the 15 kg mass is on a frictionless surface, calculate:

(a) the acceleration of the system

(b) the tension in the string.



(a) The unbalanced force is the force of gravity acting on the 6 kg mass.

$$m = 6\,\text{kg}$$
$$a = 9.8\,\text{ms}^{-2}$$
$$F_{unb} = ?$$

$$F_{unb} = m\,a$$
$$= 6 \times 9.8$$
$$\underline{\underline{F_{unb} = 58.8\,\text{N}}}$$

This unbalanced force is pulling on the two masses:

$$F_{unb} = 58.8\,\text{N}$$
$$m = 21\,\text{kg}$$
$$a = ?$$

$$F_{unb} = m\,a$$
$$58.8 = 21\,a$$
$$a = \frac{58.8}{21}$$
$$\underline{\underline{a = 2.8\,\text{ms}^{-2}}}$$

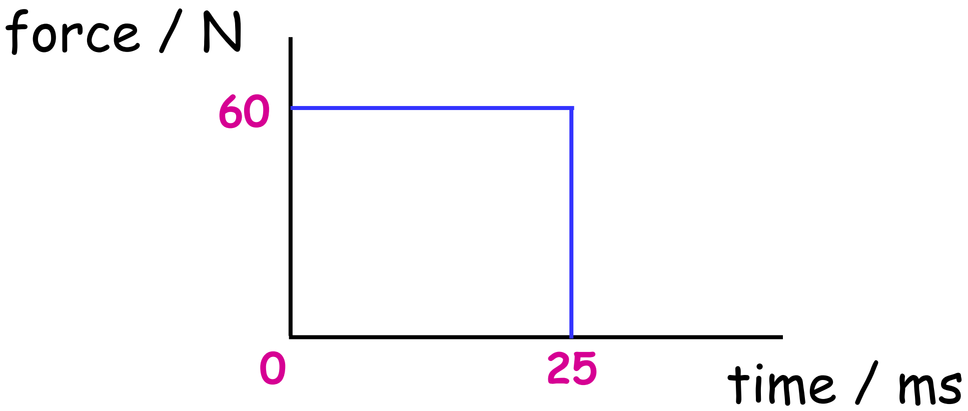
(b) Now using acceleration of the system, calculate the tension caused by the 15 kg mass.

$$m = 15\,\text{kg}$$
$$a = 2.8\,\text{ms}^{-2}$$
$$F_T = ?$$

$$F_T = m\,a$$
$$= 15 \times 2.8$$
$$F_T = 42\,\text{N}$$

NOTE:

The force of 60 N is assumed to be constant during the 25 ms.



In practice, the force

Worksheet – Dynamics Problems

?????????