

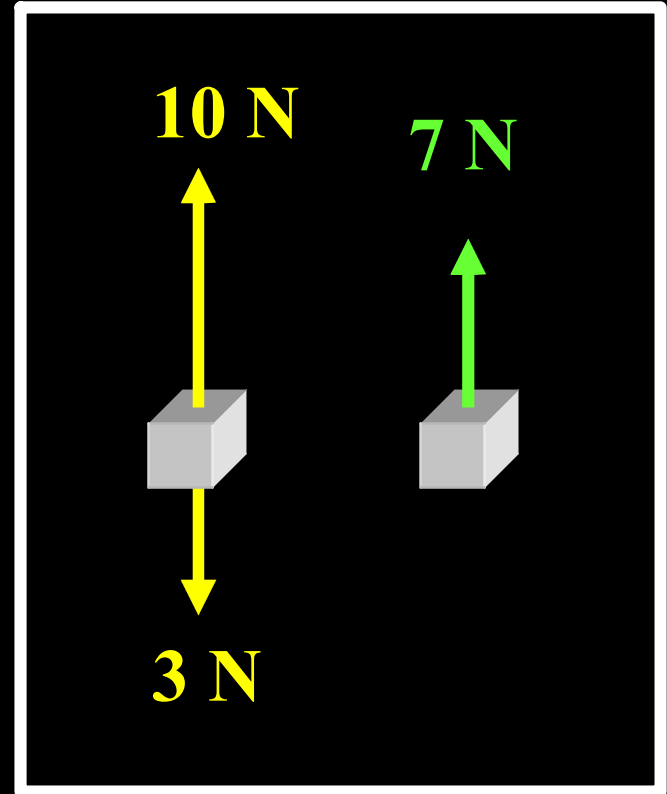
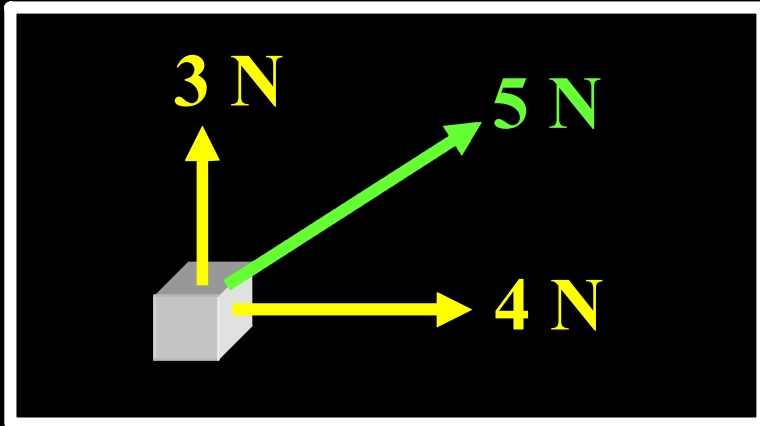
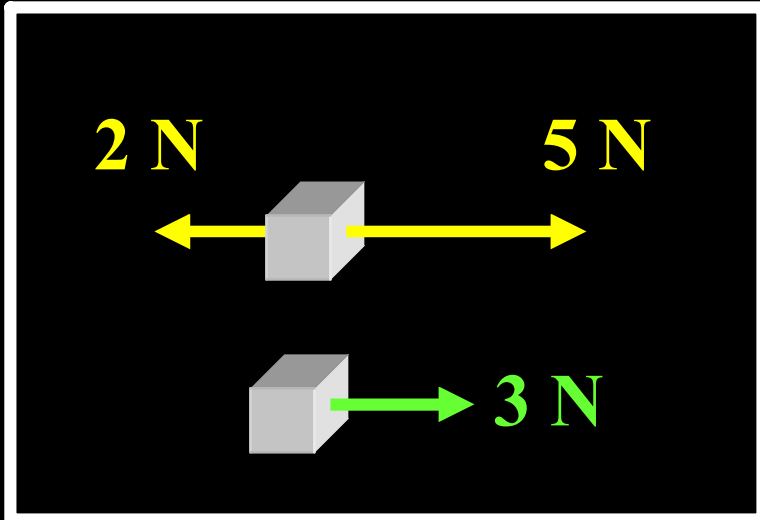
Chapter 9

Force

Mass

Momentum

Resultant Force



When a resultant force acts on a body ...
the velocity of the body will change

The body will ... **speed up**
slow down
or **change direction**

The body will accelerate



Resultant Force

Speed changes



4.8 seconds

0 to 100 km h⁻¹

Engine force ...

Direction changes



Centripetal Force ...

Tyres

Ferrari

Force

That which causes ...

... the velocity of a body to change

or

That which causes ...

... a body to accelerate

Mass

A measure of how difficult it is
to accelerate a body

Mass is a scalar

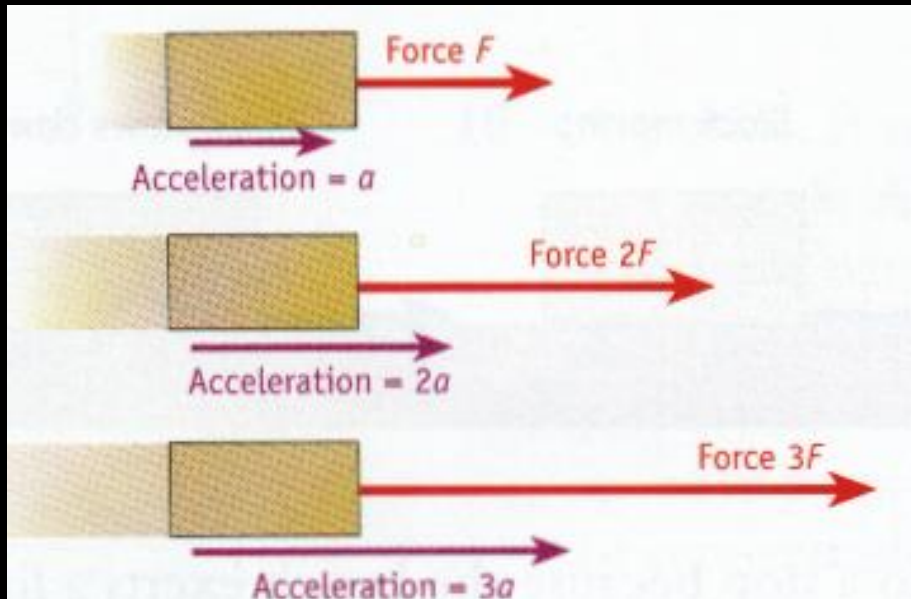
... it has magnitude only

Symbol: m

Unit: kg

Acceleration and Force

Changing the force ...



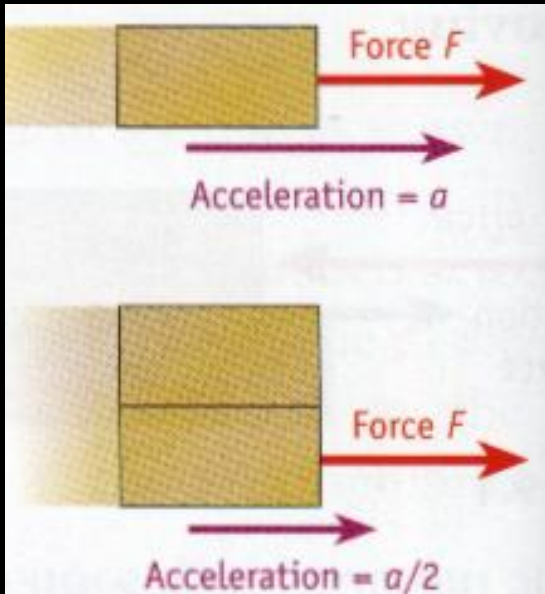
Acceleration
is directly proportional to
Force

$$a \propto F$$

(fixed m)

Acceleration and Force

Changing the mass ...



Acceleration
is inversely proportional to
Mass

$$a \propto 1/m$$

(fixed F)

Acceleration and Force

$$a \propto F$$
$$a \propto \frac{1}{m}$$

$$\Rightarrow a \propto \frac{F}{m}$$

$$\Rightarrow a = k \frac{F}{m}$$

$$\Rightarrow F = k m a$$

Later ...

$k = 1$, therefore ...

$$F = m a$$

FORCE

That which causes ...

... the velocity of a body to change

or

That which causes ...

... a body to accelerate

Force is a Vector

... it has magnitude and direction

Symbol: F

Units: N

FORCE

Vector ... it has magnitude and direction

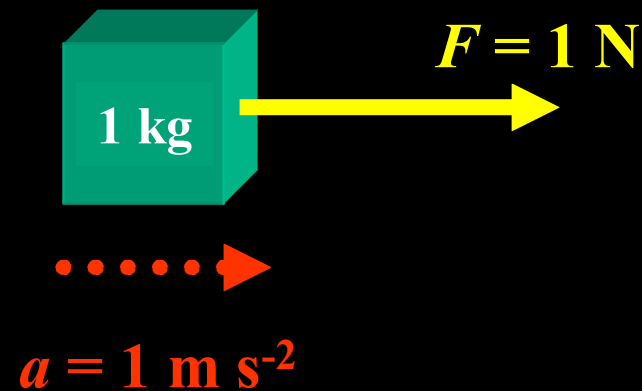
Symbol: F

Units: N

Definition of the Newton:

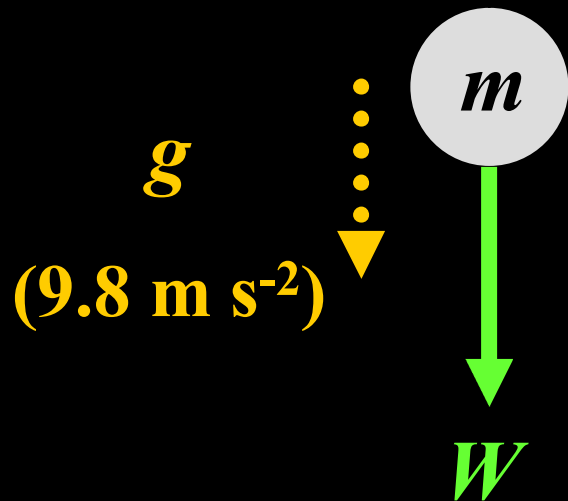
**1 N is the force
that gives a mass of 1 kg
an acceleration of 1 m s⁻²**

$$(F = ma)$$



Weight and Mass

Weight = the force of the earth's gravity



$$F = m a$$

$$W = m g$$

$$W = m g$$

Weight and Mass

What is the weight of a 1 kg bag of sugar?

$$W = mg$$

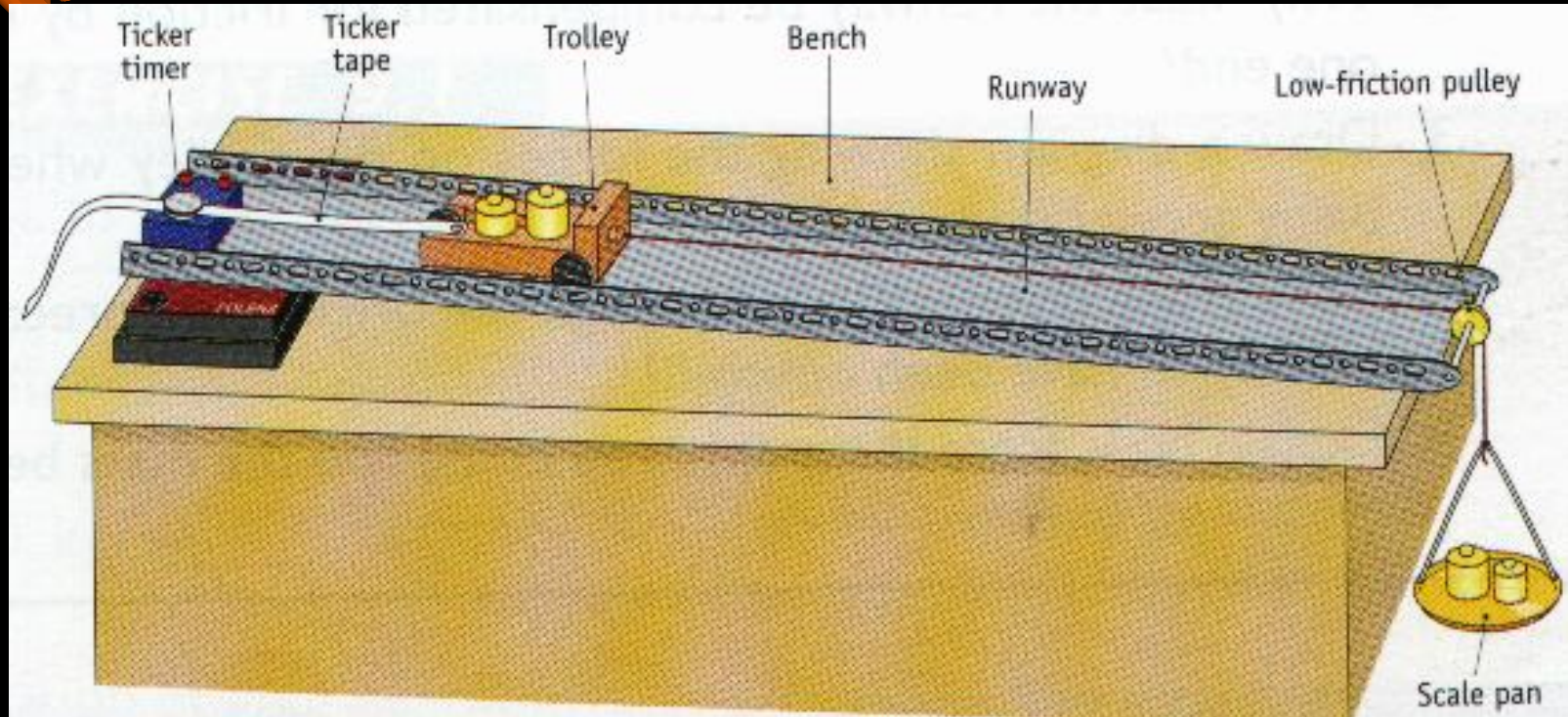
$$W = 1 \times 9.8$$

$$W = 9.8 \text{ N}$$



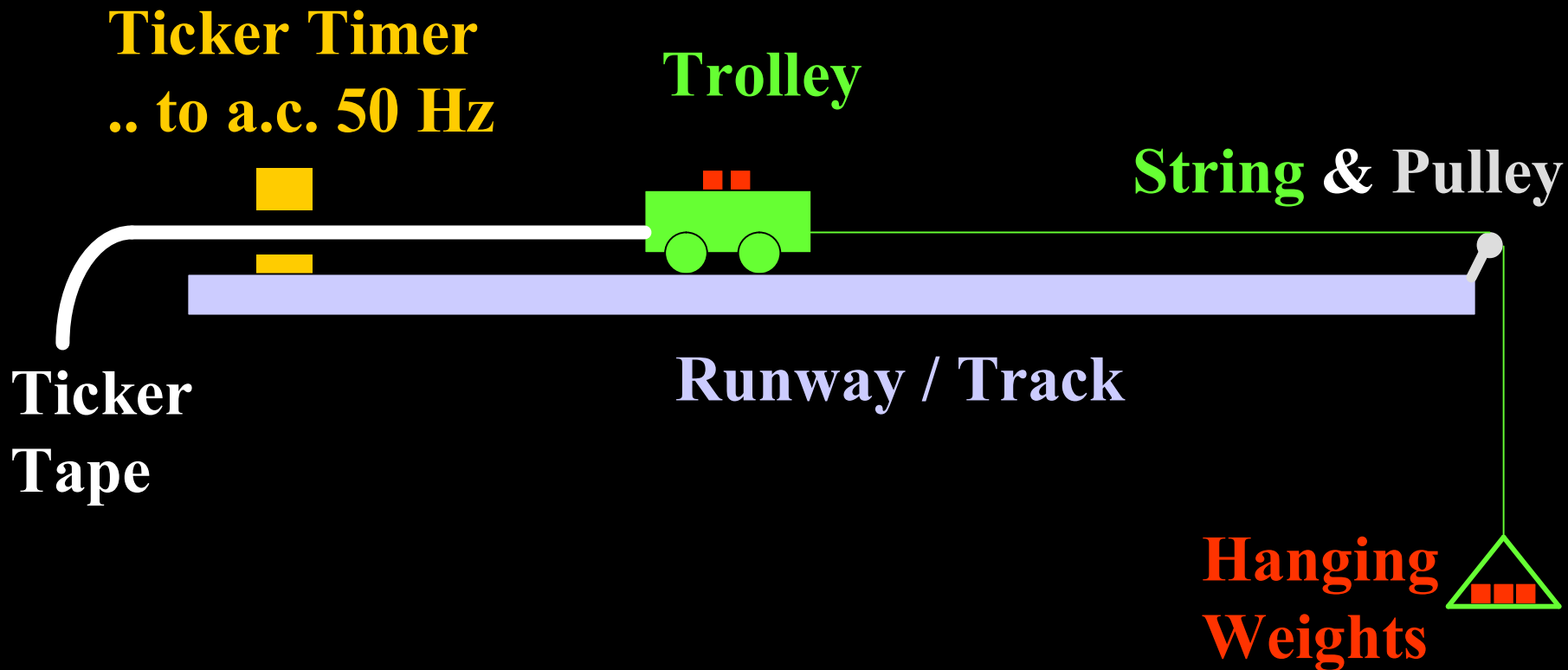
Experiment: To Show that $a \propto F$

Apparatus



Experiment: To Show that $a \propto F$

Apparatus



Procedure

1. Release trolley ... accelerates ... pattern of dots on ..
Repeat using other weights in pan.

2. Measure ...
... force (F) & acceleration (a)

3. $F = \text{Weight of (pan + weights)}$

$$a = \frac{v - u}{t} \quad \text{where} \quad u = \frac{s_1}{3/50}, \quad v = \frac{s_2}{3/50}, \quad t = (n \times 1/50)$$

4. Repeat ... other weights in pan ... to graph

F / N	a / m s⁻²	a ÷ F
1	0.20	0.20
2	0.39	0.20
3	0.59	0.20
4	0.82	0.21
5	1.00	0.20
6	1.24	0.21
7	1.43	0.20
8	1.58	0.20

$$\frac{a}{F} = a \text{ constant}$$

$$\Rightarrow a \propto F$$

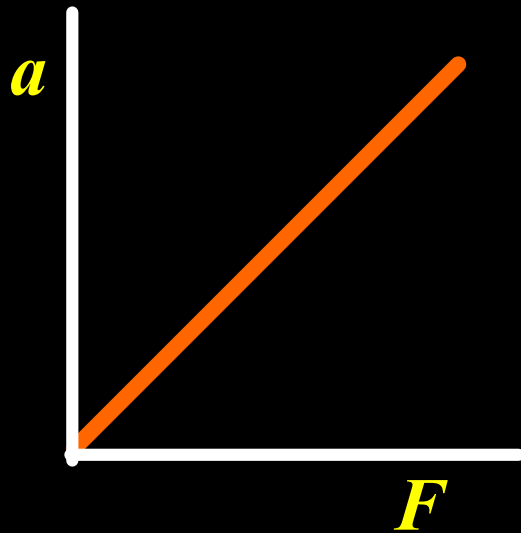
Results

Method 1

Results

Method 2

F / N	$a / \text{m s}^{-2}$
1	0.20
2	0.39
3	0.59
4	0.82
5	1.00
6	1.21
7	1.43
8	1.58



“SLTO”

$$\Rightarrow a \propto F$$

Precautions

1. Wedge to ...
2. Keep mass of system constant. How ??
3. Oil ... Why ??
4. Have u and v patches well separated. Why ??
5. Etc.

P4 A force of 20 N acts on a body of mass 5 kg which is at rest. What is the velocity of the body after 8 s?

$$v = u + at \quad = 0 + a(8)$$

$$F = ma \Rightarrow a = \frac{F}{m} = \frac{20}{5} = 4.0 \text{ m s}^{-2}$$

$$v = u + at \quad = 0 + (4.0)(8) = 32 \text{ m s}^{-1}$$

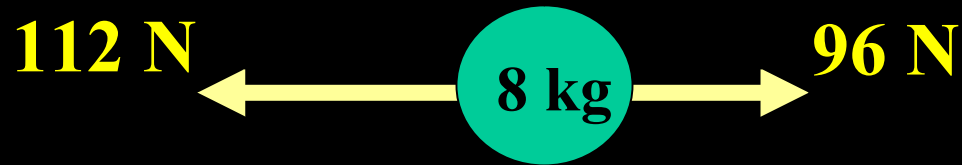
P5 A body of mass 105 kg has a velocity of 10 m s⁻¹.
What force is required to stop it in 0.5 s?

$$F = m a = 105 (a)$$

$$v = u + at \Rightarrow 0 = 10 + a(0.5) \Rightarrow a = -20 \text{ m s}^{-2}$$

$$F = m a = 105 \times (-20) = 2100 \text{ N}$$

P6 Find the acceleration of the 8 kg mass.



Resultant force = 112 - 96 = 16 N to the left

$$F = ma$$

$$\Rightarrow a = F / m$$

$$a = 16 / 8 = 2.0 \text{ m s}^{-2}$$

to the left

Momentum

Momentum = mass x velocity

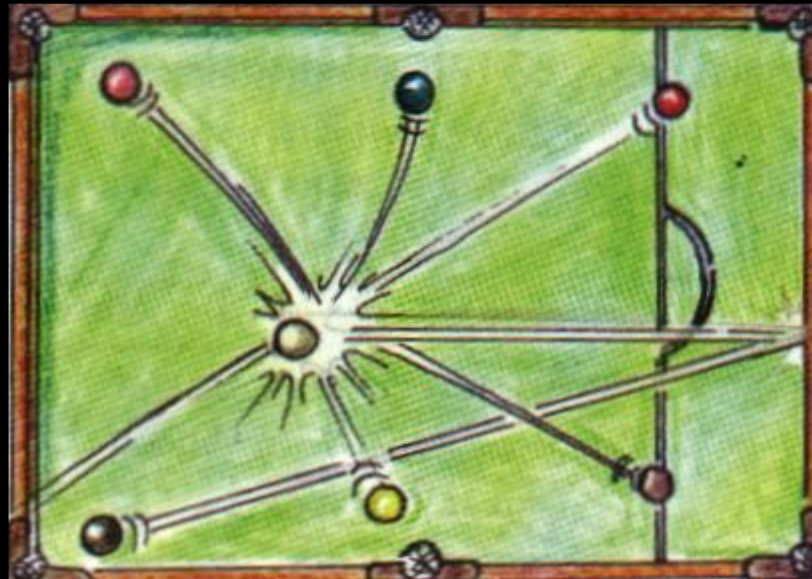
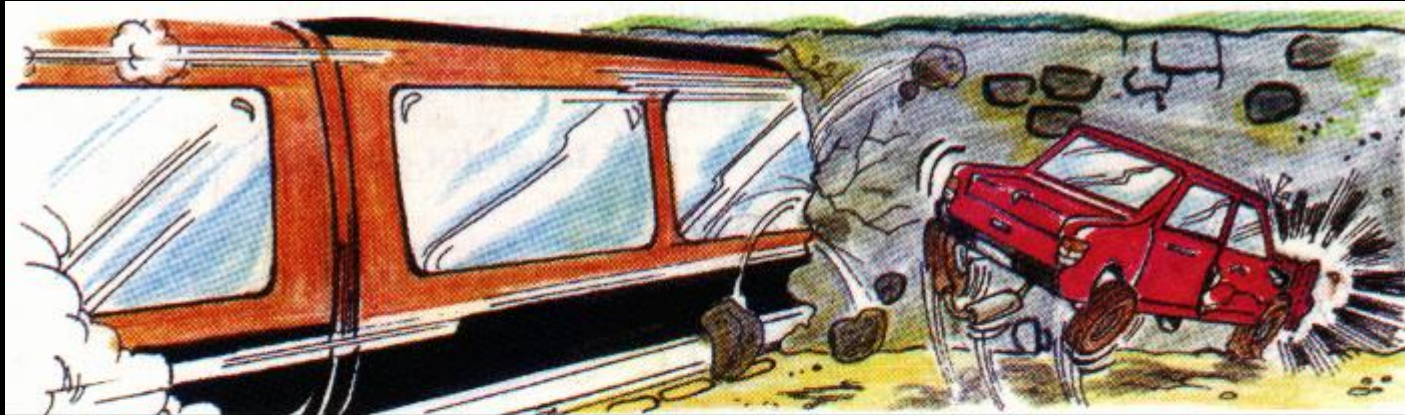
$$*p = mv*$$

Symbol: p

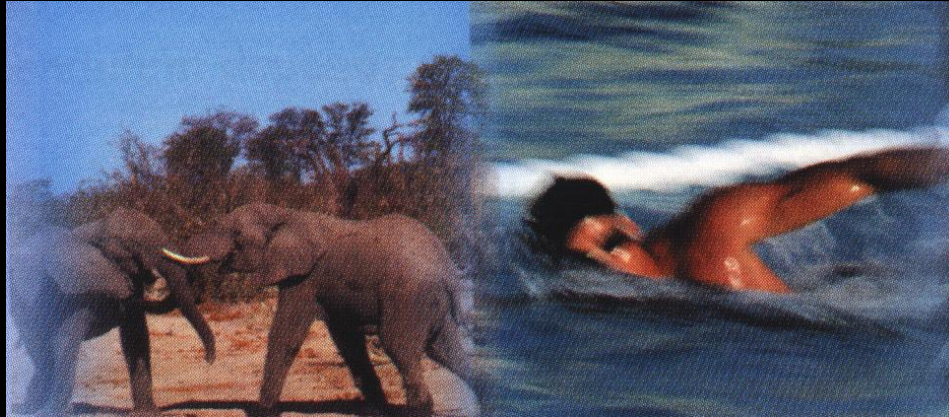
Momentum is a vector

Units = ?? kg m s⁻¹

Momentum = mv



Momentum = mv



P7 A body of mass 5000 kg moves East at 15 m s⁻¹.
Find its momentum.

$$p = mv$$

$$p = (5000) \times (15)$$

$$p = 75,000 \text{ kg m s}^{-1}$$

East

Newton's Laws Of Motion

1687

A Summary Of Force

How Force Affects A Body



Newton's Laws Of Motion

Law 1 **Resultant Force = 0 ...**

Law 2 **Yes, a Resultant Force acts ...**

Law 3 **Action / Reaction**

Newton's Laws Of Motion

Law 1 **A body remains at rest
or remains at constant velocity
unless a resultant force acts on the body**

Law 2 **When a resultant force acts on a body
the rate of change of momentum
is directly proportional to the resultant force
and takes place in the direction of the force**

Law 3 **To every action
there is an equal and opposite reaction.**



Newton's 1st Law Of Motion

A body

**remains at rest or remains at constant velocity
unless a resultant force acts on the body**

OR

A body

**remains at rest or remains at constant velocity
when resultant force on the body is zero**

Newton's 1st Law Of Motion

stopped



No forces acting
No resultant force
Stays stopped

stopped



Resultant force = 0
Stays stopped

Newton's 1st Law Of Motion

Velocity constant



Resultant force = 0
Velocity remains constant



Resultant force ... YES
Velocity changes

Newton's 1st Law Of Motion



Driver ...

**constant velocity & through
windscreen unless ...**

... seat belt / air bag

Newton's 2nd Law Of Motion

**Rate of change of momentum
is directly proportional to
the resultant force**

Newton's 2nd Law Of Motion


$$F = ma$$

$$F = ma$$

is a special case of Newton's 2nd law.

$F = ma$ from Newton's 2nd Law Of Motion

$F \propto$ Rate of change of

$$\Rightarrow F = ma$$



$$F \propto \frac{\text{Change in momentum}}{\text{Time for change}}$$

Momentum increases
from mu to mv
in time t

$$F \propto \frac{\text{Final mtm.} - \text{Initial mtm.}}{\text{Time for change}}$$

$$F \propto \frac{mv - mu}{t}$$

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

$$F \propto ma$$

$$F = kma$$

Definition of the Newton :

$$1N \dots 1 \text{ kg} \dots 1 \text{ m s}^{-2}$$

$$\Rightarrow k = 1$$

Newton's 2nd Law Of Motion

$F \propto$ Rate of change of mtm .

$F = k$ (Rate of change of mtm .)

Since $k = 1$...

$F =$ Rate of change of mtm .

$$F = \frac{mv - mu}{t}$$

Newton's 3rd Law Of Motion

**To every action
there is an equal and opposite reaction**

**If body A exerts a force on body B,
then B exerts an equal but opposite force on A**

Newton's 3rd Law Of Motion

Action / Reaction

Forces ...in pairs

... acting on different bodies



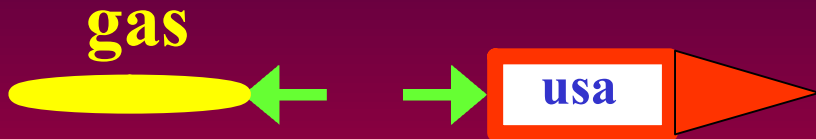
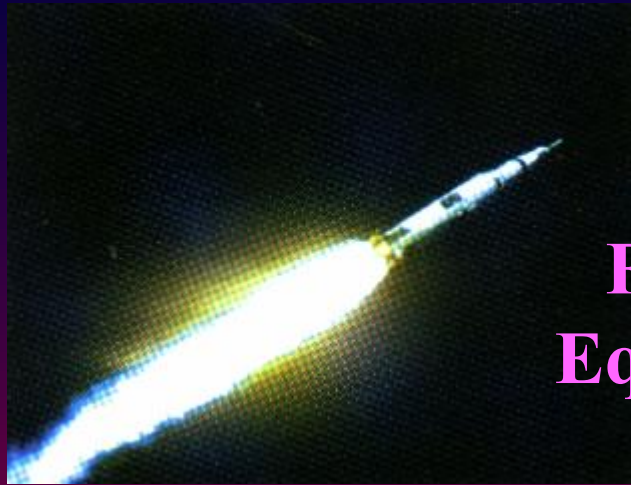
Car hits wall
Wall “hits” car
(Equal & opposite)

Newton's 3rd Law Of Motion

Why does the spacecraft accelerate forward?

Spacecraft expels hot gas at high speed backwards.

**Force backwards by spacecraft on gas
Equal force forward by gas on spacecraft
⇒ Spacecraft accelerates forward**

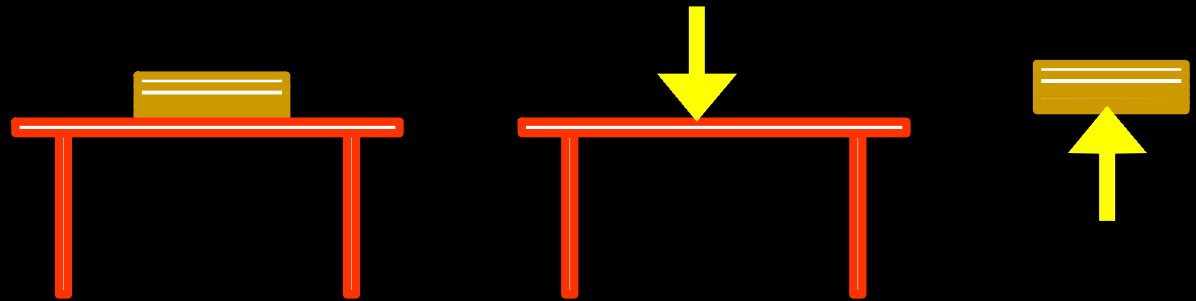


Newton's 3rd Law Of Motion

Others ...

How would a spacecraft be turned to the right? Explain

Book on a table ...



Walking ...

Force backwards ... foot on ground

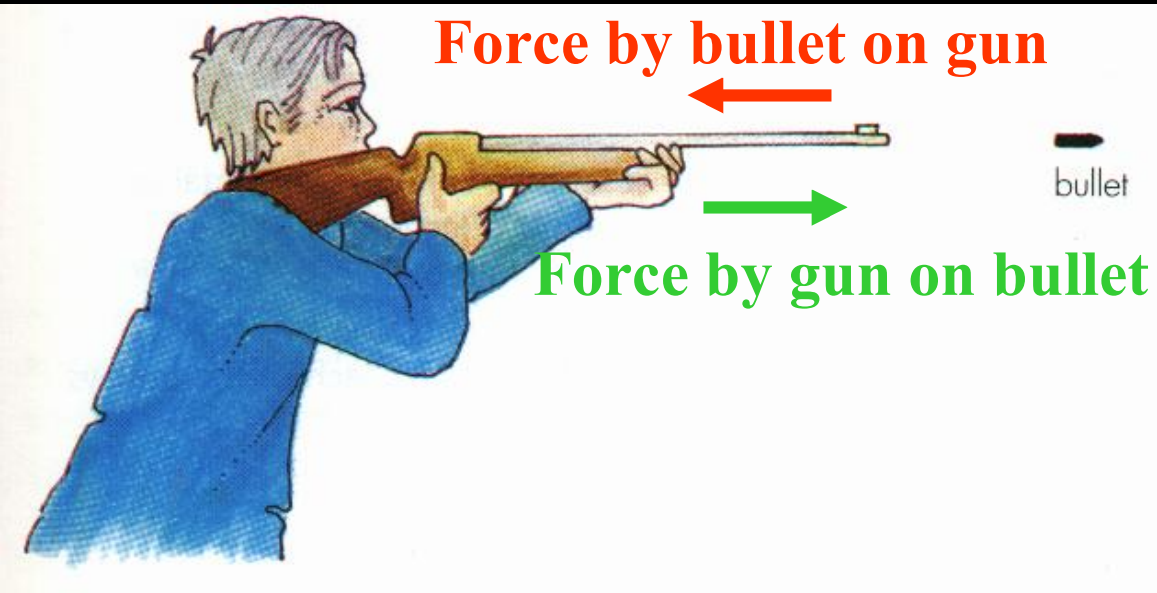
Equal force forwards ... ground on foot

=> Person accelerates forward

Newton's 3rd Law Of Motion

Others ...

The Recoil Of A Gun



Force .. gun on bullet
.. forward

Equal & opposite ...

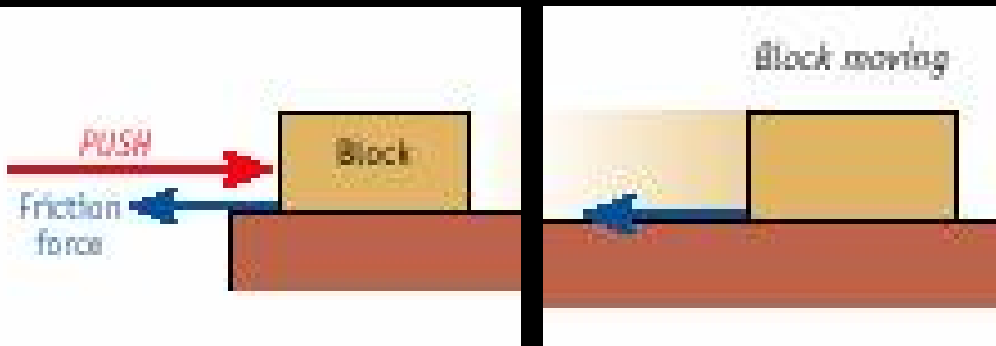
Force .. bullet on gun
.. backwards

Gun recoils

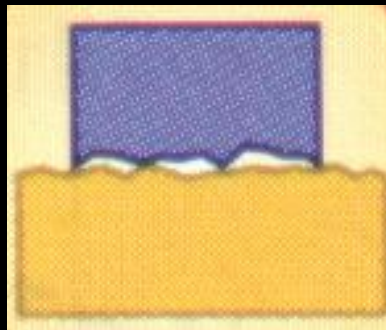
Conservation of Momentum

The Force Of Friction

A force opposing motion



Friction either
stops a body from moving
or tends to slow it down



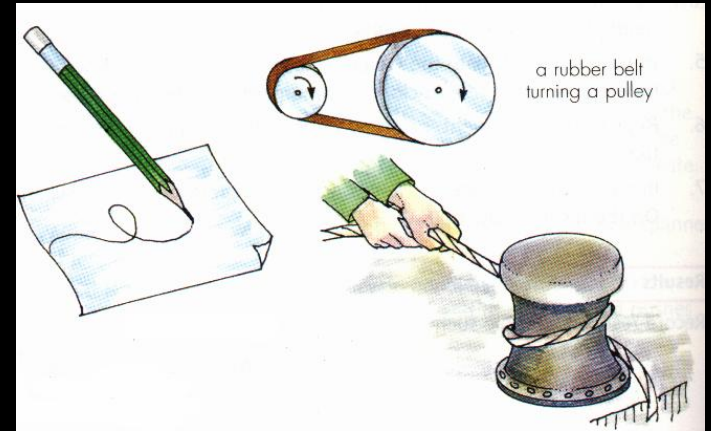
**Microscopic
View**

Useful Friction



4.8 seconds

0 to 100 km h⁻¹



Also ...

- **Bicycle Brakes**
- **Car Brakes**
- **Nails in timber**

Grip between ...

Disadvantages Of Friction

- **Machines wear out because of friction**
- **Overheating**
- **Energy must be supplied to overcome friction**
(“Useful energy” is wasted as heat, e.g. car)

Reducing Friction

Lubricant (Oil / Grease / Graphite)

Car engine Bicycle Hinges etc.

Air Cushion

Hovercraft Air Track

Bearings

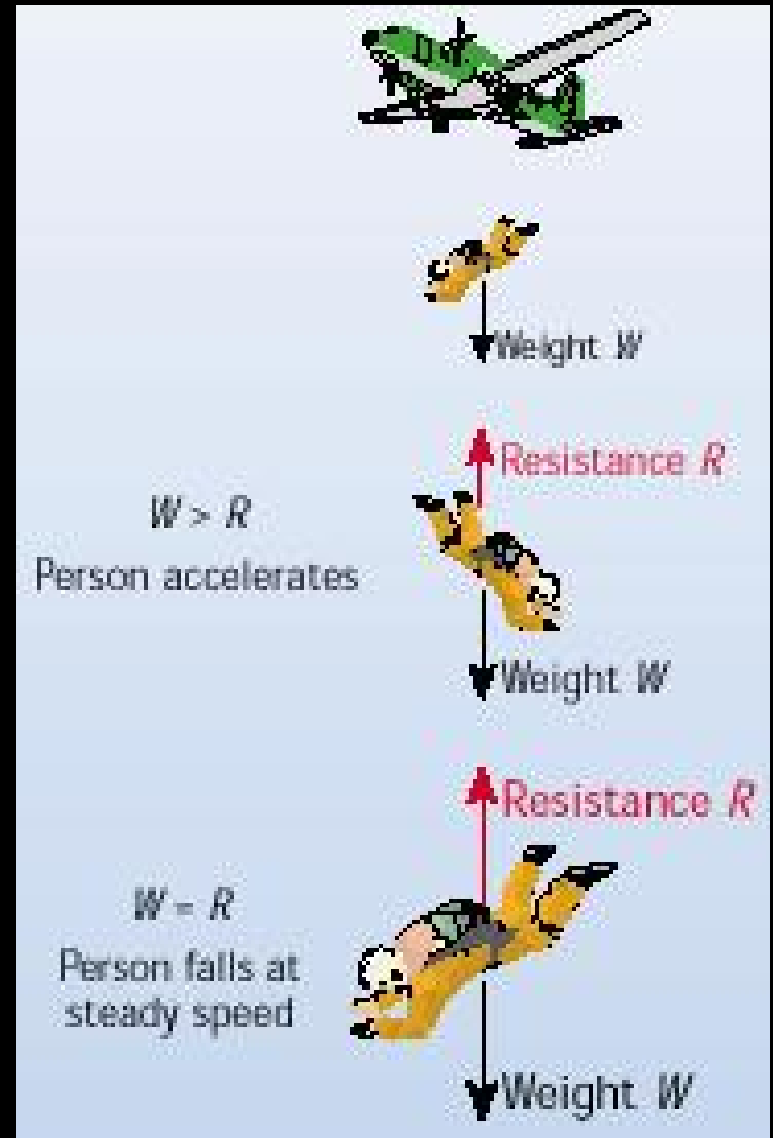
Polish / Sand

Friction Due To Air (Air Resistance)

Terminal Velocity

Resultant Force
 \Rightarrow Accelerates
[Newton's 2nd Law]

Resultant Force = 0
 \Rightarrow Acceleration = 0
 \Rightarrow Constant Velocity
[Newton's 1st Law]



P8 A crane lifts a block of mass 20 kg from the ground to the top of a building by means of a cable.

- (i) What force does the cable exert on the block if the block is accelerating upwards at 1.5 m s^{-2} ?
- (ii) What force does the cable exert on the block if the block is moving upwards at constant speed?

(i) $[F = ma]$

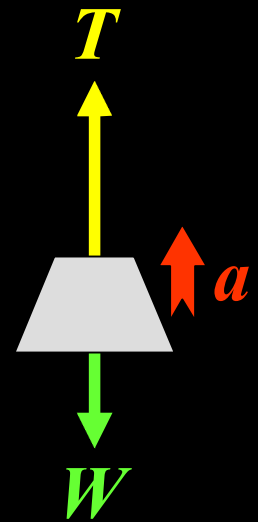
Up = + direction

$$(+T - W) = ma$$

$$+T - mg = ma$$

$$+T - (20)(9.8) = (20)(1.5)$$

$$T = 226 \text{ N}$$

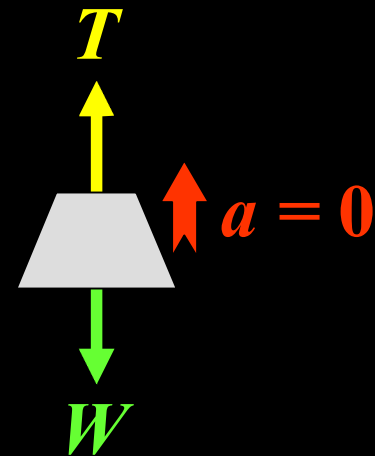


P8 A crane lifts a block of mass 20 kg from the ground to the top of a building by means of a cable.

(i) What force does the cable exert on the block if the block is accelerating upwards at 1.5 m s^{-2} ?

(ii) What force does the cable exert on the block if the block is moving upwards at constant speed?

$$\begin{aligned} \text{(ii)} \quad & [F = ma = 0] \\ & (+T - W) = 0 \\ & +T - mg = 0 \\ & T = mg = (20)(9.8) \\ & = 196 \text{ N} \end{aligned}$$



P9 A man of mass 80 kg stands on a weighing scales in a lift.

If the scales reads newtons, find the reading on it when the lift,

(i) is at rest,

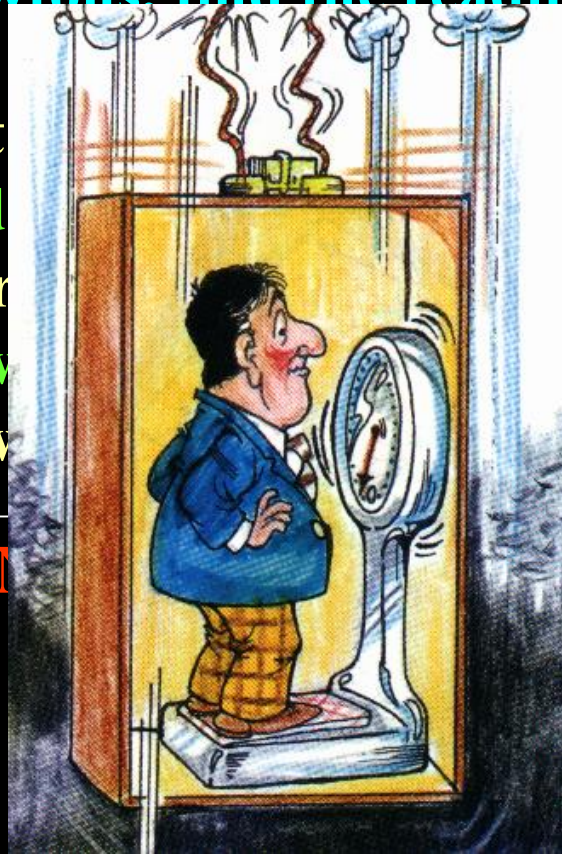
(ii) moves upwards at 3 m s^{-1} ,

(iii) moves downward at 4 m s^{-1} ,

(iv) accelerates upward,

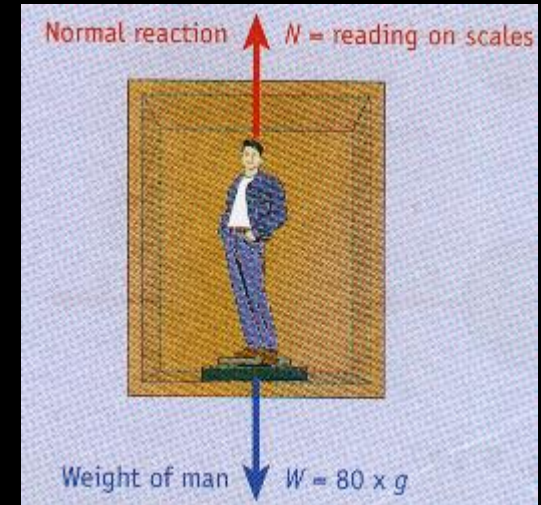
(v) accelerates downward,

(vi) accelerates downward.



Normal Reaction (N) on scales

$$\text{Weight of man} = mg = 80 \times g$$



P9 A man of mass 80 kg stands on a weighing scales in a lift.

If the scales reads newtons, find the reading on it when the lift,

(i) is at rest,

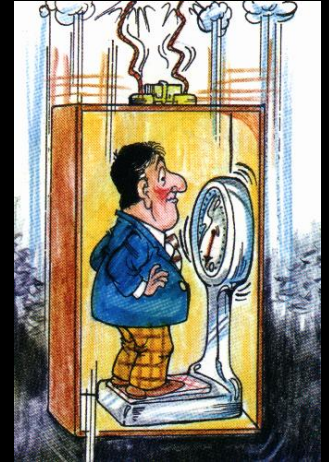
(ii) moves upwards at a constant speed of 3 m s^{-1} ,

(iii) moves downwards with a steady speed of 4 m s^{-1} ,

(iv) accelerates upwards at 2 m s^{-2} ,

(v) accelerates downwards at 2 m s^{-2} ,

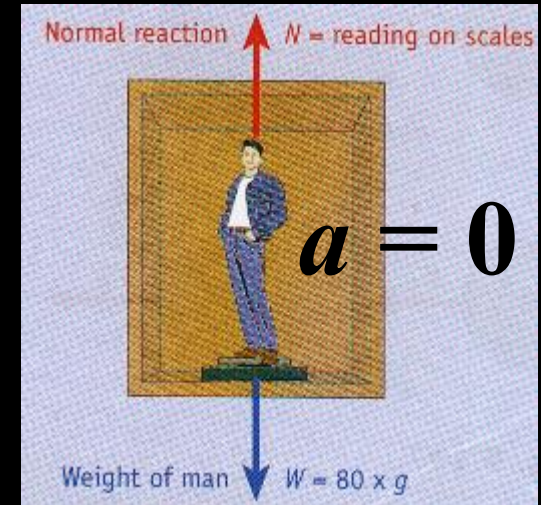
(vi) accelerates downwards at 9.8 m s^{-2} .



(i), (ii), & (iii) [$F = ma$]

$$a = 0 \quad \Rightarrow \quad F = 0$$

$$\begin{aligned} \Rightarrow \quad N &= mg \\ &= 80 \times 9.8 = \mathbf{784 \text{ N}} \end{aligned}$$



P9 A man of mass 80 kg stands on a weighing scales in a lift.

If the scales reads newtons, find the reading on it when the lift,

(i) is at rest,

(ii) moves upwards at a constant speed of 3 m s^{-1} ,

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(iv) accelerates upwards at 2 m s^{-2} ,

(v) accelerates downwards at 2 m s^{-2} ,

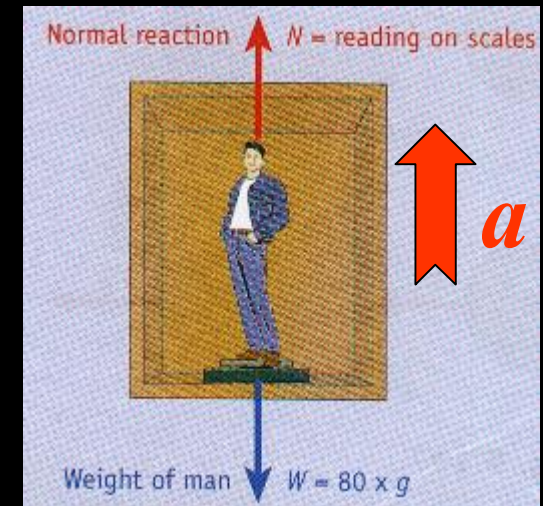
(vi) accelerates downwards at 9.8 m s^{-2} .

(iv) Up = + direction

$$+N - mg = ma$$

$$+N - (80)(9.8) = (80)(2)$$

$$N = 944 \text{ N}$$



P9 A man of mass 80 kg stands on a weighing scales in a lift.

If the scales reads newtons, find the reading on it when the lift,

(i) is at rest,

(ii) moves upwards at a constant speed of 3 m s^{-1} ,

(iii) moves downwards with a steady speed of 4 m s^{-1} ,

(iv) accelerates upwards at 2 m s^{-2} ,

(v) accelerates downwards at 2 m s^{-2} ,

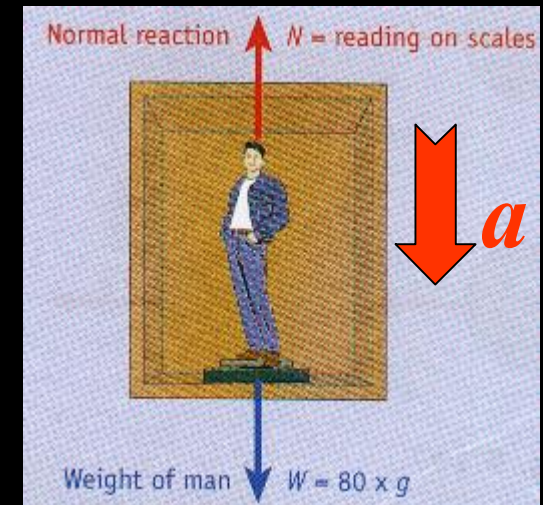
(vi) accelerates downwards at 9.8 m s^{-2} .

(iv) **Down = + direction**

$$+mg - N = ma$$

$$+(80)(9.8) - N = (80)(2)$$

$$N = 624 \text{ N}$$



P9 A man of mass 80 kg stands on a weighing scales in a lift.

If the scales reads newtons, find the reading on it when the lift,

(i) is at rest,

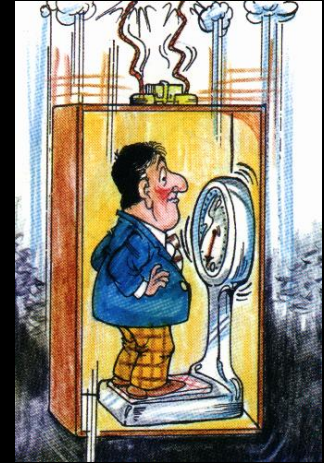
(ii) moves upwards at a constant speed of 3 m s^{-1} ,

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(iv) accelerates upwards at 2 m s^{-2} ,

(v) accelerates downwards at 2 m s^{-2} ,

(vi) accelerates downwards at 9.8 m s^{-2} .



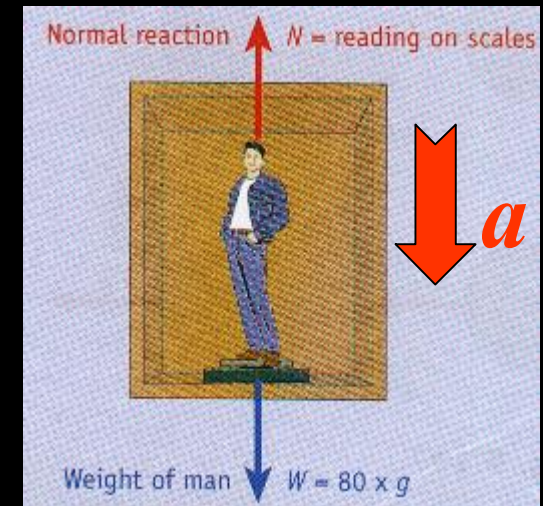
(iv) Down = + direction

$$+mg - N = ma$$

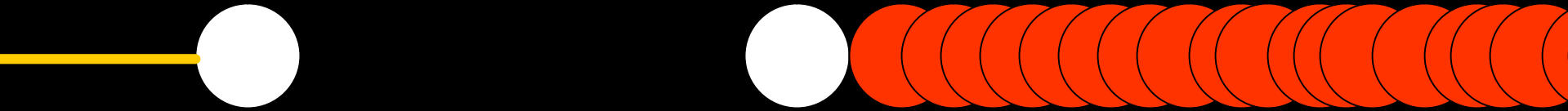
$$+(80)(9.8) - N = (80)(9.8)$$

$$N = 0$$

Weightless ... astronauts



The Principle Of Conservation OF Momentum

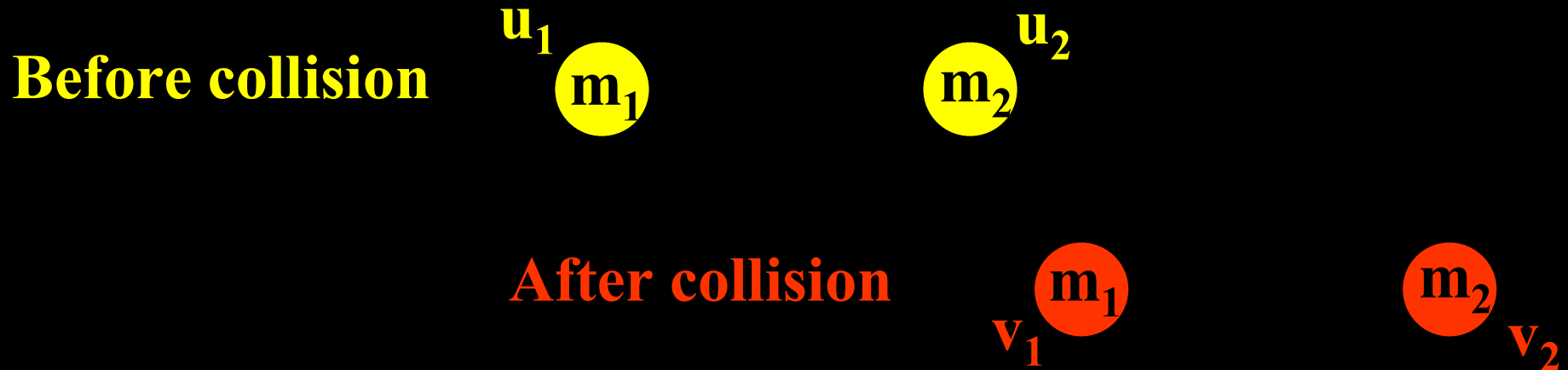


Momentum Before = Momentum After

an interaction between masses

provided no external forces act on the system

The Principle Of Conservation OF Momentum

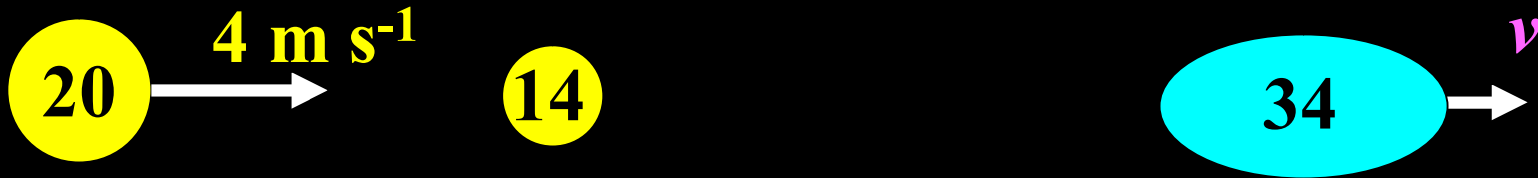


$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

Momentum Before = Momentum After
an interaction between masses
provided no external forces act on the system

P10 A body of mass **20 kg** moving at a speed of **4 m s⁻¹** collides with a body of mass **14 kg** which is **at rest**.

If the bodies stick together on colliding, find the velocity with which the combined mass moves off.



Momentum before = Momentum after

$$20(4) + 14(0) = 34 \times v$$

$$v = 80/34 = +2.35 \text{ m s}^{-1}$$

2.35 m s⁻¹ in the direction of the 20 kg

P11 A 10 kg mass is moving at a speed of 5 m s⁻¹.
A mass of 4 kg is moving at a speed of 20 m s⁻¹ in
the opposite direction. Find their total momentum.

Positive direction = direction of the 10 kg mass

$$\text{Total momentum} = 10(+5) + 4(-20)$$

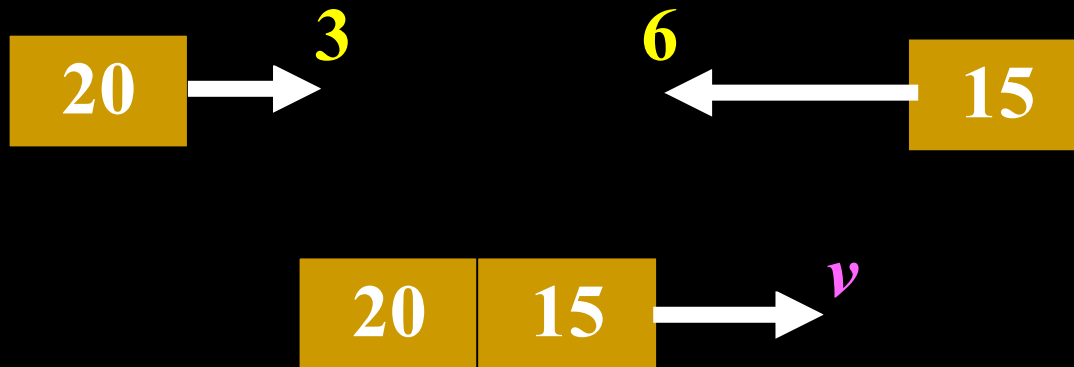
$$= +50 - 80$$

$$= -30 \text{ kg m s}^{-1}$$

30 kg m s⁻¹ in the direction of the 4 kg

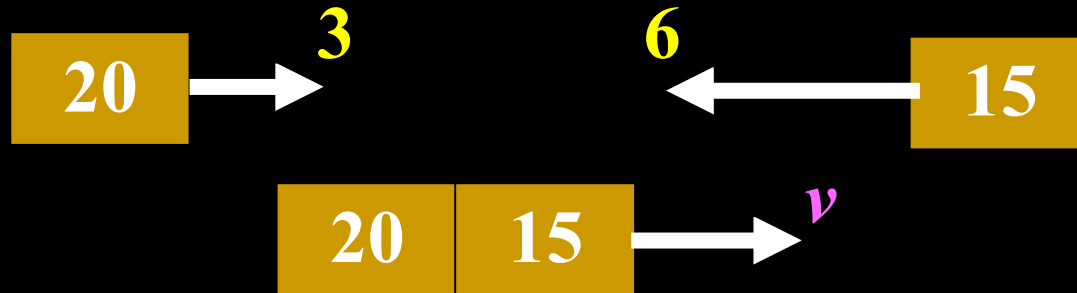


P12 A body of mass **20 kg** with a velocity of **3 m s^{-1}** collides with another body of mass **15 kg** which is moving at **6 m s^{-1}** in the opposite direction. The two bodies stick together on colliding. Find the velocity with which the combined mass moves off.



Positive direction ... to the right

P12 A body of mass 20 kg with a velocity of 3 m s⁻¹ collides with another body of mass 15 kg which is moving at 6 m s⁻¹ in the opposite direction. The two bodies stick together on colliding. Find the velocity with which the combined mass moves off.



Momentum before = Momentum after

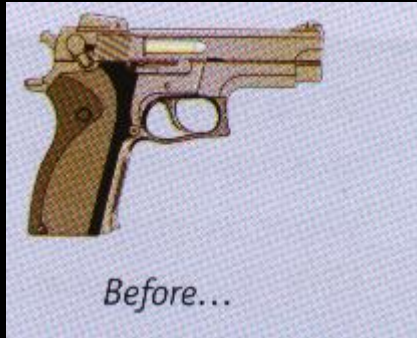
$$20(+3) + 15(-6) = (20 + 15)(v)$$

$$+60 - 90 = 35v$$

$$v = -0.86 \text{ m s}^{-1}$$

0.86 m s⁻¹ in the direction of the 15 kg

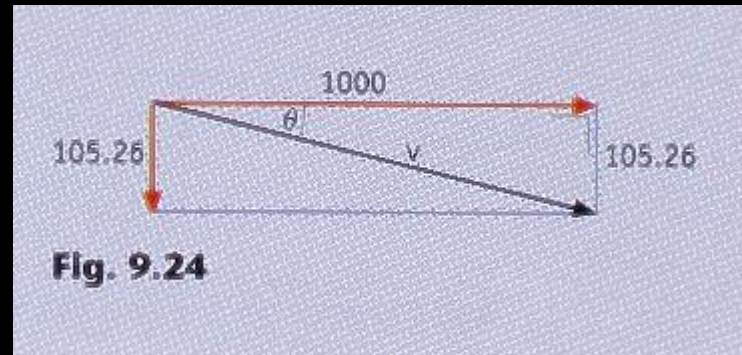
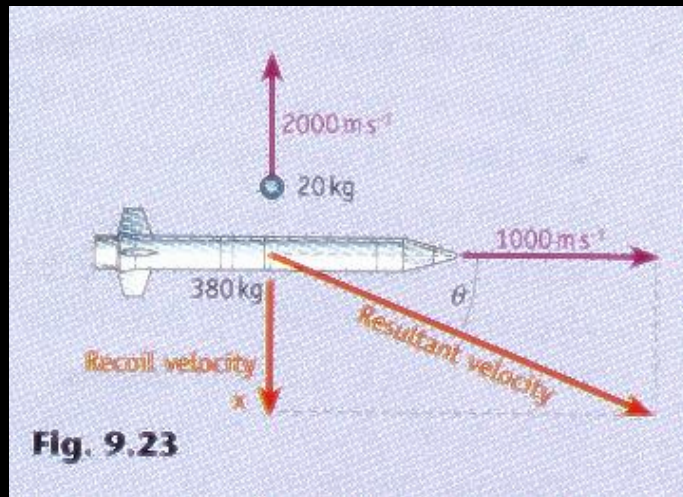
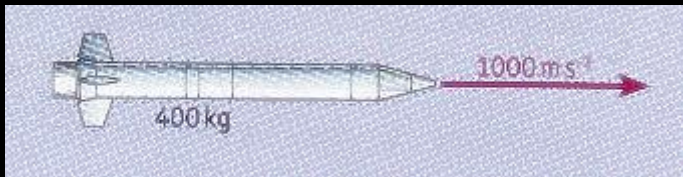
P13 A gun of mass 3 kg fires a bullet of mass 10 g with a velocity of 500 m/s. Calculate the recoil velocity of the gun.



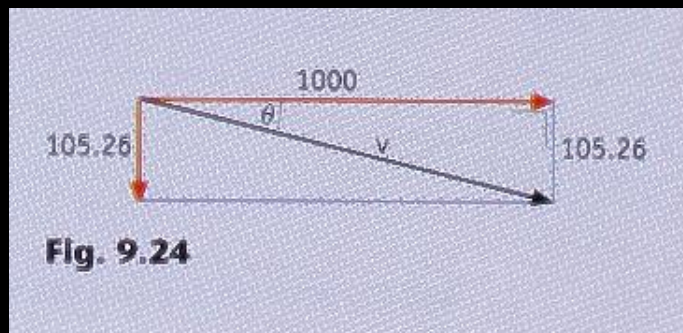
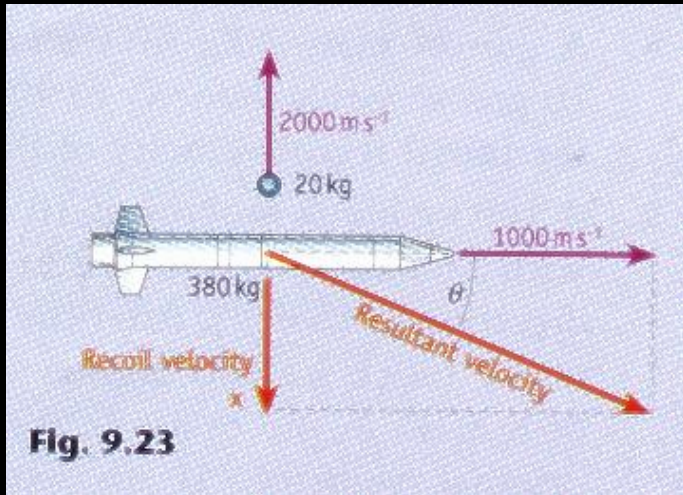
$$\text{Momentum before} = \text{Momentum after}$$
$$(3)(0) + (0.01)(0) = (3)v + (0.01)(500)$$
$$v = -1.67 \text{ m s}^{-1}$$

1.67 m s⁻¹ backwards

P14 A spacecraft of mass 400 kg moving at 1000 m s^{-1} ejects an object of mass 20 kg at a speed of 2000 m s^{-1} at right angles to the direction in which the craft is moving. Calculate the resultant velocity of the craft in magnitude and direction.



P14 A spacecraft of mass 400 kg moving at 1000 m s^{-1} ejects an object of mass 20 kg at a speed of 2000 m s^{-1} at right angles to the direction in which the craft is moving. Calculate the resultant velocity of the craft in magnitude and direction.



Perpendicular to spacecraft
Mtm. before = Mtm. after
 $0 = (380)(x) + (20)(2000)$
 $x = 105 \text{ m s}^{-1}$

Resultant Velocity:
 $v^2 = (1000)^2 + (105)^2$
 $v = 1005 \text{ m s}^{-1}$

$\tan \theta = 105 / 1000$
 $\theta = 6^\circ$

1005 m s^{-1} at 6° to original direction

Acceleration Of A Spacecraft



Momentum

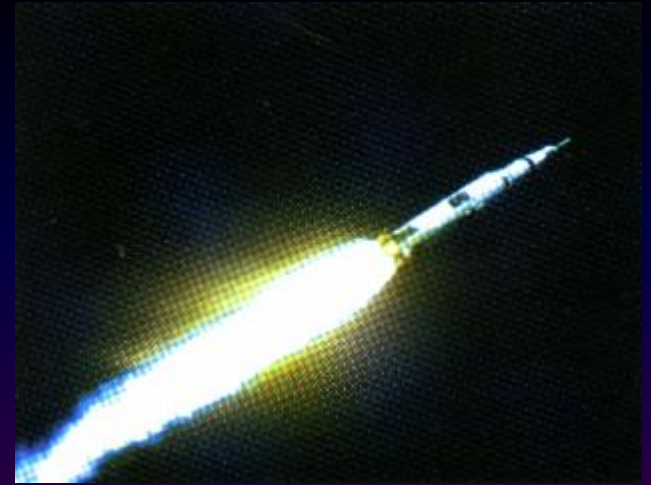
= Gain in momentum of spacecraft forwards

⇒ Spacecraft accelerates forward

Spacecraft

How is it slowed down?

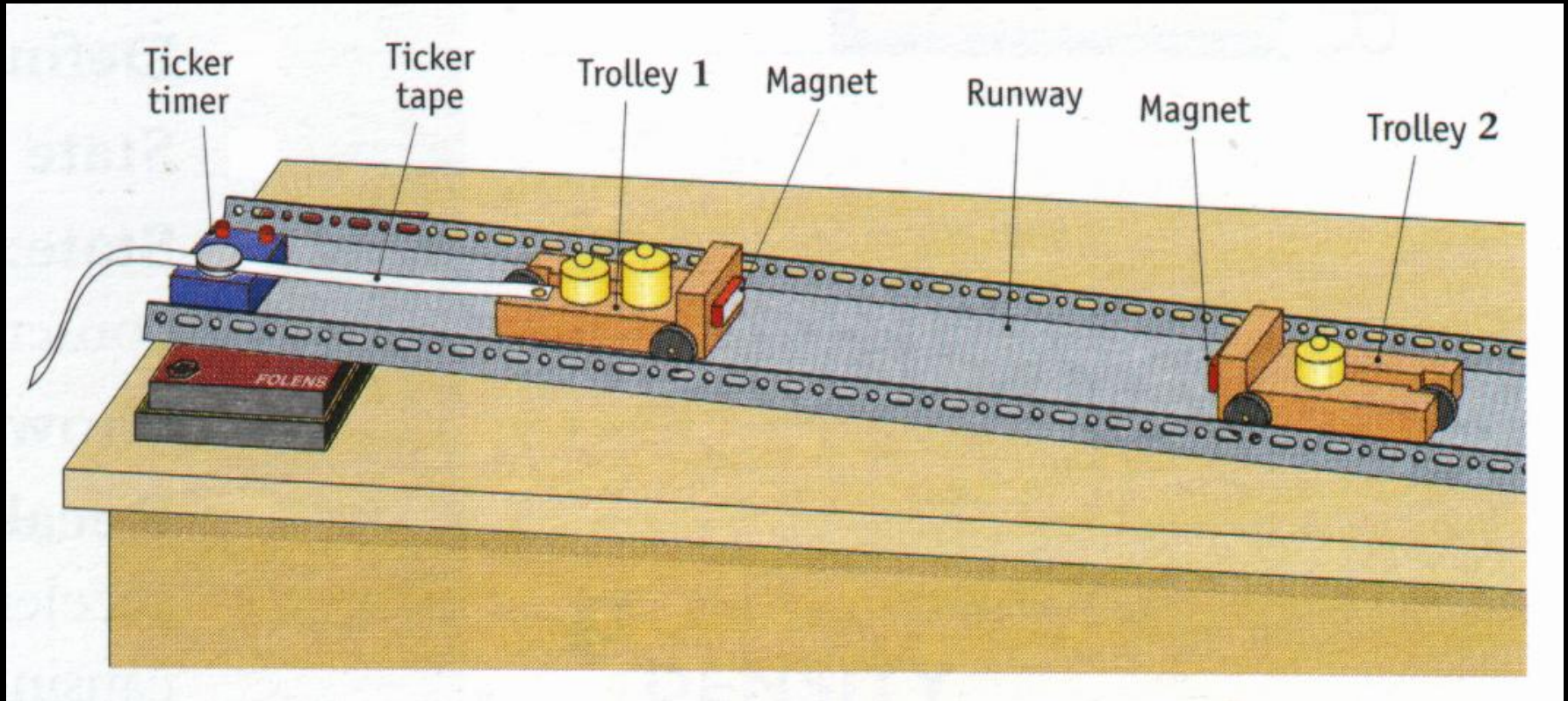
How is it turned to the right?



Can also be explained by ...

Conservation of Momentum

Expt. To Verify The Principle Of Conservation Of Momentum



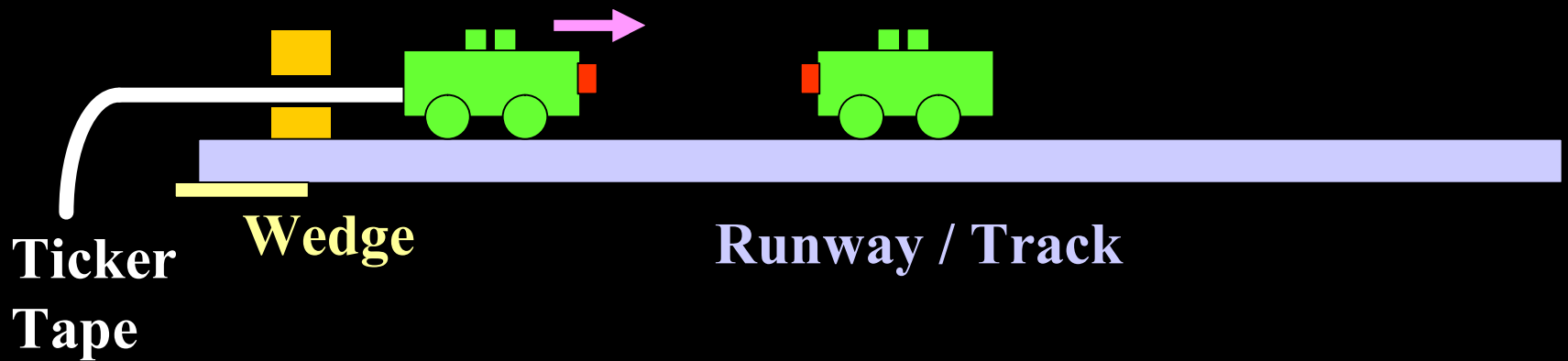
Expt. To Verify The Principle Of Conservation Of Momentum

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$
$$m_1u_1 = (m_1 + m_2)v$$

Apparatus

Ticker Timer
.. to a.c. 50 Hz

Trolleys
with Magnets



Expt. To Verify The Principle Of Conservation Of Momentum

Results Momentum before = Momentum after

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

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

m_1	m_2	$(m_1 + m_2)$	u_1	v	m_1u_1	$(m_1 + m_2)v$
0.50	0.50	1.00	0.65	0.33	0.33	0.33
0.50	0.75	1.25	1.26	0.51	0.63	0.64
0.50	1.00	1.50	0.85	0.29	0.43	0.44
0.75	0.50	1.25	0.78	0.47	0.59	0.59
1.00	0.50	1.50	0.56	0.37	0.56	0.56

Expt. To Verify The Principle Of Conservation Of Momentum

Precautions

1. Oil the trolleys ... why?
2. Use the patches immediately before and after collision ... why?
3. Use more than 10 patches ...why?
4. Repeat ... other masses ... why?
5. Etc. ...