PHYSICS

What is Physics?

Physics falls under the branch of sciences called **physical sciences**. The physical sciences deal with the **properties** and **behaviour** of **non-living** things, unlike the biological sciences which deal with living things. The physical sciences are mainly sub-divided into two:

1. Physics and
2. Chemistry.

As it is difficult to make a clear-cut distinction between physics and chemistry, broadly speaking:

- chemistry deals with the way different substances interact with each other in chemical reactions to form new substances.

- Physics deals with properties of matter in relation to energy and the mathematical relationship between/among them, if any. Physics is concerned with the universe – ranging from stars that are millions and millions of kilometers away to particles that are smaller than atoms.
  E.g. Physics explores matter in relation to different kinds of energy. Since physics is the most fundamental of sciences, it finds numerous applications in other fields e.g. technology, medicine, research etc.
  For elementary purposes, the study of physics may be divided into sections (headings) e.g. general physics and mechanics, thermal physics (heat), wave motion (light/optics and sound), electricity and magnetism (electromagnetism), and atomic and nuclear physics.

MEASUREMENTS IN PHYSICS

The building blocks of physics are the physical quantities that we use to express the laws of physics.
Measurements are comparisons or ratios. Experimental measurements which are (quantitative observations) are fundamental in physics. Before a measurement can be made, a standard or **unit** must be chosen. The size of the quantity to be measured is then found with an instrument having a scale marked in the appropriate unit.

S.I. UNITS OF MEASUREMENT

The International System of Units (abbreviated S.I. from the French le Systěme International d'Unitěs) is a set of metric units now used in many countries. The S.I. units are derived from the older (earlier) MKS [so called because its first 3 basic units are the metre (m), kilogram (kg), second (s)].

The S.I. system is a decimal system in which units are divided or multiplied by 10, 100, 1 000 to give larger or smaller units.

- The S.I. unit of *length* is the *metre*, m
- The S.I. unit of *mass* is the *kilogram*, kg
- The S.I. unit of *time* is the *second*, s

Physical Quantities

A physical quantity is any measurable feature or property of a body or an object (those properties that are not measurable e.g. love, hate etc are non-physical quantities).

There are seven basic quantities in use in physics and these are:

(i) Length (l)
(ii) Mass (m)
(iii) Time (t)
(iv) Electric current (I)
(v) Thermodynamic temperature (T)
(vi) Amount of substance (n)
(vii) Luminous intensity (brightness of a luminous body), (I)

BASIC S.I. UNITS

Quantity, abbreviation for quantity	***Name of S.I. unit***	***Symbol for unit***
Length, *l*	metre	m
Mass, m	kilogram	kg
Time, t	second	s
Thermodynamic Temperature, T	kelvin	K
Electric current, I	ampere	A
Luminous intensity, I	candela	cd
Amount of substance, n	mole	mol

DERIVED S.I. UNITS

Other physical quantities e.g. force, velocity, density etc are based on these basic units and have their units derived from the basic units
e.g. (1) Speed has derived S.I. units of m/s or ms^{-1} (speed depends upon distance or length and time, hence is measured in terms of a distance standard and time standard).

i.e. $$from\ speed = \frac{distance, m}{time, s} = \frac{m}{s}\ or\ m/s$$

(2) Area, has derived S.I. units of m^2.
i.e. from Area = l x b
= m x m = m^2
(3) Volume, has derived S.I. units of m^3
i.e. from Volume = l x b x h
= m x m x m = m^3
(4) Density has derived S.I. unit of kg/m^3
i.e. from Density = $\frac{m}{V} = \frac{kg}{m^3}$ or kg/m^3

Exercise

1. Find the derived S.I. units for
   (a) density
   (b) weight

PHYSICAL QUANTITIES WITH DERIVED S.I. UNITS

Quantity, abbreviation for quantity	*Name of derived S.I. unit*	*Symbol for unit*
Area, A	Square metre	m^2
Volume, V	Cubic metre	m^3
Density, ℓ	Kilogram per cubic metre	kgm^{-3} or kg/m^3
Velocity, v or u or c	Metre per second	m/s or ms^{-1}
Speed, c or u or v	Metre per second	m/s or ms^{-1}
Acceleration, a	Metre per second squared	m/s^2 or ms^{-2}
Acceleration of free fall, g	Metre per second squared	m/s^2 or ms^{-2}
Force, F	Newton	N
Weight, W	Newton	N
Momentum, p	Newton second	Ns
Pressure, p	Pascal	Pa
Power, P	Watt (or joules per second)	W (J/s)
Work, w, W	Joule (or Newton metre)	J (Nm)
Energy, E	Joule	J
Specific heat capacity, c	Joule per kilogram Kelvin	$JK^{-1}kg^{-1}$
Period, T	Second	S
Frequency, f	hertz (per second)	Hz (s^{-1})
Wavelength, λ	metre	m
Speed of electromagnetic waves, C	Metre per second	ms^{-1} or m/s
Electric charge, Q	coulomb	C
Electric potential difference, V	volt	V
Electromotive force, E	volt	V
Resistance, R	ohm	Ω
Capacitance, C	Farad	F

Scientific notation or standard form

Scientists often deal with very large or very small numbers. A short hand way of writing these numbers involve a number written as a factor multiplied by a power of 10.

e.g. (1) 2 000 = 2 x 1 000 = $\underline{2 \times 10^3}$

(2) 5 600 000 = $\underline{5.6 \times 10^6}$

(3) 0.001 = $\underline{1 \times 10^{-3}}$

Significant Figures

The accuracy of a measurement can never be higher than the least accurate measurement within it. Thus the final answer should have the same number of significant figures as the least accurate measurement.

Examples

Two significant figures	*Three significant figures*	*Four significant figures*
18	185	4 526
96	0.00843	0.6780
0.18	0.234	508.6
67	650	5.060

Exercise

1. Calculate the following and give the answer to the appropriate number of significant figure:

(a) 264.68 – 2.4711 =

(b) 2.345 x 3.56 =

METRIC PREFIXES

All or almost all the units used in physics belong to the S.I. units. All basic units can be made bigger or smaller by adding a metric prefix as shown in the table below:

Metric Prefixes

Name	**Symbol**	**Value**	**= x by**
Giga	G	10^9	= 1,000,000,000
Mega	M	10^6	=1,000,000
Kilo	K	10^3	= 1,000
Deci	D	10^{-1}	$^1/_{10}$ = 0.1
Centi	C	10^{-2}	= $^1/_{100}$ = 0.01
Milli	M	10^{-3}	= $^1/_{1\,000}$ = 0.001
Micro	µ	10^{-6}	= $^1/_{1000000}$ = 0.000001
Nano	N	10^{-9}	= $^1/_{1000000000}$ = 0.000000001
Pico	P	10^{-12}	= $^1/_{1000000000000}$ = 0.000000000001

Examples

Name	Symbol	Value cm S.I. units
4 gigawatts	4 GW	4×10^{9} watts
2 megajoules	2 MJ	2×10^{6} joules
57 kilohertz	57 kHz	57×10^{3} Hertz
3 decibels	3 dB	0.3 bels
1 decimetre	1 dm	1 x 0.1 m = (0.1 m)
50 centimetres	50 cm	0.5 metres
40 milliamperes	40 mA	0.04 amperes
1 milligram	1 mg	1×10^{-3} grammes
8 microamperes	8 μA	8×10^{-6} amperes
5 nanoseconds	5 ns	5×10^{-9} seconds
10 picofarads	10 pF	10×10^{-12} farads

N.B.: The prefixes used with 'kilogram' are anomalous for an S.I. base unit since they are added to the word 'gram' (1×10^{-3} kg).

1 kg = 1 x 1 000 g = 1 000 g

1 000 g = 1 kg

$$\frac{1000\,g}{1000} = \frac{1\,kg}{1000}$$

1 g = 0.001 kg

Examples

1. 2 centimetre = 2 cm = 2×10^{-2} m
2. 5 kilogram = 5 kg = 5×10^{3}g
3. 4 gigawatts = 4 GW = 4×10^{9} W
4. 6 megajoules = 6 MJ = 6×10^{6} J

Exercise

1. Express

(a) 10 000 milliseconds in seconds (Ans: 10 s)
(b) 2 000 km in metres (Ans: 2 000 000 m)
(c) 2 000 km in megametres (Ans: 2 Mm)
(d) 0.002 g in micrograms (Ans: 2 000 μg)

I. MEASUREMENT OF LENGTH

Length is a linear measurement of the shortest distance between any two points.
The S.I. unit of length is the metre (m). For larger distances the kilometre (km) may be used and the centimetre (cm), and mm, µm, η m for shorter distances.

(a) 1 km = 1 000 m (10^3 m)
(b) 100 cm = 1 m

$$\therefore 1\text{ cm} = \frac{1}{100}m = 0.01m = 10^{-2}m$$

(c) 1 000 mm = 1 m

$$\therefore 1\text{ mm} = \frac{1}{1000}m = 0.001m = 10^{-3}m$$

Different instruments e.g. metre rule, vernier caliper, engineers' calipers and micrometer screw gauge are used to measure lengths depending on the size of length to be measured and the accuracy required. A metre ruler is used to measure distance (length) from 1 mm to 1 m. A tape (steel tape) is used to measure longer distances. Very small lengths are measured by ***vernier or slide calipers*** and ***micrometer screw gauges***.

The smallest possible measurement that the instrument can give is the accuracy of the particular instrument.

Instrument	***Accuracy***
Metre rule	1 mm
Vernier caliper	0.1 mm
Micrometer screw gauge	0.01 mm

Exercise

1. The diameter of a small ball bearing was measured as accurately as possible using three different instruments; the metre rule, the micrometer screw gauge and the vernier caliper. Copy and complete the following table by giving the appropriate instrument that give each reading:

Diameter/mm	***Instrument used***
3.12	
3.0	
3.1	

2. How many millimeters are there in
   (a) 1 cm?
   (b) 4 cm?

3. Change

(a) 40 mm to m (Ans: 0.04 m)
(b) 60 cm to km (Ans: 0.0006 km)
(c) 50 cm to m (Ans: 0.5 m)
(d) 1 m^2 to mm^2 (Ans: 1 x 10^6 mm^2)
(e) 1 cm^2 to m^2 (Ans: 1 x 10^{-4} m^2)
(f) 1 mm^2 to m^2 (Ans: 1 x 10^{-6} m^2)

4. What are these lengths in metres:

(a) 300 cm
(b) 550 cm

Measurements
P.65 Tom Duncan

1. (a) 1 cm → <u>10 mm</u>

(b) 1 cm → 10 mm
4 cm → <u>40 mm</u>

(c) 1 cm → 10 mm
0.5 cm → 0.5 x 10 = <u>5 mm</u>

(d) 1 cm → 10 mm
6.7 cm → 6.7 x 10 = <u>67 mm</u>

(e) 10 mm → 1 cm
1 000 mm ← 100 cm = 1 m

100 cm = 1 m

2. (a) 100 cm → 1 m
300 cm → $^{300}/_{100}$ = <u>3 m</u>

(b) 100 cm → 1 m
550 cm → $^{550}/_{100}$ = <u>5.5 m</u>

(c) 100 cm → 1 m
870 cm → $^{870}/_{100}$ = <u>8.7 m</u>

(d) 100 cm → 1 m
43 cm → $^{43}/_{100}$ = <u>0.43 m</u>

(e) 1 m → 1 000 mm
0.1 m = $^{100}/_{1000}$ ← 100 mm

$(100\ cm)^3 = (1\ m)^3$
$10^6\ cm^3 = 1\ m^3$

7. V = 4.1 cm x 2.8 cm x 2.1 cm = <u>24.1 cm^3 (2.4 x 10^{-5} m^3)</u>

8 (i) V = 10 cm x 2 cm x 2 cm = <u>40 cm^3 (4.0 x 10^{-5} m^3)</u>

(ii) $\frac{40 cm^3}{8 cm^3} = 5$

1. Write

   (a) $1\ m^2$ = …………………mm^2

   $1\ cm^2$ = …………………m^2

   $1\ mm^2$ = ………………...m^2

   (b) $1\ m^3$ = …………………..mm^3

   $1\ mm^3$ =…………………m^3

   $1\ cm^3$ =…………………..m^3

2. Give the name of the S.I. unit for each of the following:

   (a) length (b) time (c) volume (d) mass (e) distance
   (f) density (g) area

3. Give the symbol and value of the following metrix prefixes:

   (a) milli (b) micro (c) kilo (d) mega (e) centi
   (f) nano (g) giga (h) pico

4. How many millimeters are there in?

   (a) 1 cm? (b) 4 cm? (c) 50 cm? (d) 1 m? (e) 1.2 m?

5. Write the following without using prefixes

   (a) 4 MW (b) 3 mm (c) 1 µA (d) 6 cm (e) 7.3 kHz

6. Rewrite using the most suitable prefix

   (a) 5 000 joules (b) 0.02 metres (c) $^4/_{1\,000}$ (0.004) grams
   (d) 0.000001 seconds

7. Write

   (a) $2\ m^2$ in mm^2 (b) $4\ m^2$ in cm^2 (c) $3\ mm^2$ in m^2
   (d) $1\ mm^3$ in m^3 (e) $8\ cm^3$ in m^3 (f) $5\ m^3$ in mm^3

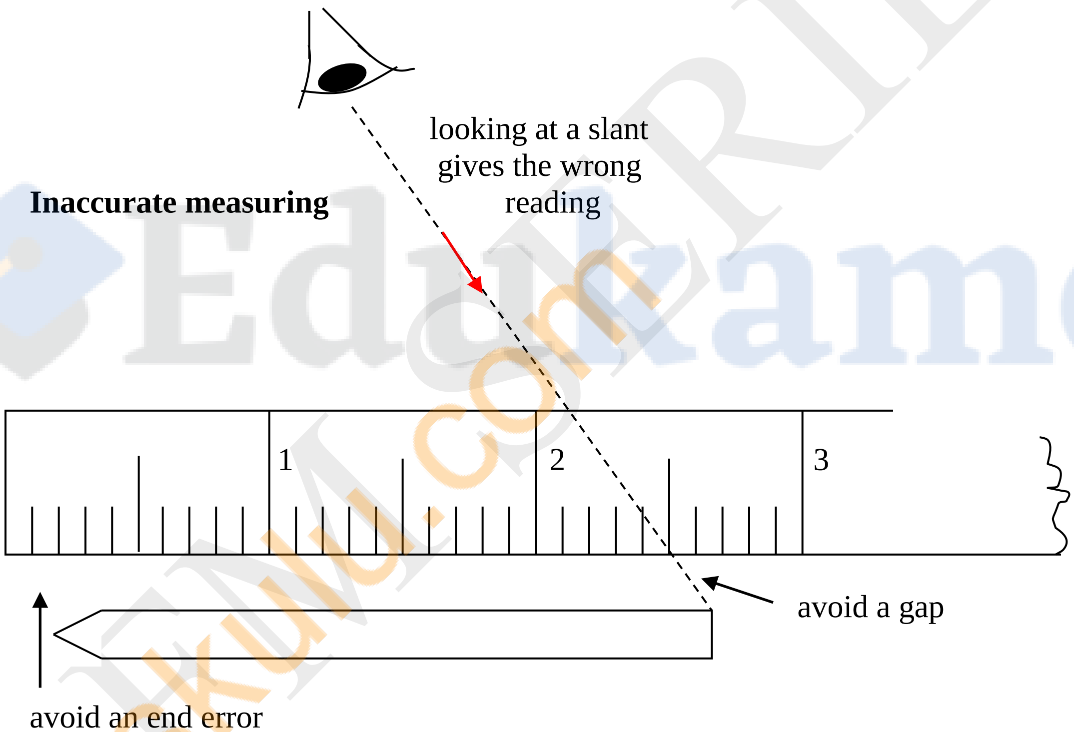
A. **THE RULER/RULE**

While measuring the lengths, your eye must be right over the mark on the scale, otherwise the thickness of the ruler causes errors – due to parallax. A parallax error results from wrong positioning of the eye in which there is apparent change in the position of an object.

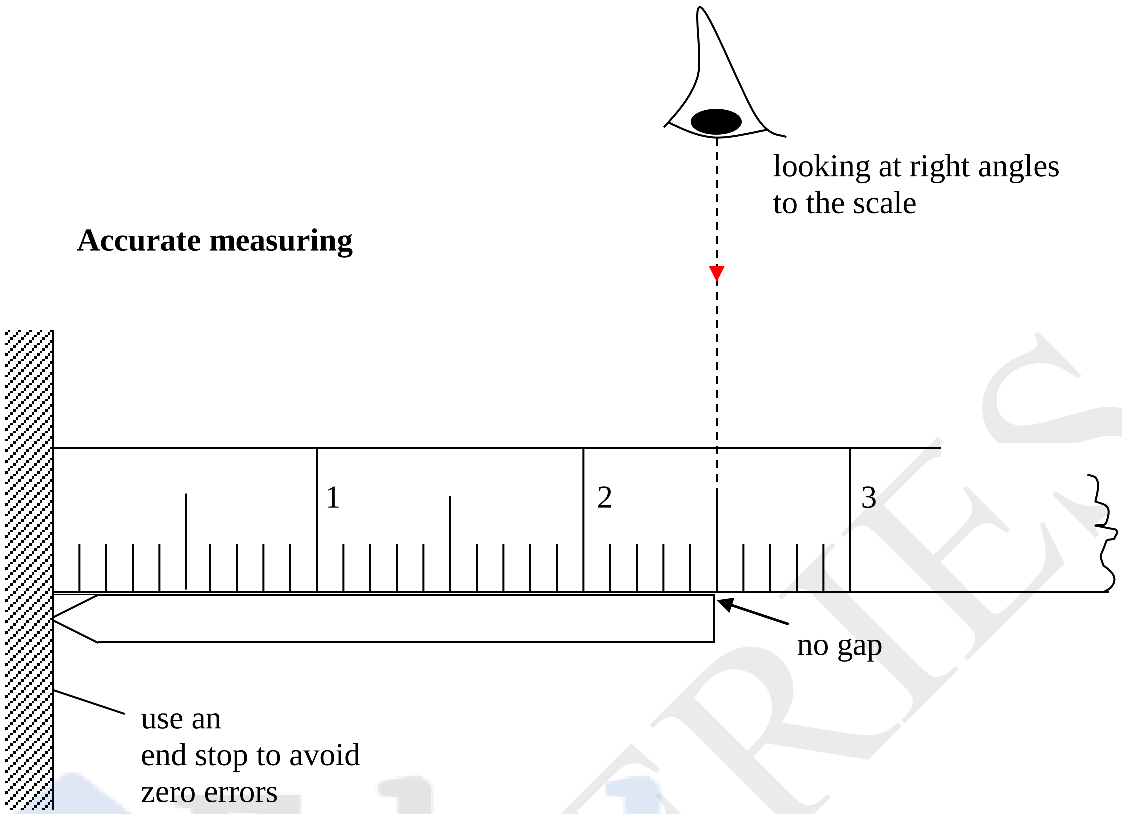
Precautions to take when using a rule/ruler

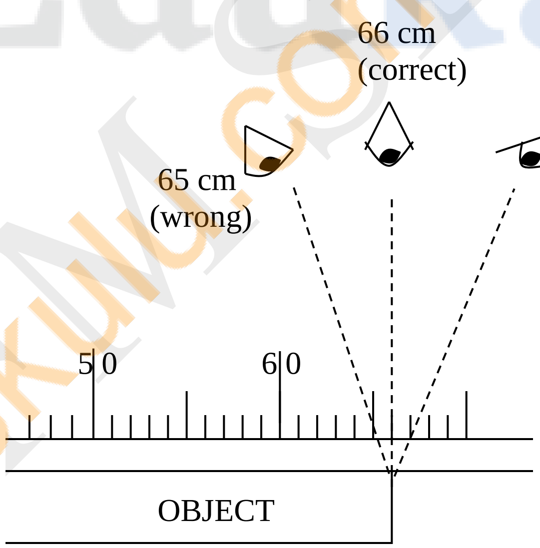
1. The line of sight must be right (i.e. at right angles to the scale) over the mark being read to avoid parallax error.
2. Take a reading starting from say the 10 cm mark to avoid the end error in case of wear and tear at the start of ruler.
3. Avoid a gap between the rule and object whose length is to be measured.

Inaccurate measuring



Accurate measuring



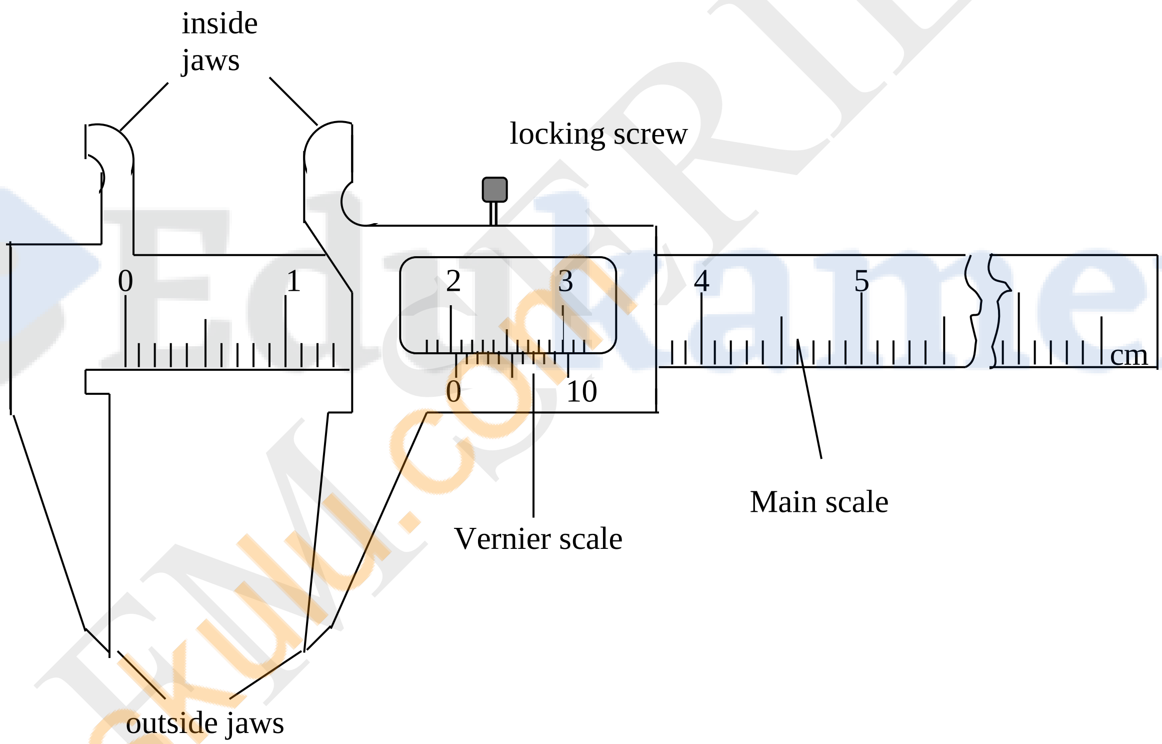


The reading is <u>66 cm</u>

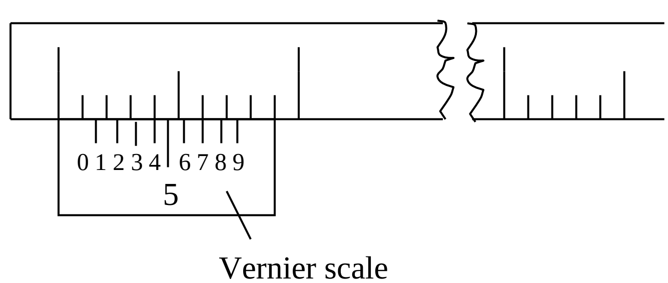
B. **VERNIER CALIPERS AND VERNIER SCALES**

Vernier (slide) calipers consist of a main scale graduated in centimetres (cm) and millimeters (mm) with a fixed jaw at one end and a small vernier scale which slides along the main scale on the sliding jaw. The vernier scale enables us to obtain accurately the second decimal place in centimetre (cm). Thus a vernier caliper is used for measurements accurate to 0.01 cm (0.1 mm). The accuracy of the vernier caliper is said to be 0.1 mm. Vernier calipers can be used to measure diameters of balls and hollow cylinders (e.g. internal and external diameters of small test tubes). The object to be measured is placed between the outside (fixed) jaw and the sliding jaw. Some calipers also have inside jaws that can be used for such measurements as the internal diameters of tubes.

SLIDE OR VERNIER CALIPERS



Vernier scale

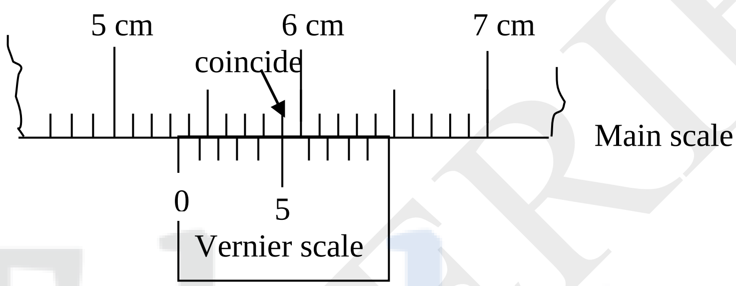


Reading a vernier

There are 10 equal divisions on the vernier scale which make 9 mm in length (read from the main scale). Thus, each division on the vernier scale is $^{9}/_{10}$ mm = 0.9 mm = 0.09 cm. So, the difference in length between the main scale division (0.1 cm or 1 mm) and vernier scale division (0.09 cm or 0.9 mm) is 0.1 mm = 0.01 cm.

- The reading on the main scale to the nearest mm or cm is given by the value on the main scale mark that appears just before the zero of the vernier scale.
- The second figure after the decimal point is given by the number/line/division on the vernier scale which coincides exactly (is colinear) with a division on the main scale.

E.g.



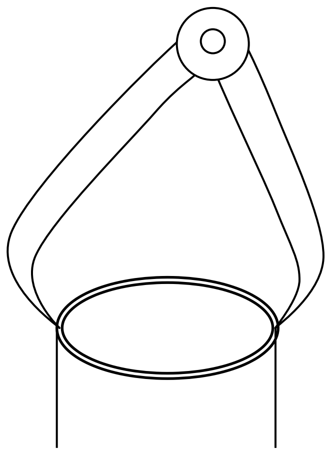
Readings

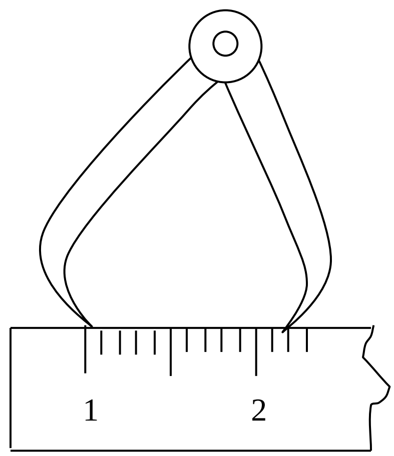
(i) main scale reading = 5.3 cm
(ii) vernier scale reading = 5 x 0.01 cm (5th mark on vernier scale coincides with a division on main scale)

∴ Final reading = main scale reading + vernier scale reading
= 5.3 cm + 0.05 cm
= <u>5.35 cm</u>

Besides vernier calipers, a pair of engineer's calipers can also be used for measuring lengths on solid objects where an ordinary ruler cannot be applied directly. They consist of a pair of hinged steel jaws which are closed or opened until they touch the object in the desired position. The distance between the open jaws is afterwards measured on an ordinary scale of a rule.

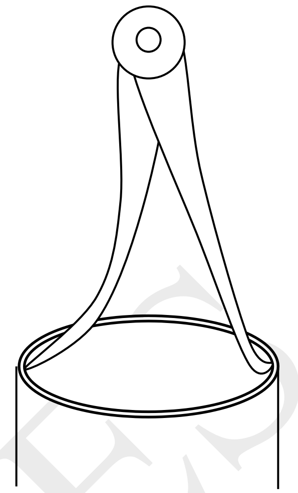
Outside calipers for external diameter





Measuring along a rule

Inside calipers for internal diameter



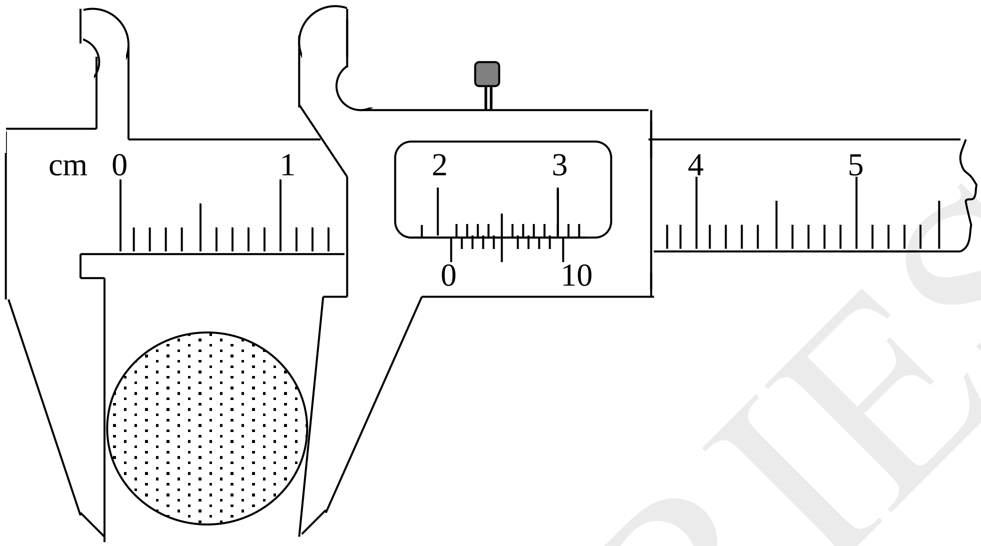
Experiment: To take measurements, using vernier calipers:

(a) Length and width of a small wooden block.
(b) The internal and external diameters of a small test tube.

Object	*Measurement*	*Reading on main scale*	*Reading on vernier scale*	*Final reading = main scale + vernier scale reading*
Wooden cube	Length	4.8 cm	2 x 0.01 cm = 0.02cm	4.8 cm + 0.02 cm = 4.82 cm
Cuboid	Length	6.0 cm	9 x 0.01 cm = 0.09 cm	6.0 cm + 0.09 cm = 6.09 cm
	Breadth	3.7 cm	6 x 0.01 cm = 0.06 cm	3.7 cm + 0.06 cm = 3.76 cm
	Height	2.9 cm	2 x 0.01 cm = 0.02 cm	2.9 cm + 0.02 cm = 2.92 cm
Test tube	Internal diameter	1.6 cm	3 x 0.01 cm = 0.03 cm	1.6 cm + 0.03 cm = 1.63 cm
	External diameter	1.8 cm	9 x 0.01 cm = 0.09 cm	1.8 cm + 0.09 cm = 1.98 cm

Exercises: (Reading ***Vernier Calipers***)

(a)



The diagram shows vernier calipers being used to determine the diameter of a cylindrical rod. What is the reading shown by the calipers?

Solution

Readings

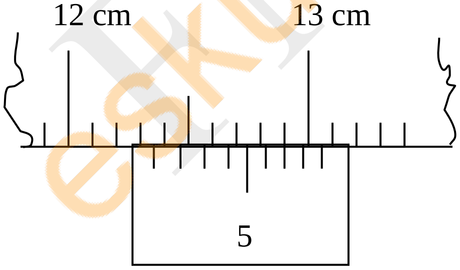
(i) Main scale reading = 2.1 cm = 2.1 cm

(ii) Vernier scale reading = 5 division x 0.01 cm = 0.05 cm

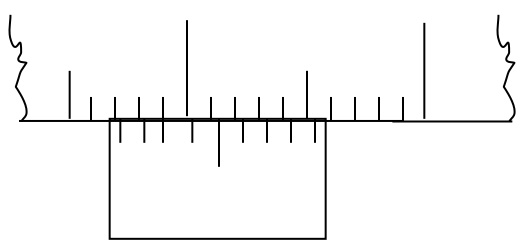
∴ Final caliper reading = main scale reading + vernier scale reading

= 2.1 cm + 0.05 cm = 2.15 cm

(b) (i)



(ii)



Solutions

(b) (i) Readings

⇒ main scale reading = 12.2 cm

⇒ vernier scale reading = 7 x 0.01 cm

∴ Final reading = 12.27 cm

(b) (ii) Readings

⇒ main scale reading = 3.6 cm

⇒ vernier scale reading = 3x0.01cm = 0.03 cm

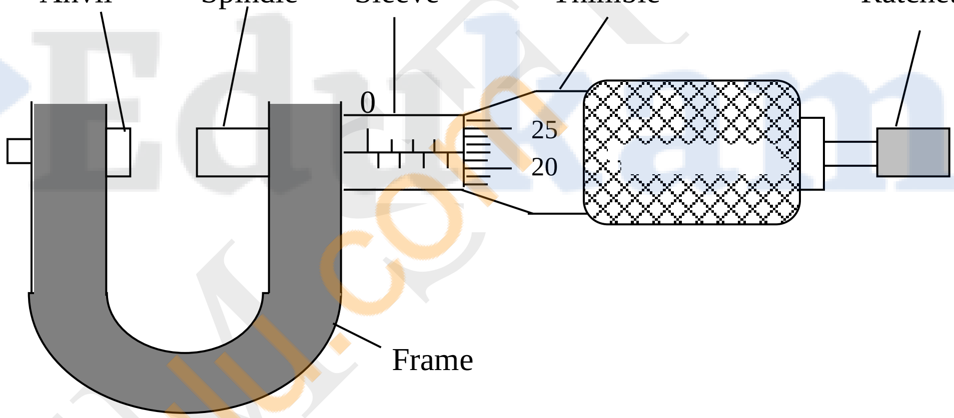
∴ Final reading = 3.63 cm

C. **MICROMETER SCREW GAUGE**

The micrometer screw gauge is an instrument for measuring accurately the diameters of wires or thin rods, the thickness of flat sheets e.g. a razor blade, and other thin objects which cannot be measured accurately using vernier calipers. The micrometer screw gauge measures with an accuracy of 0.01 mm (0.001 cm).

The micrometer screw gauge consists of two scales; a shaft/sleeve scale which is a fixed one gives one decimal place and a drum/thimble scale which is rotating one, gives the second decimal place (in mm). The two scales are in turn connected to a screwed spindle, whose screwed portion is totally enclosed to protect it from damage.

One complete turn/revolution of the thimble, moves the spindle through (forward or back) 0.5 mm (on the sleeve scale). The pitch of the screw is thus said to be 0.5 mm. If less than one revolution/turn is made, the length/distance moved through by the spindle is read on the thimble scale alone. For a thimble which has a scale of 50 equal divisions round it, each division represents
$^{0.5\text{ mm}}/_{50} = 0.01$ mm.



Reading a micrometer

The object whose thickness is to be measured rests on the face of the anvil and then the thimble is turned gently by means of the ratchet until the face-end of the spindle just touches the object gently. The ratchet prevents the user from exerting undue pressure by clicking when no further turning of the thimble is desired.

- Two readings can thus be taken in mm:

(i) the sleeve scale reading, gives up to the first decimal place (the forward or backward movements of the spindle) e.g. 0.5 mm, 1.5 mm, 2.5 mm, 3.5 mm, 4.5 mm, 5.5 mm etc.

(ii) The thimble scale reading gives the second decimal place .0.08 mm. e.g. 0.20 mm, 0.21 mm, 0.25 mm

$\therefore$ Final reading = sleeve scale reading + thimble scale reading

For example, if:

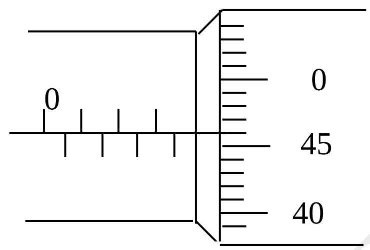
(i) The reading on the sleeve = 3.5 mm
(ii) The reading on the thimble = 21 divisions = 22 x 1 mm = 0.22 mm

$\therefore$ Final reading = reading on sleeve + reading on thimble
= 3.5 mm + 0.22 mm = 3.72 mm

Exercises (Reading Micrometer Screw Gauges)

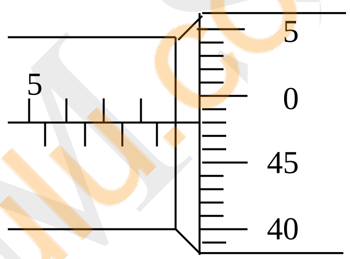
1. Write down the micrometer screw gauge readings shown below:

(a)



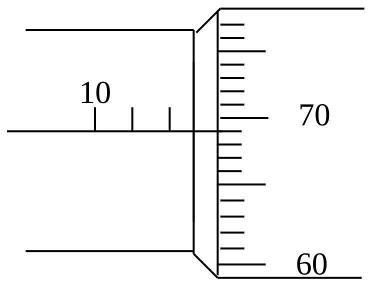
Readings
(i) Sleeve scale reading = 3.5 mm
(ii) Thimble scale reading = 46 division x 0.01 mm = 0.46 mm
$\therefore$ Final reading = 3.5 mm + 0.46 mm = 3.96 mm

(b)



Readings
(i) Sleeve scale reading = 8.5 mm
(ii) Thimble scale reading = 48 x 0.01 mm = 0.48 mm
$\therefore$ Final reading = 8.5 mm + 0.48 mm = 8.98 mm

(c)



Readings

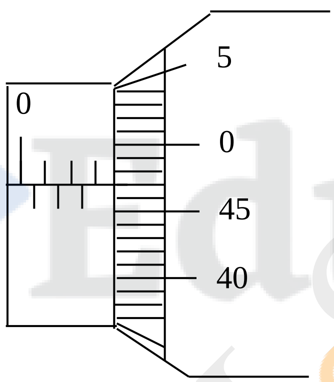
(i) Sleeve scale reading = 12.0 mm

(ii) Thimble scale reading = 69 division x 0.01 mm = 0.69 mm

$\therefore$ Final reading = 12.0 mm + 0.69 mm = <u>12.69 mm</u>

2. Find the reading given that the horizontal (sleeve) scale is in mm above and half mm below:

(a)



Readings

(i) sleeve scale reading = 3.0 mm

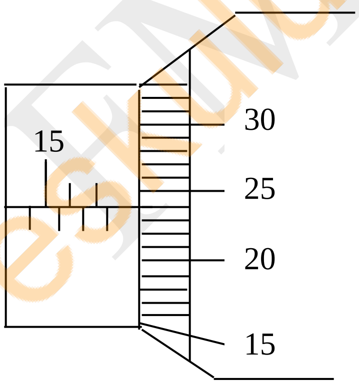
(ii) thimble scale reading = 47 x 0.01 mm

$\therefore$ Final reading = sleeve scale reading + thimble scale reading

= 3.0 mm + 0.47 mm

= <u>3.47 mm</u>

(b)



Readings

(i) sleeve scale reading = 17.5 mm

(ii) thimble scale reading = 24 x 0.01 mm

= 0.24 mm

$\therefore$ Final reading = sleeve scale reading + thimble scale reading

= 17.5 mm + 0.24 mm

= <u>17.74 mm</u>

Experiment: To take measurements using micrometer screw gauge:

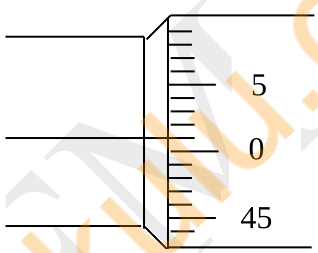
(a) thickness of a coin
(b) diameters of a coin and a metal wire.

Object	*Measurement*	*Reading on sleeve*	*Reading on thimble = No. of divisions x 0.01 mm*	*Final reading: sleeve + thimble readings*
20 Ngwee Coin	Thickness	2.0 mm	9 x 0.01 mm = 0.09 mm	2.0 mm + 0.09 mm = 2.09 mm
5 Ngwee Coin	Diameter	19.0 mm	47 x 0.01 mm = 0.47 mm	19.0 mm + 0.47 mm = 19.47 mm
Metal wire	Diameter	6.5 mm	40 x 0.01 mm = 0.40 mm	6.5 mm + 0.40 mm = 6.90 mm

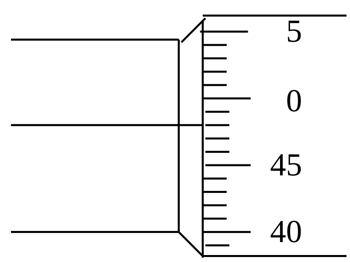
Precautions when using a micrometer screw gauge

1. Wipe clean the faces of anvil and spindle before use to remove any dust/dirt particles which might cause false readings.
2. The instrument may have a <u>zero error</u> (the instrument shows a reading other than zero when the space between anvil and spindle is closed without object) space between anvil and spindle. Thus, the zero reading must <u>always</u> be checked and recorded and be used to correct all your measurements, (i.e. a '+' or '–' correction should be applied to the final answer).
   e.g. The diagrams below show the thimble scales for the space between anvil and spindle which are closed without object in between.

(a)



(b)



What zero error is shown in each case. What corrections of zero errors would be applied to the readings obtained from these scales.

Solutions

(a) Zero error = 0.01 mm
$\therefore$ Correction to readings obtained by such a faculty instrument: Reduce all your readings by 0.01 mm (a – 0.01 mm correction)

(b) Zero error = 0.02 mm

∴ Correction to readings obtained by such a faculty instrument: Add 0.02 mm to all your readings (a +0.02 mm correction)

3. With object e.g. wire in the gap, make a firm but gentle contact with the screw, i.e. do not over-screw.

4. For such objects as wire take measurements at three different places along the wire to allow for lack of uniformity.

The readings/measurements obtained from the different measuring instruments can be used in calculating quantities such as the area, and volume of objects.

AREA MEASUREMENT

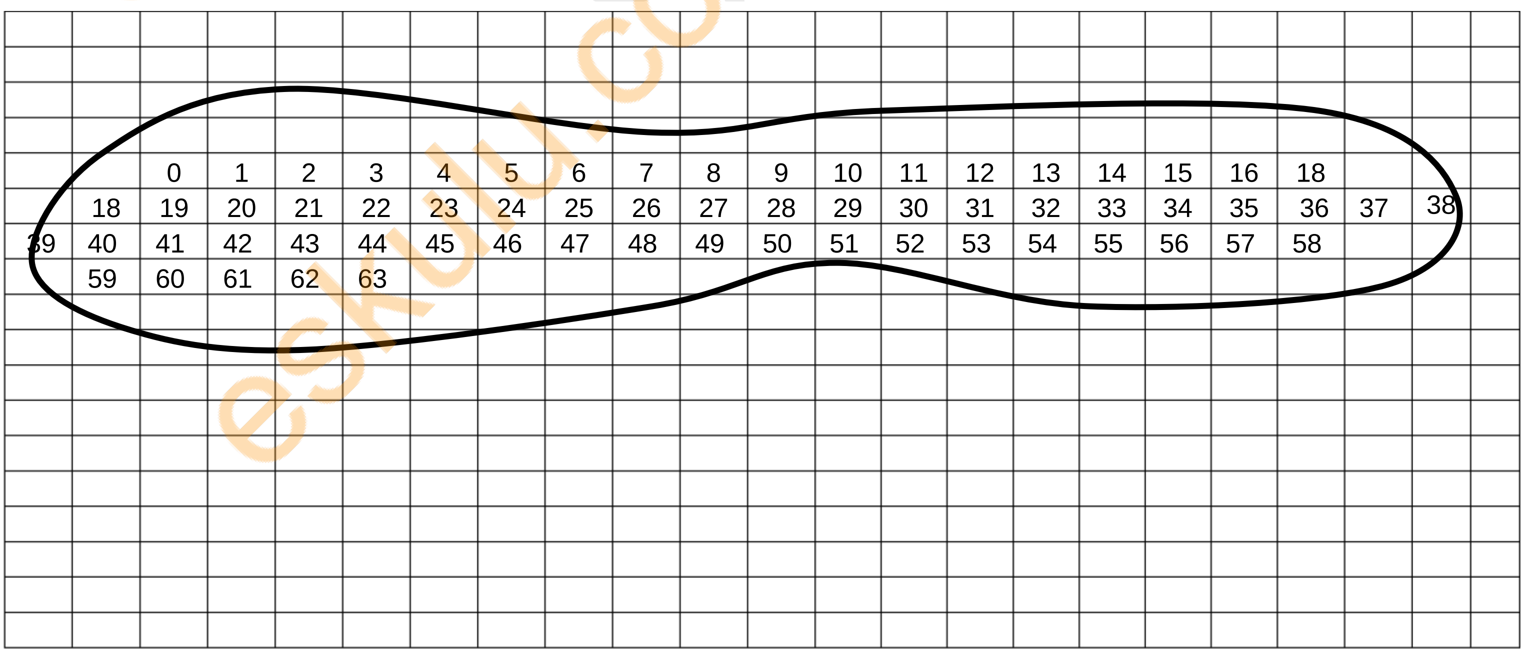
Definition: Area is the two dimensional space or extent of measurement of a flat surface bounded by a figure.

The S.I. unit for area is the square metre (m^2). Two type of areas will be considered:

1. **Area of irregular shaped bodies is found by estimation method on squared paper.**

The area of an irregular object e.g. leaf, the foot (shoe sole), the palm can be measured by using the squared paper method.

The outline of the irregular object is traced out on squared paper, such as graph paper, as shown below:

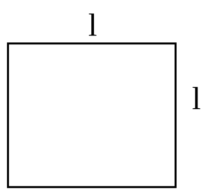
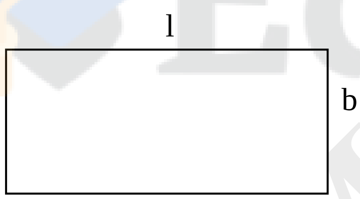
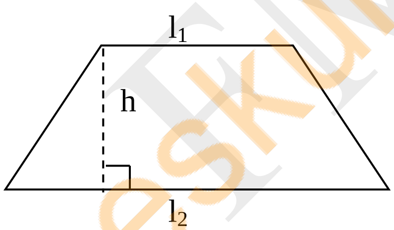
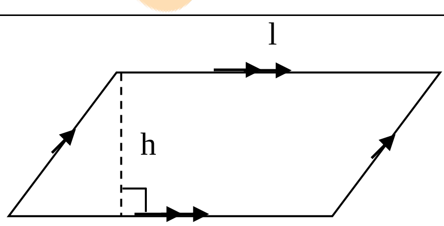


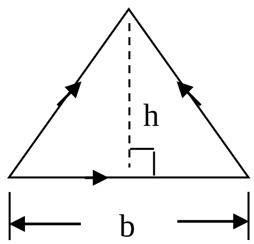
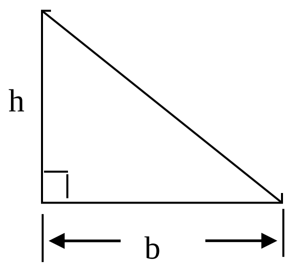
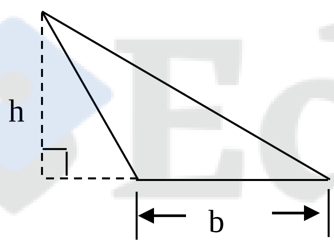
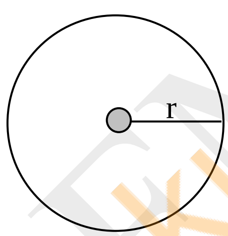
The squares inside the boundary of the outline that are half or more than half are counted as one while those that are less than half are ignored.

The total number of the squares counted is multiplied by the area of one square to get the area of the irregular shaped object.
e.g. 65 square units = 65 units^2
if area of one square = 0.2 cm
then Area of irregular shaped object = 65 x 0.04 cm = <u>2.6 cm^2</u>

2. **Area of regular shaped bodies**

The areas of regular shapes can be calculated by substituting the values of the obtained measurements in a known mathematical formula

Shape of Object	***Name of Shape***	***Formula for Area (m^2)***
	Square	$A = l^2$
	Rectangle	A = l x b
	Trapezium	$A = \left(\frac{l_1 \; x \; l_2}{2}\right) x \; h$
	Parallelogram	A = l x h

	Triangles	
	- acute triangle	A = ½ bh
	- right angled triangle	A = ½ bh
	- obtuse angled triangle	A = ½ x b x h
	Circle	A = πr^2

Exercise (regular shaped bodies) (area measurement)

1. A square has side 5 cm. Calculate it's are"

   (a) in cm^2 (Ans: 25 cm^2)
   (b) in m^2 (Ans: 0.0025 m^2)

2. Change

   (a) 1 cm^2 to m^2 (Ans: 1×10^{-4} m^2)
   (b) 2 cm^2 to mm^2 (Ans: 200 mm^2)
   (c) 4 m^2 to cm^2 (Ans: 4×10^4 cm^2)

VOLUME MEASUREMENT

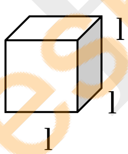
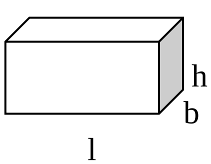
Definition: Volume is the amount of space occupied by a body or an object.
The S.I. unit of volume is the <u>cubic metre</u> (m^3) but as this is rather large, for most purposes the cubic centimetre (cm^3) is used. The litre or cubic decimetre and millilitre can also be used for volumes of liquids. Also the

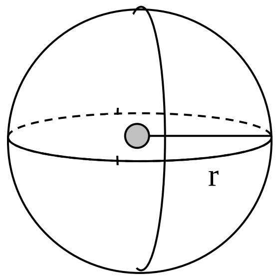
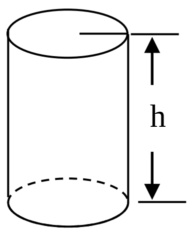
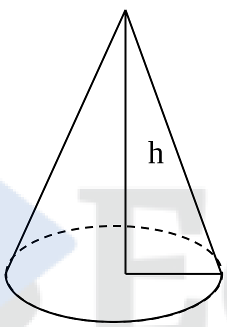
$1\ m^3 = 1 \times 10^6\ cm^3$
$\boxed{1 \text{ litre} = 1\,000\ cm^3 = 1\,000 \text{ ml}}$
$\boxed{1\ cm^3 = 1 \text{ ml}}$

$(100\ cm)^3 = (1\ m)^3$
$1\,000\,000\ cm^3 = 1\ m^3$
1 cubic decimeter (dm^3) = 1 litre

(a) **Volume of regular shaped solids**

The volume of regular solids can be determined by substituting the values of the obtained measurements in a known mathematical formula.

Shape of Object	***Name of Shape***	***Formula for Volume (m^3)***
	Cube	$V = l \times l \times l = l^3$
	Cuboid	$V = l \times b \times h$

	Sphere	$V = \frac{4}{3} \pi r^3$
	Cylinder	$V = \pi r^2 h$ $V = Ah$
	Cone	$V = {}^1/_3 \pi r^2 h$

Exercise (regular shaped bodies) (volume measurement)

1. Find the volume of a cube of side 4 cm: (Ans: 64 cm^3)
2. Find the volume of a cuboid of length 3 cm, breadth 2 cm and height 5 cm. (Ans: 30 cm^3)
3. A cylinder has diameter 8 cm and height 14 cm. Calculate it's volume (where necessary, take $\pi = {}^{22}/_7$) (Ans:)

Exercise

A) **Volume of regular shaped bodies**

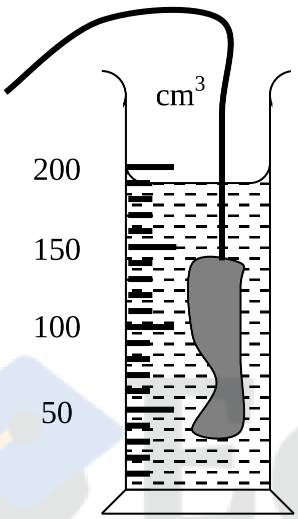
1. A cube of side 3 cm is placed in a graduated measuring cylinder. 125 cm^3 of water is then added and the cube remains at the bottom of the cylinder. What will be the reading on the measuring cylinder.

Solution

Reading on the cylinder = volume of water + volume of cube in the cylinder
= 125 cm^3 + (3 x 3 x 3) cm^3
= <u>152 cm^3</u>

B) (i) **Volume of irregular shaped bodies**

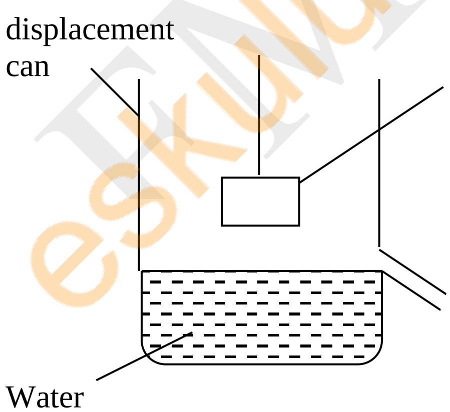
1. A body of mass 500 g was suspended in 100 cm^3 of water by a piece of cotton as shown. What is the volume of the body?



Solution
Vol. of body = vol. of water + body – vol. of water alone
= 190 cm^3 – 100 cm^3 = <u>90 cm^3</u>

(ii) **Volume of irregular solids (not descent)**

1. The diagram below shows a displacement can which has been filled with water.



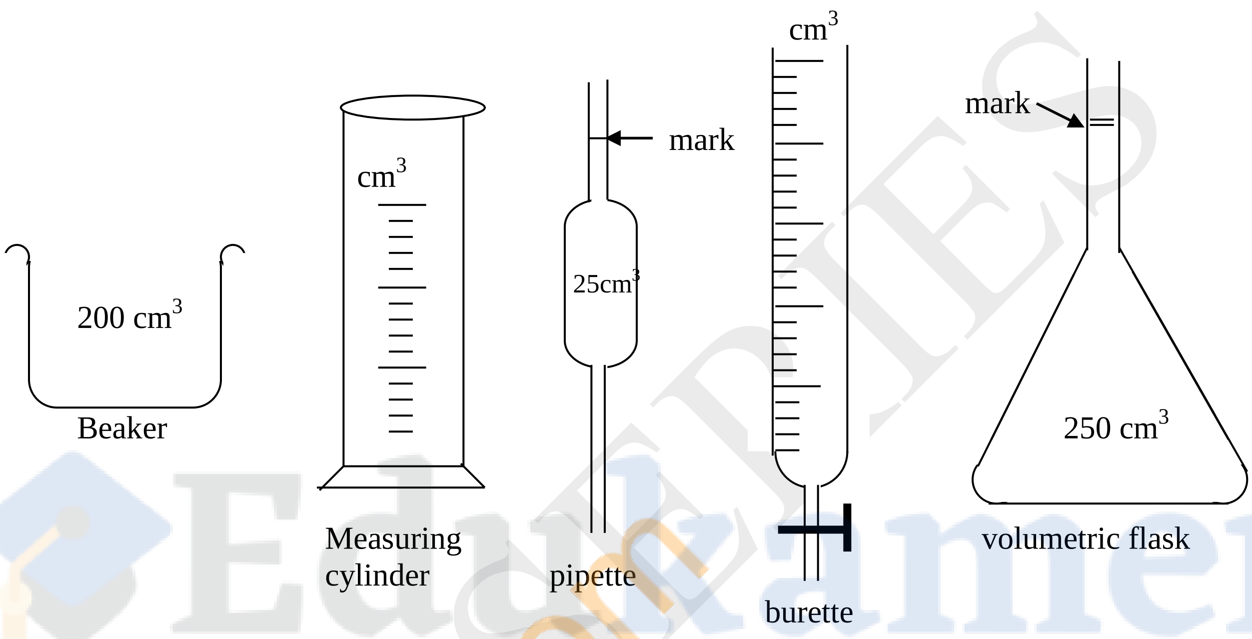
When the block of is lowered into the can until it is totally immersed in the water, 110 cm^3 of water overflow. What is the volume of block of metal?

Solution
Volume of displaced water = volume of block of metal = <u>110 cm^3</u>

(b) **Volume of Liquids**

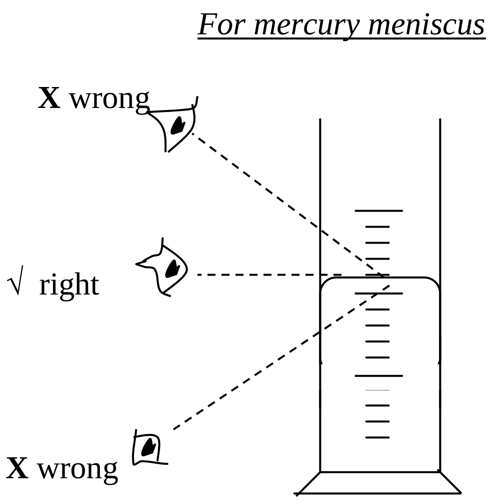
A measuring cylinder, burette, pipette, measuring flask (or volumetric flask) can be used to measure the volume of a liquid. The internal volume of these apparatus are pre-determined, calibrated and marked by the manufacturers.

- The burette is used for delivering any required volume up to its total capacity.
- The pipette, the beaker and the volumetric flask are used for getting pre-determined volumes.

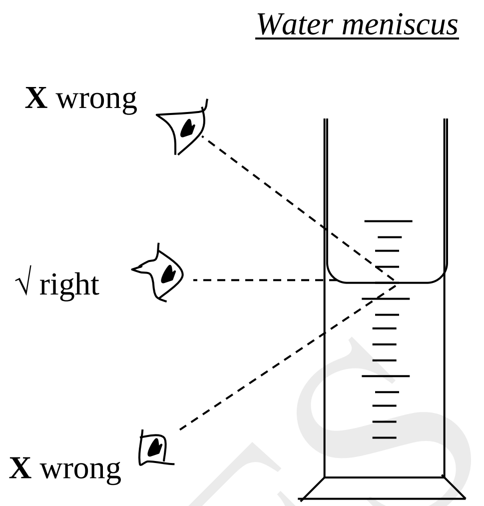


Precautions when taking readings

1. The pipette and burette must be vertical to avoid errors due to tilting.
2. Place the measuring cylinder and volumetric flask, beaker upright on a horizontal flat (table/bench) surface.
3. Take the reading when the liquid is settled (not shaking).
4. Always take the reading from the lower meniscus (reading should be taken in a horizontal plane at ninety degrees to the meniscus) for a concave meniscus and from the top of the convex meniscus.



(Convex meniscus)



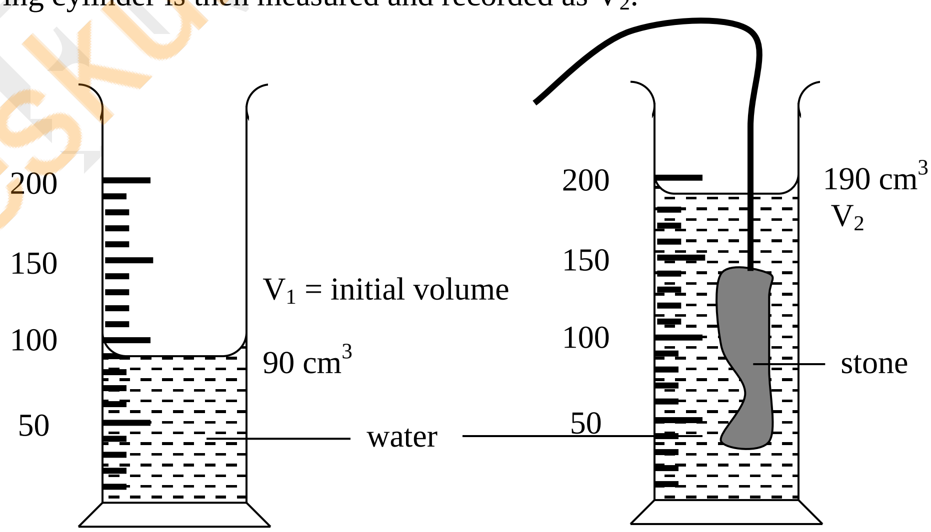
(Concave meniscus)

(c) **Volume of irregular shaped bodies**

Volume of an irregularly shaped solid, e.g. stone can be determined by **displacement method** using a liquid, generally water, a measuring cylinder and displacement can. Of course, the method only work for **solids** which do not dissolve or react in water. In this method; the principal involved is that a solid will displace a volume of liquid equal to its own volume when it is fully submerged into the liquid:
Volume of displaced liquid = volume of irregular solid that has displaced the liquid.

(i) **For an irregular solid which can easily fit into a measuring cylinder**

For an irregular solid which can easily go (fit) into a measuring cylinder, the liquid e.g. water is poured into the measuring cylinder and the initial volume measured and recorded as V_1.
The irregular solid is then gently lowered, by means of a string, into the measuring cylinder and immersed (or submerged) completely in water. The final volume on the measuring cylinder is then measured and recorded as V_2.



Here V_1 = volume of water (or any liquid) alone

V_2 = volume of water + irregular object (stone)

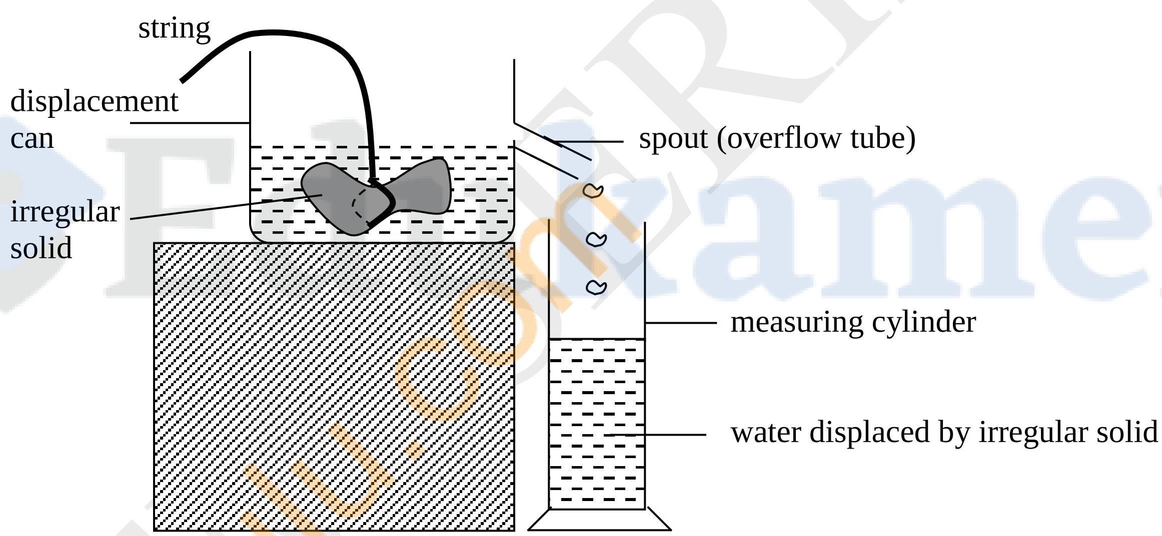
$\therefore$ Volume of irregular solid = $V_2 - V_1$

If $V_1 = 90\ cm^3$, $V_2 = 190\ cm^3$, then

$$\begin{aligned}\text{Volume of solid} &= V_2 - V_1 \\ &= 190\ cm^3 - 90\ cm^3 \\ &= 5\ cm^3\end{aligned}$$

(ii) **For an irregular solid too big for a measuring cylinder**

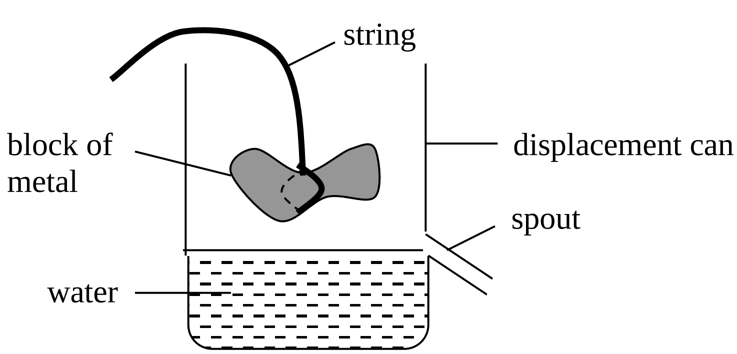
If an irregular object is too big and can not fit into a measuring cylinder, it's volume can be found by using a **displacement can** (or overflow can or eureka can), liquid (generally water) and a measuring cylinder. Water is now poured into a displacement can until it over flows. When no more water drips from the overflow tube (spout), put a clean and dry measuring cylinder directly under the spout. Then immerse the irregular solid gently by means of string until it is **completely immersed** under water in the displacement can. The displaced water is collected into the measuring cylinder and the volume recorded.



Volume of irregular object = Volume of water displaced (reading on measuring cylinder)

Exercise

The diagram shows a displacement can which has been filled with water to the spout.

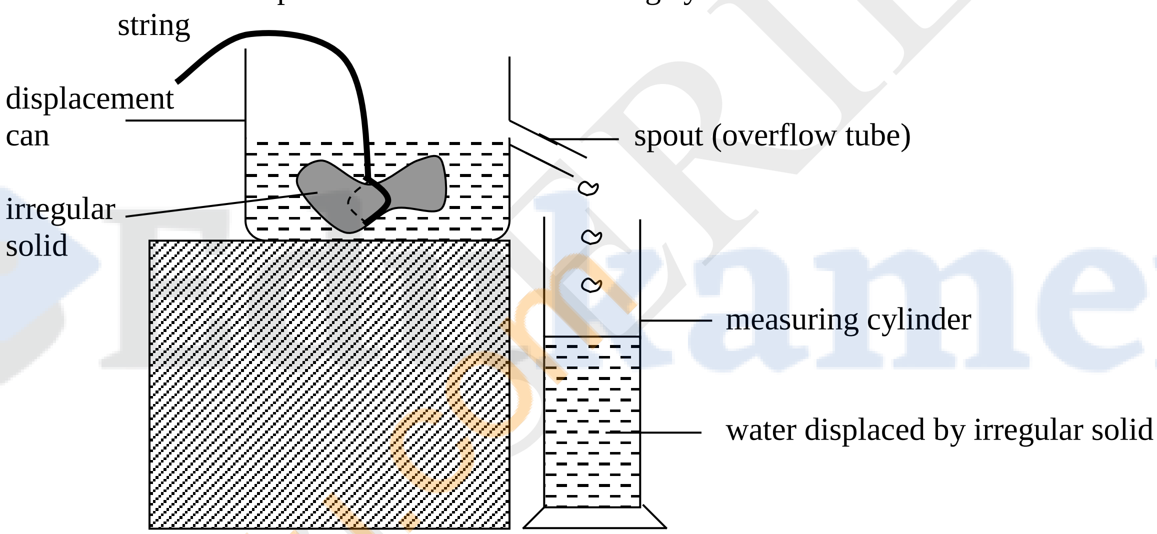


When the block of metal is lowered into the can until it is totally immersed in the water, 110 cm^3 of water overflows. What is the volume of the block of metal (Show your reasoning).

Volume of irregular object = volume of water displaced
$\therefore$ Volume of the block of metal
= 110 cm^3

(ii) **For an irregular solid too big for a measuring cylinder**

If an irregular solid is large enough not to go into a measuring cylinder, its volume **can** be found by using **displacement** (overflow or Eureka) can water and a measuring cylinder. Pour water into a displacement can until it overflows. When no more water drips from overflow tube (spout), place an empty measuring cylinder under the spout. Gently slide the irregular solid into the can by means of a string/thread and immerse it **completely** in water. Collect the displaced water in the measuring cylinder and read the volume.



Volume of displaced water = volume of irregular body

MEASUREMENT OF TIME

Time is an interval between two identical events which repeat at regular intervals. Therefore, time can be measured by any event which repeats itself at regular intervals e.g. beat of pulse, steady dripping of water from a tap etc. In traditional clocks and watches a small wheel (the balance wheel) oscillates to and fro; in digital clocks and watches the oscillations are produced by a tiny quartz crystal; a swinging pendulum controls a pendulum clock.

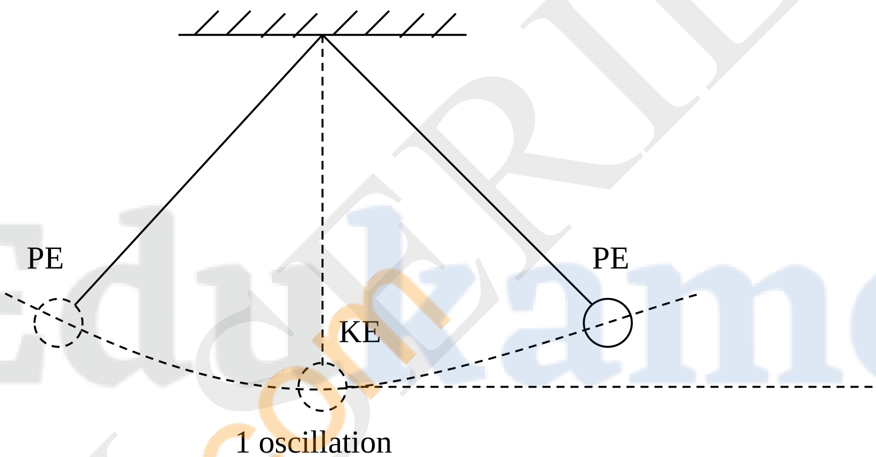
The S.I. unit of time is the second(s). Other smaller units include the milliseconds, nano second while larger units include the minute, hour, day, week, month, year, decade, generation, century, millennium etc.

1 minute = 60 seconds
1 hour = 60 minutes = 60 x 60 s = 3 600 seconds
1 s = 1 000 ms
1 day = 24 hours

All time measuring devices rely on some kind of constantly repeating oscillations.

The swinging (simple) pendulum

A swinging pendulum controls a pendulum clock. A simple pendulum is a small heavy body (lead bob or brass bob) suspended by a light inextensible string.



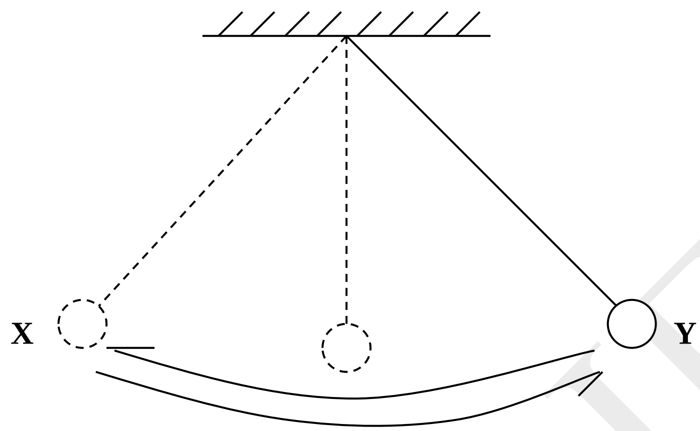
For a simple pendulum:

- One complete to and fro movement of the bob is called an **oscillation** or cycle or vibration.
- The time taken to make one complete oscillation is called the **period** or **periodic time, *T***.

The pendulum is a useful time-keeper because it marks out equal intervals of time i.e. its periodic time is constant even when the oscillations are dying out.

Example:

It takes 20 seconds for a pendulum to swing from **X** to **Y** and back again twenty times. What is the period of this pendulum?



Solution:

Periodic time, T = time taken to make 1 complete oscillation.

20 oscillations = 20 seconds

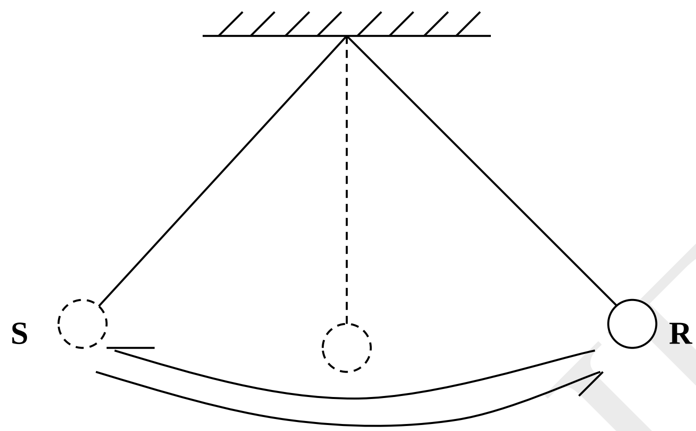
$$\frac{20\,oscillation}{20} = \frac{20\,s}{20}$$

1 oscillation = 1 s

$\therefore T = 1$ s

Exercise

1. It takes 13.8 seconds for a pendulum to swing from **S** to **R** and back again twenty times. What is the period of this pendulum?



Periodic time, T = time taken to make 1 complete oscillation.
20 oscillations = 13.8 seconds

$$\frac{20\,oscillation}{20} = \frac{13.8\,s}{20} = 0.69\,s$$

$\therefore$ Periodic time, T = 0.69 second

MEASUREMENT OF MASS

Definition: The mass of a body is the quantity of matter contained in the body.
The S.I. unit of mass is kilogram (kg).
However, the mass of smaller objects can be measured in grams (g) and milligrams (mg).

1 000g = 1 kg
1 000 mg = 1 g

Larger masses can also be measured in tonnes.

1 tonne = 1 000 kg

Mass is measured using a beam balance. Generally

(i) Triple beam balance
(ii) Lever balance
(iii) Top-pan (compression) balance
(iv) Electronic balance (most modern and accurate) can be used.

Precaution: (i) Never attempt to find the mass of a hot object
(ii) Always wipe the outside of a bottle or vessel containing liquid before placing it on the balance pan

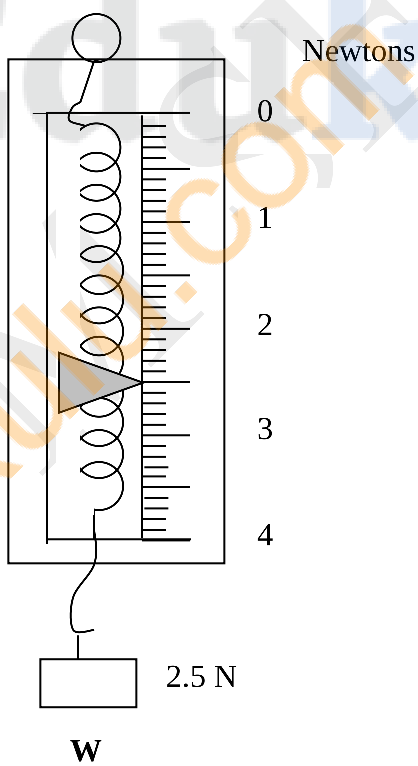
At this stage the terms mass and weight should **never be** used interchange ably.

Weight of a body is the force of gravity, acting on the body.
The S.I. unit of weight is Newton (N).

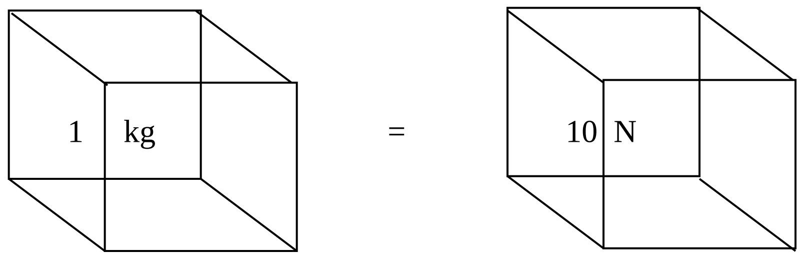
MEASUREMENT OF WEIGHT

Definition: The weight of a body is the force of gravity acting on the body (and which the body in return exerts on its support).
W = mg
Where m = mass of object in kg
g = acceleration due to gravity in m/s^2 or N/kg.
hence W = weight in newtons (N)
The S.I. unit of weight is thus newtons (N). The weight of a body can be measured by hanging the body on a spring balance, calibrated in newtons.

A Spring Balance



Weight varies from one place to another, depending on the gravitational intensity of a place. On the surface of the Earth the weight of a body of mass 1 kg is 9.8 N. This is often taken as 10 N. Thus: 1 kg mass = 10 N weight.



1 kg = 10 N
1 000 g 10 N
100 g = 1 N

Differences between *mass* and *weight*

Mass	***Weight***
1. Quantity of matter present in a body	Force of gravity acting on a body
2. S.I. of mass is kilogram (kg)	S.I. unit of weight is newtons (N)
3. Mass remains the same everywhere	Weight varies from one place to another depending on gravitational intensity.
4. Measured by using a beam balance	Measured by using a spring balance.
5. Scalar quantity	Vector quantity

Exercise (measurement of mass/weight)

(Where necessary take a 1 kg mass to have 10 N weight. Gravitational pull on moon is $^{1}/_{6}$ that on earth).

1. (a) Find the weight of the following bodies on Earth

   (i) 5.5 kg (Ans: 55 N)
   (ii) 500 g (Ans: 5 N)

   (b) Find the masses of the following bodies on Earth.

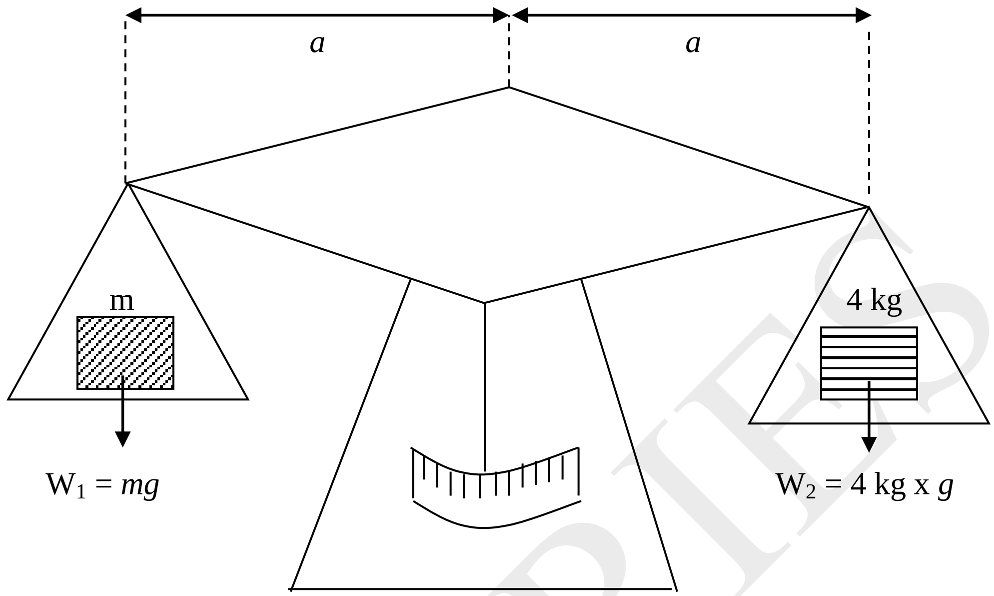
   (i) 9 N (Ans: 0.9 kg)
   (ii) 18 N (Ans: 1.8 kg

2. A body of mass 6.6 kg was taken to the moon from Earth. What is its

   (a) mass on the moon (Ans: 6.6 kg)
   (b) (i) weight on Earth (Ans: 66 N)
   (ii) weight on moon (Ans: 11 N)

A common beam balance clearly compares masses and **not** weight. Suppose an unknown mass *m* in one scale pan is counter-balance by exactly a mass of 4 kg on the other scale pan:

If the beam balance is a lever with equal arms length, a, then on weighing, the moments of the force about the pivot are equal (i.e. beam balances).



$W_1 \times a = W_2 \times a$

$m_1 g \times a = m_2 g \times a$ (a and g cancel as they are same both sides)

$m_1 = m_2$

$\therefore m_1 = 4\text{ kg} = m_2$

The same result m = 4 kg would be obtained with a common balance at any part of the world since it is independent of g.
Hence a common balance compares masses!!

Exercise 2

1. When a block of metal is hung in air from a spring balance the reading is 9.6 N.

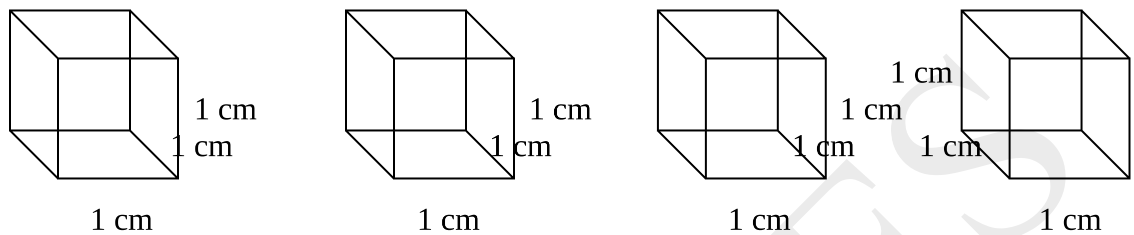
   (a) What is the weight of the block of metal? (Ans: 9.6 N)
   (b) What is the mass of the block of metal? (Ans: 0.96 N)

DENSITY

Equal volumes of different substances have different masses. This gives us some idea of mass of equal volumes.

e.g.

Gold	Water	Copper	Wood

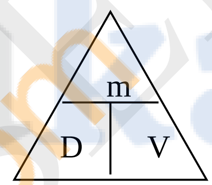


V = 1 cm^3	V = 1 cm^3	V = 1 cm^3	V = 1 cm^3
m = 19.3 g	m = 1 g	m = 8.9 g	m = 0.8 g

Definition: Density is the mass per unit volume of a substance.

$\therefore$ Density = $\frac{mass}{valume}$

D = $\frac{m}{v}$ or $\rho = \frac{m}{v}$



Also V = $\frac{m}{\rho}$ *and* $m = \rho V$ ($\rho = rho$)

The S.I. unit of density is the kilogram per cubic metre (kg/m^3 or kgm^{-3}). However, for smaller density measurements the gram per cubic centimeter (g/cm^3 or gcm^{-3}) is also used converting from g/cm^3 to kg/m^3 (and vice versa).

$$g/cm^3 \underset{\div 1\,000}{\overset{\times 1\,000}{\rightleftarrows}} kg/m^3$$

e.g.

1. The density of mercury is 13.6 g/cm^3 in kg/m^3.
   13.6 g/cm^3 = 13.6 x 1 000 kg/m^3 = 13 600 kg/m^3
2. The density of aluminium is 2 700 kg/m^3 in g/cm^3.
   2 700 kg/m^3 = $\frac{2700}{1000} g/cm^3$ = 2.7 g/cm^3

Exercise

1. (a) The density of pure water at 4^{o}C is 1.0 g/cm^3. What is the density of water in kg/m^3? (Ans: 1 000 kg/m^3)

   (b) The density of gold is 19 300 kg/m^3. What is the density of gold in g/cm^3? (Ans: 19.3 g/cm^3)

Density of some common substances

Substances	*Density (g/cm^3)*	*Density (kg/m^3)*
Solids		
Aluminium	2.7	2 700
Copper	8.9	8 900
Gold	19.3	19 300
Iron	7.8	7 800
Lead	11.3	11 300
Glass	2.5	2 500
Wood	0.4 to 0.8	400 to 800
Ice (at 0^{o}C)	0.92	920
Liquids		
Pure water (at 4^{o}C)	1.0	1 000
Mercury	13.6	13 600
Meths	0.8	800
Paraffin	0.8	800
Petrol	0.8	800

Density is one of the characteristic physical property of a material that can help us identify different materials.
The temperature at which the density is reported must be specified as density varies with temperature. For example, when a substance is heated its **mass** remains the **same** but its volume increases as it expands, hence its **density** will **decrease**.

When the temperature at which the density was measured is not specified assume it was room temperature (25^{o}C).

NB: The density of pure substance e.g. pure metal is constant (same) regardless of the size.

Importance of density measurements

1. In construction, Architects and Engineers use densities of various building materials.
2. To measure purity of substances.

Floating and Sinking as related to density

An object sinks in a substance of smaller (lesser) density than its own. It floats partially or wholly in a substance of larger density than its own.
For example, a piece of glass of density 2.5 g/cm^3 sinks in water (density 1.0 g/cm^3) but floats in mercury (density 13.6 g/cm^3.

Exercise

1. Why does a piece of wood float and a piece of lead sink in water?
2. Which is denser, milk or cream? Give a reason for your answer.

Measurement of density

To find the density of a substance, the mass, *m* and the volume, *V* of the substance must be determined as accurately as possible.
The mass of any substance (solid, liquid or gas) can be measured using a beam balance or electronic balance. The volume can be found depending on the shape and state of object.

(a) **Density of Solids**

Solids can be in two categories:

(i) regular shaped solid
(ii) irregular shaped solid

(i) ***Density of regular shaped solid***

The mass can be found easily by using a suitable balance while the volume can be calculated using a known mathematical formula (after measuring the appropriate dimensions)
Then

$$\rho = \frac{m}{v} \; g/cm^3$$

(ii) ***Density of irregular shaped solids***

The mass can be determined by using a suitable balance and the volume can be found using the displacement method.
Then

$$\rho = \frac{m}{v} \; g/cm^3$$

(b) **Density of liquids**

A known volume of liquid is transferred from a burette or a measuring cylinder or pipette or volumetric flask into a pre-weighed beaker.
The beaker is then re-weighed with its contents and the mass difference gives the mass of the liquid:

$$density\ of\ liquid = \frac{mass\ of\ liquid}{volume\ of\ liquid}\ g/cm^3$$

Exercise

1. A piece of anthracite has a volume of 15 cm^3 and a mass of 27 g. What is its density in

   (a) g/cm^3 (Ans: 1.8 g/cm^3)
   (b) kg/m^3 (Ans: 1 800 kg/m^3)

2. A room measuring 8 m by 5 m by 3 m is full of air of density 1.2 kg/m^3.

   (a) What is the volume of the air in the room? (Ans: 120 m^3)
   (b) What is the mass of the air in the room? (Ans: 144 kg)
   (c) What is the weight of the air in the room? (Ans: 1 440 N)
   (d) The room is open to the atmosphere in which conditions are constant. State and explain the changes, that take place in the density of the air in the room when the room temperature rises.

3. The following are typical experiment results obtained by grade 11C learners in an experiment with glycerine.
   Volume of glycerine = 28.2 cm^3
   Mass of empty beaker = 25.2 g
   Mass of beaker + glycerine = 60.4 g
   Use the information to calculate the density of glycerine. (Ans: 1.25 g/cm^3)

4. A cube of glass of side 5 cm and mass 306 g has a cavity inside it. If the density of glass is 2.55 g/cm^3, what is the volume of the cavity? (Ans: 5 cm^3)

5. A Perspex box has a 10 cm square base and contains water to a height of 10 cm. A piece of rock of mass 600 g is lowered into the water and the level rises to 12 cm.

   (a) What is the volume of water displaced by the rock? (Ans: 200 cm^3)
   (b) What is the volume of the rock? (Ans: 200 cm^3)
   (c) Calculate the density of the rock. (Ans: 3 g/cm^3)

6. An empty 60 litre petrol tank has a mass of 10 kg. What will be its mass when full of fuel of density 0.72 g/cm^3? (Ans: 53.2 kg)

7. A wooden block whose volume is 16 cm^3, has a hole with the volume of 1.0 cm^3 drilled in it. The hole is filled with lead. Will the block sink or float in water? Give reasons for your answer and show any calculation you make.
(density of lead = 11 g/cm^3 ; wood = 0.5 g/cm^3 ; water = 1.0 g/cm^3)

(c) **Density of mixture**

The density of a mixture depends on the proportions in which the substances are mixed.

$$\rho_{mix} = \frac{m_{mix}}{v_{mix}}$$

- m_{mix} is the mass of the mixture which is the sum of the masses in the mixture.
- V_{mix} is the total volume of the mixture which is the sum of the volumes in the mixture (provided no volume change takes place on mixing).

Example

If 200 cm^3 of water (density 1.0 g/cm^3) is mixed with 300 cm^3 of methylated spirit (density 0.8 g/cm^3), what is the density of the mixture?

$$\rho_{mix} = \frac{m_{mix}}{v_{mix}}$$

From m = ρ v

$$m_{water} = \frac{1.0\,g}{\cancel{cm^3}} x\ 200\,\cancel{cm^3} = 200\,g$$

$$m_{meth} = \frac{0.8\,g}{\cancel{cm^3}} x\ 300\,\cancel{cm^3} = 240\,g$$

$$\therefore \rho_{mix} = \frac{200\,g + 240\,g}{200\,cm^3 + 300\,cm^3} = \frac{440\,g}{500\,cm^3}$$

$$\rho_{mix} = 0.88\,g/cm^3$$

Exercise

1. If 200 g of water (density 1.0 g/cm^3) is mixed with 240 g of methylated spirit (density 0.8 g/cm^3), what is the density of the mixture? (Ans: 0.88 g/cm^3)

2. Calculate the density of a mixture of 360 g of liquid **A** (density 1.2 g/cm^3) and 100 g of liquid **B** (density 1.0 g/cm^3). (Ans: 1.15 g/cm^3)

3. A light alloy consists of 70% aluminium and 30% magnesium by mass. What is its density? (Density of aluminium = 2 700 kg/m^3; magnesium = 1 740 kg/m^3)
(Ans: 2 325.58 kg/m^3)

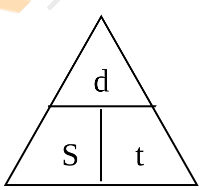
4. When salt is added to water the resulting solution is called brine. If 56 g of salt is added to 1 000 cm^3 of water, calculate the density of brine. Assume the density of water is 1.0 g/cm^3. What other assumption must be made in this calculation.

SPEED, VELOCITY AND ACCELERATION

SPEED

Speed is a change of distance moved with time (or rate of distance moved).
The S.I. units of speed are **metre per second** (m/s or ms^{-1}). Other non-S.I. units in common use are kilometres per hour (km/hr or kmhr^{-1}).
Speed is a **scalar quantity** (i.e. it has only size or magnitude but no direction).
Usually its very difficult to measure the actual value of speed of a body. What we usually measure is the **average speed**. Since a body may not move at a constant speed, throughout

$$Average\,speed = \frac{total\ distance}{total\ time}\ m/s$$



Also

1. d = S x t
   distance = average speed x time
2. $t = \dfrac{d}{S}$

$$time = \frac{dis\tan ce}{average\,speed}$$

Exercise

1. Change to m/s

   (a) 36 km/hr (Ans: 10 m/s)
   (b) 72 km/hr (Ans: 20 m/s)
   (c) 90 km/hr (Ans: 25 m/s)

Uniform or Constant Speed

Uniform speed is when a body travels equal distances in equal times:

e.g.

Distance (m)	0	2	4	6	8
Time (s)	0	1	2	3	4
Speed (m/s)	0	2	2	2	2

$$\therefore Average\,speed = \frac{total\ dis\tan ce}{total\ time} = 2m/s$$

Exercise

1. A car moves 225 km in 5 hrs. Find its average speed in

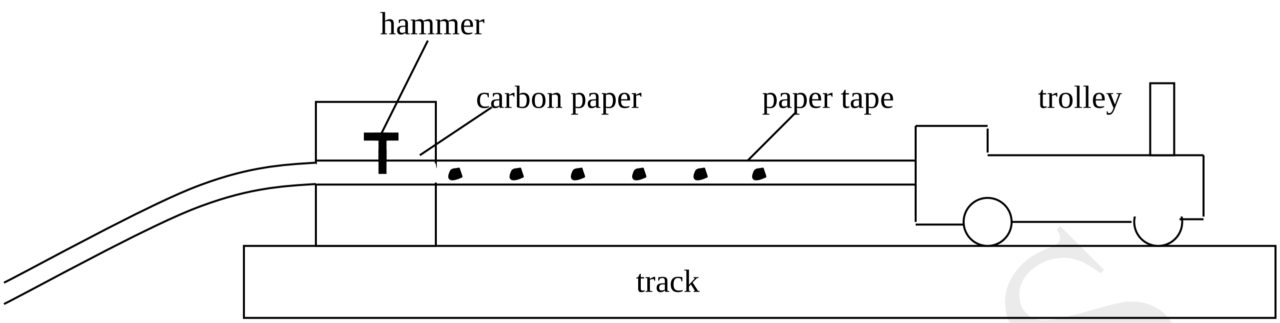
   (a) km/hr (Ans: 45 km/hr
   (b) m/s (Ans: 12.5 m/s)

2. A satellite used for world television communication takes 24 hrs to move round the earth in a circular path 60 000 km long. Find its average speed in

   (i) km/hr (Ans: 2 500 km/hr)
   (ii) m/s (Ans: 694.44 m/s)

Measuring speed using a ticker timer

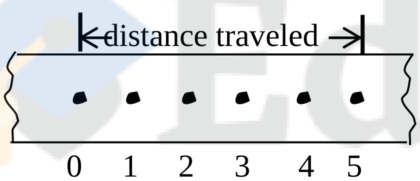
A ticker timer is a device used to measure speed in the school laboratory.
One end of a tapes is attached to a moving object and the other end passes through the ticker timer carrying a vibrating hammer. The hammer strikes up and down (vibrates) on a tape 50 times each second, therebt making ticks or dots on the paper tape as the tape is pulled through the ticker timer.
Each successive pair of dots represent a time interval of $^{1}/_{50}$ s (or 0.02), no matter how far apart these dots may be.



$$speed\ of\ trolley = \frac{total\ distance}{total\ time}$$

From the tape, you can record both the distance moved and the time taken. Thus the distance between any two successive dots is the distance the object (trolley) has moved in 0.02 sec.

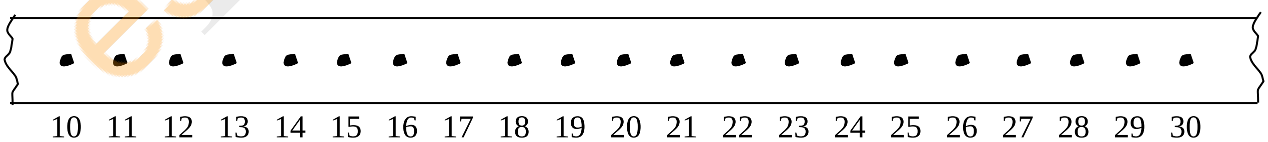
Analysis of the tape



time interval between any two successive dots = 0.02 s
time taken = total number of dots (intervals between dots) x 0.02 s
Note: Usually there's a mess on the start of tape so measure the time and distance from, say, the tenth dot.

Example

1. Calculate the speed of the object which pulls the paper strip through the ticker timer that the distance between the tenth dots and the thirtieth dot is 80 cm.



50 dots = 1 sec

$$\frac{50\ dot}{50} = \frac{1\,s}{50} = 0.02\,s$$

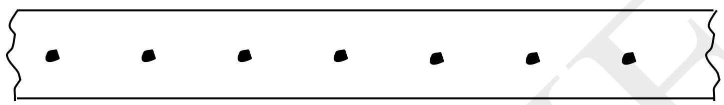
1 dot = 0.02 s
20 dots = 20 x 0.02 s = 0.4 s

$$Average\,speed = \frac{total\ distance}{total\ time} = \frac{0.8\,m}{0.4\,s} = 2\,m/s$$

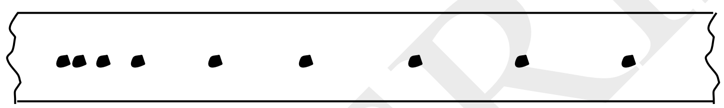
Interpreting the ticker tape

The appearance of the dots on the tape gives important immediate information about the movement of tape.

- Equally or evenly spaced dots show that equal distances are traveled in equal times, i.e. the tape is moving with uniform or constant speed.



- When the distance between the ticks increases, the tape is accelerating.



- When the distance between the dots decreases, the tape is decelerating.

VELOCITY

Velocity is the distance traveled with time in a specific (stated) direction, i.e. velocity is speed in a particular direction.

$$Average\,velocity = \frac{total\ distance\ in\ a\ given\ direction}{total\ time}$$

but distance moved in a given direction is called a displacement.

$$Average\,velocity = \frac{total\ displacement}{total\ time}$$

The S.I. units of velocity are metres per second (m/s or ms^{-1}). Velocity is a vector quantity (it has both size and direction).
Displacement (unlike distance) is a vector quantity.

Consider two cars:

1. Travelling due north at 20 m/s
   What can be said about the speed and velocity of these two cars?
- Speed: same speed of 20 m/s
- Velocity: same velocity (20 m/s due north)

2. Travelling, one due north at 20 m/s and the other due south at 20 m/s.
   What can be said about the speed and the velocity of these cars?
- Speed: same speed (20 m/s)
- Velocity: different velocities (one at 20 m/s due north and the other 20 m/s due south).

Constant or Uniform velocity

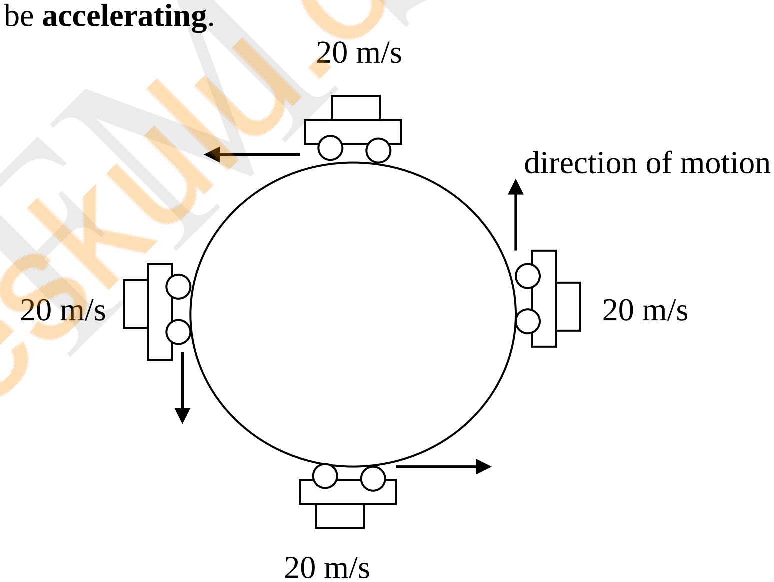
Constant velocity is when a body travels equal displacements in equal times.
e.g.

Displacement (m)	0	2	4	6	8	10
Time (s)	0	1	2	3	4	5
Velocity (m/s)	0	2	2	2	2	2

Constant velocity = <u>2 m/s</u>

Velocity round a curved path

The velocity is not uniform for a body which moves in a curved path at constant speed. This is because its direction of motion would be continuously changing, hence velocity would be changing too although the speed remains constant. Therefore such a body would be **accelerating**.



Examples

1. A car travels 120 m due north along a perfectly straight road in 8 seconds. Find its velocity.

Solutions

$$Average\,velocity = \frac{total\ displacement}{total\ time} = \frac{120\,m}{8\,s} = 15\,m/s$$

$\therefore$ Velocity = 15 m/s due north.

Exercise

1. A car has a velocity of 72 km/hr. How far does it travel in ½ minute?
   (Ans: 600 m)

ACCELERATION

When the velocity of a body is changing (i.e. it is not constant, it is 'speeding up' or slowing down') the body is said to be accelerating.
Acceleration is the change of velocity (not speed) with time **OR** is the rate of change of velocity.

$$Average\,acceleration = \frac{change\ in\ velocity}{time\ taken\ for\ change}$$

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

Where a = acceleration (in m/s^2)
v = final velocity (in m/s)
u = initial velocity (in m/s)
t = time (in seconds)

The S.I. units for acceleration are **metres** per second squared (m/s^2 or ms^{-2})
Acceleration is a vector quantity (both its size and direction are stated).
A body traveling with a uniform velocity has **zero acceleration**. Acceleration is regarded as positive if the velocity increases and negative if the velocity decreases. A negative acceleration is also called **deceleration** or **retardation**.

-ve (a) = retardation or deceleration

Constant or uniform acceleration

A body is said to be moving with constant acceleration if its velocity increases by equal amounts in equal times.
An example of motion with uniform acceleration is that a body falling freely under gravity (g = 10 m/s^2).

A body is said to be moving with a constant deceleration if its velocity decreases by equal amounts in equal times.

Vel (m/s)	0	12	24	36	48	60	60	60	60	60	50
Time (s)	0	2	4	6	8	10	12	18	24	30	32
Acceleration (m/s^2)	0	6	6	6	6	6	0	0	0	0	-5

Vel (m/s)	40	30	20	10	0
Time (s)	34	36	38	40	42
Acceleration (m/s^2)	-5	-5	-5	-5	-5

Exercise

1. A car increases its velocity uniformly from rest to 960 m/s in $1^2/_3$ minutes. Calculate its acceleration. (Ans: 9.6 m/s^2)
2. A train traveling at 36 km/hr accelerates to 108 km/hr in 10 seconds. Find its acceleration. (Ans: 2 m/s^2)
3. A motor car is uniformly retarded and brought to rest from a velocity of 108 km/hr in 15 seconds. Find its acceleration. (Ans: -2 m/s^2)

Equations of linear motion with uniform acceleration

Many problems on motion can be solved from first principles or graphically. However, it is useful to have a set of general formulae which can be applied to all problems of uniformly accelerated motion. These equations are derived from the definitions of acceleration and average velocity.

Suppose an object is accelerating uniformly, with initial velocity *u*, and final velocity *v* at the end of a time *t*, then

The basic equations are:

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

where a = acceleration

u = initial velocity
v = final velocity
t = time

and displacement (distance) = average velocity x time but average velocity for a uniformly accelerated body with initial velocity u and final velocity v is given by $\frac{u+v}{2}$. Hence displacement,

$$S = \left(\frac{u+v}{2}\right) t$$

where S = displacement (distance)

u = initial velocity
v = final velocity

Thus from

1. $a = \frac{v-u}{t}$, we get equation 1:

$\boldsymbol{v = u + at}$ ………………………….. Eqn 1

2. $S = \left(\frac{u+v}{2}\right) t$, substituting $v = u + at$ we get equation 2:

$$S = \left(\frac{u+u+at}{2}\right) t$$

$\boldsymbol{S = ut + \frac{1}{2} at^2}$ ………………………….. Eqn 2

3. $S = \left(\frac{v+u}{2}\right) t$, substituting $t = \frac{v-u}{2}$, we get equation 3:

$$S = \left(\frac{v+u}{2}\right)\left(\frac{v-u}{a}\right)$$

$$S = \frac{v^2 - u^2}{2a}$$

$\boldsymbol{v^2 = u^2 + 2aS}$ ………………………….. Eqn 3

$\therefore$ The following are the equations of linear motion with uniform acceleration:

1. $a = \dfrac{v - u}{t}$

2. $v = u + at$

3. $S = \left(\dfrac{u + v}{2}\right) t$ or $S = ut + \dfrac{1}{2}at^2$, also $h = ut + \dfrac{1}{2}gt^2$

4. $v^2 = u^2 + 2aS$, also $v^2 = u^2 + 2gh$

Example

1. Calculate the velocity of a trolley after 4 seconds if it is initially traveling at 5 m/s and its acceleration is 10 m/s^2.

   Data

   u = 5 m/s
   a = 10 m/s^2
   t = 4 seconds
   v =

   v = u + at
   = 5 + (10 x 4) m/s
   = (5 + 40) m/s
   = 45 m/s

Exercise

1. A body starts from rest and moves with a uniform acceleration of 2 m/s^2 in a straight line.

   (a) What is its velocity after 5 seconds? (Ans: 10 m/s)
   (b) How far has it traveled in this time? (Ans: 25 m)
   (c) After how long will the body be 100 m from its starting point? (Ans: 10 s)

2. A car accelerates from 4 m/s to 20 m/s in 8 seconds. How far does it travel in this time? (Ans: 96 m)

3. A car is traveling with uniform acceleration of 3 m/s^2. If its starting velocity was 2 m/s, calculate its velocity after it has traveled for 10 m. (Ans: 8 m/s)

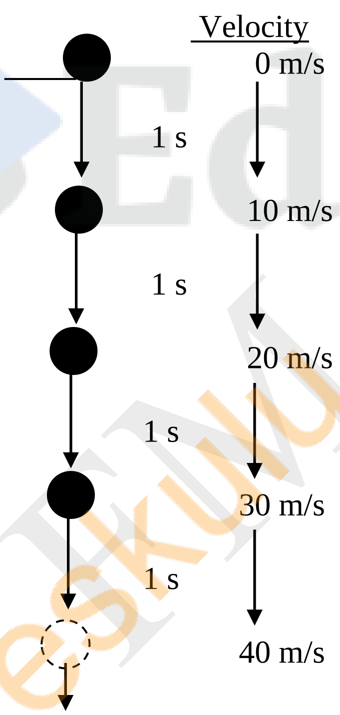
4. A body is accelerated uniformly from rest and in the first 8 seconds of its motion it travels 20 m. Calculate
   (i) the average speed for this period of 8 s (Ans: 2.5 m/s)
   (ii) the speed at the end of this period (Ans: v = 5 m/s)
   (iii) the acceleration (Ans: $a = 0.625$ m/s^2)

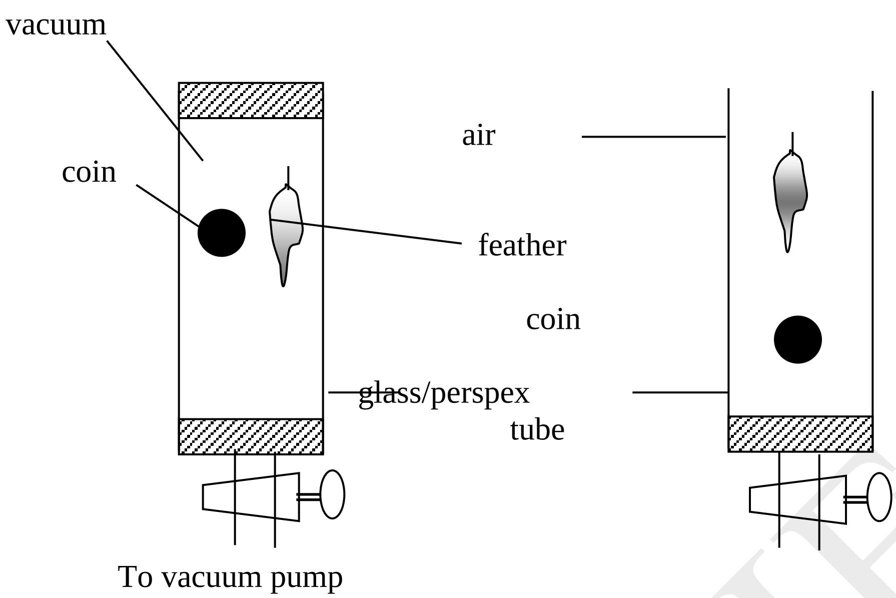
ACCELERATION DUE TO GRAVITY

All bodies falling **freely** from a **short** distance above the earth accelerate to the ground with a constant acceleration known as **acceleration due to gravity**, g (also called **acceleration of free fall**).

Neglecting air resistance, the acceleration due to gravity is constant for all objects regardless of their masses. Thus a coin and a piece of paper or feather falls at the same rate in a **vacuum**.

The value of g is 10 m/s^2. This means that the velocity of a freely falling body increases by 10 m/s every second.





- In a vacuum, the coin and feather fall at the same rate.
- In air, the coin falls rapidly than feather.

Motion under gravity

For motion under gravity (falling or ascending) the same equations of linear motion with uniform acceleration may be applied but '*a*' is replaced by '*g*'.
Also: $a = g$ (i.e. g is +ve) for falling bodies.
$a = -g$ (i.e. g is –ve) for ascending bodies.

1. $a = \dfrac{v - u}{t}$ — $\underline{a}$ m/s^2

2. $v = u + at$ — $\underline{v}$ m/s

3. $S = \left(\dfrac{u + v}{2}\right) t$ — $\underline{s}$ m

4. $S = ut + \frac{1}{2} at^2$ — $\underline{s}$ m

5. $v^2 = u^2 + 2as$ — $\underline{v^2}$ m^2/s^2

Vertical motion

Falling bodies (accelerate.)	*Ascending bodies (decelerate.)*
$g = \frac{v-u}{t}$	$-g = \frac{v-u}{t}$
$v = u + g\,t$	$v = u - g\,t$
$h = \left(\frac{u+v}{2}\right) t$	$h = \left(\frac{u+v}{2}\right) t$
$h = ut + ½\,g\,t^2$	$h = ut - ½\,g\,t^2$
$v^2 = u^2 + 2g\,h$	$v^2 = u^2 - 2g\,h$

Example

1. A boy drops a stone from a vertical height above the ground. If it takes 3 seconds for the stone to hit the ground.

   (a) how high above the ground is the vertical height.
   (b) Find the velocity with which the stone hits the ground.
   (Assume g = 10 m/s^2)

Solution

(a) **Data**: u = 0 m/s
t = 3 s $\Rightarrow t^2$ = 9 s^2
g = 10 m/s^2
h = ?

$h = ut + ½\,gt^2$
h = (0 x 3 + ½ x 10 x 9) m
h = 45 m
The vertical height above the ground = 45 m

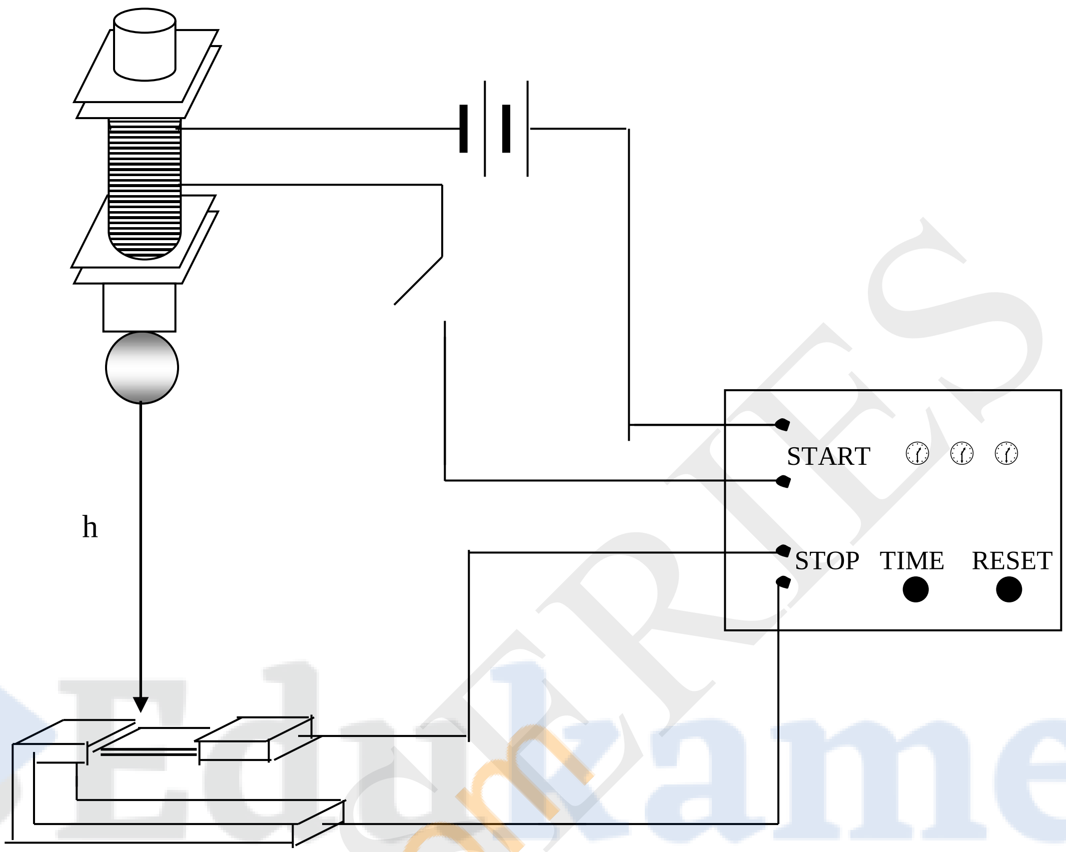
(b) $v = u + gt$
v = (0 + 10 x 3) m/s
v = 30 m/s

Exercise

1. A ball is projected vertically upwards with an initial velocity of 30 m/s. Find:
   (a) Its maximum height reached (Ans: 45 m)
   (b) Total time taken to go up and return to its starting point. (Neglect air resistance and take g = 10 m/s^2) (Ans: 6 s)

Measuring of acceleration due to gravity

1. ***Measuring g by timing direct fall of a steel ball***



When the switch is open, the ball drops immediately and the clock starts simultaneously. At the end of its fall the ball hits the contact plates, knocks it open, breaks the circuit and stop the clock.
The time for a steel ball-bearing to fall through a known height, *h* is measured by an electric stop clock. The experiment is repeated several times and an average time found.

<u>Data</u>
$u = 0$ m/s
h is known
t is known

Then from $$h = ut + \frac{1}{2}gt^2$$

$$h = \frac{1}{2}gt^2$$

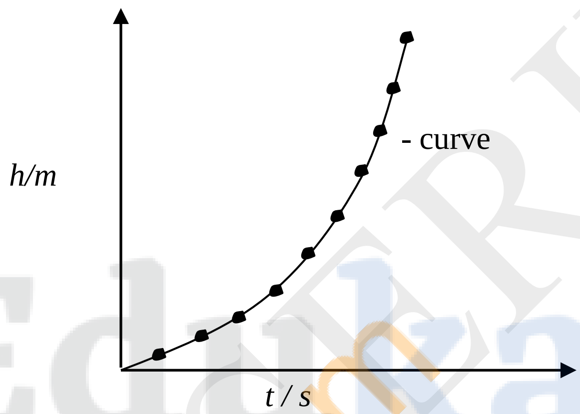
$$g = \frac{2h}{t^2}\ (m/s^2)$$

Note: The air resistance is negligible for a dense object such as a steel ball-bearing falling freely (a short distance) near the Earth.

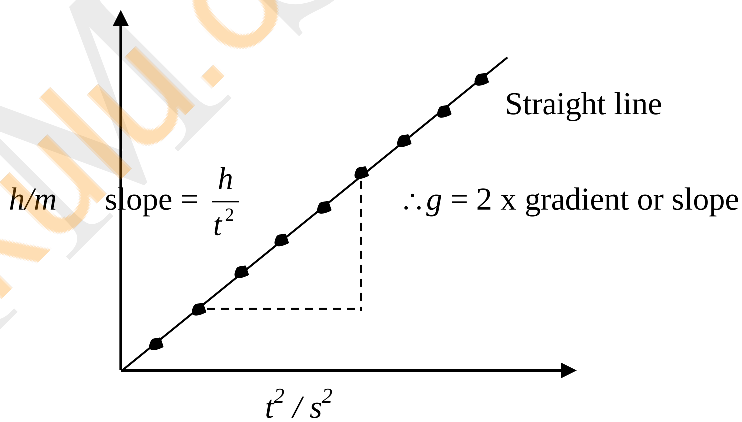
Distance-time graph for freely falling bodies

If different values of height h e.g. 2.0 m, 1.75 m, 1.5 m, 1.25 m and 1.0 m are chosen and their corresponding time of fall recorded, the graph of h against t is a curve and that of h against t^2 is a straight line passing through the origin ($h \alpha t^2$)

(i) **Graph of *h* against *t***

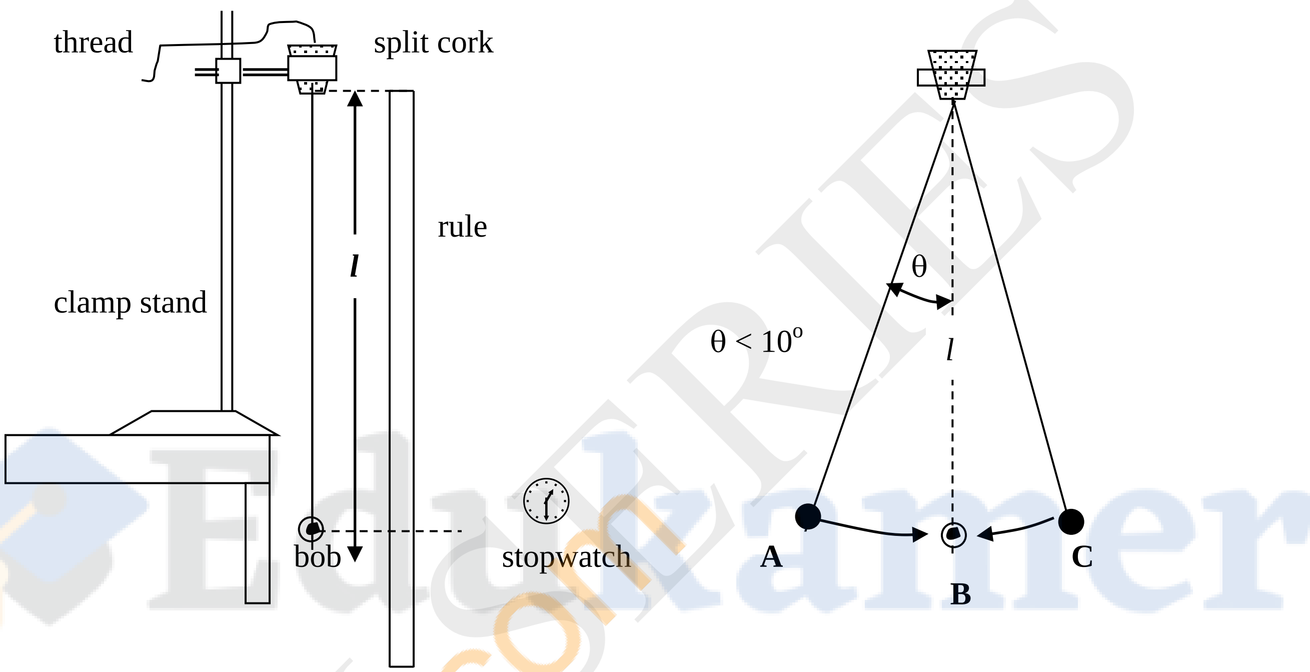


(ii) **Graph of *h* against t^2**



1. Measuring *g* using a simple pendulum

The acceleration due to gravity g can be measured by a simple pendulum method. A simple pendulum is a small heavy bob (lead bob or brass bob) suspended by a light inextensible string.



For a pendulum:

- One complete to and fro movement or swing (A to C then back to A) of the bob is called an **oscillation** or **vibration** or **cycle**.
- The period or periodic time T is the time in seconds, taken to complete one oscillation.
- The frequency f (in Hertz or per second) is the number of complete oscillations made in one second.

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

The S.I. unit of frequency is the Hertz, (Hz) or per second (s^{-1})

- The maximum displacement of the bob from its rest position is called the **amplitude**. Thus the **angular amplitude**, θ of the pendulum is the angle between the extreme and rest positions of the string.

The period, T for a simple pendulum is related to length, l and acceleration due to gravity by:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

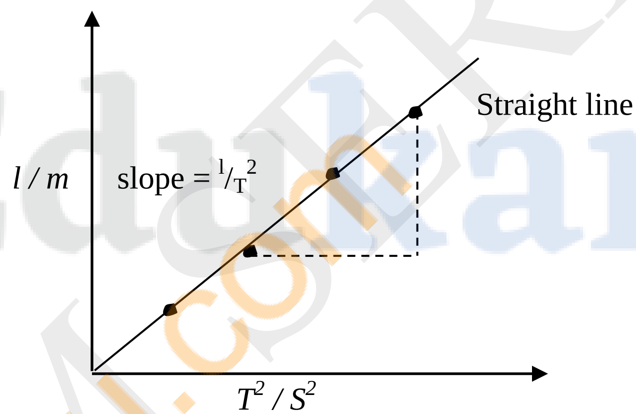
Squaring both sides

$$T^2 = 4\pi^2 \frac{l}{g}$$

$$\therefore g = 4\pi^2 \frac{l}{T^2}$$

Adjusting the l and for each new l, the corresponding T can be found and then

(i) Graph of l against T^2 is a straight line



$\therefore g = 4\pi^2$ x slope

Factors that affect the periodic time *T* of a simple pendulum
Provided the amplitude is small, the periodic time depends only on

1. The length l of the pendulum
   - all simple pendulum of the same length have the same period T, if they are in a gravitational field of the same intensity.
2. The acceleration due to gravity g
   - a pendulum swings more rapidly, i.e. with shorter period, in a strong gravitational field. It swings more slowly i.e. with longer period in a weak gravitational field.

Factors that do not affect the periodic time *T* of a simple pendulum

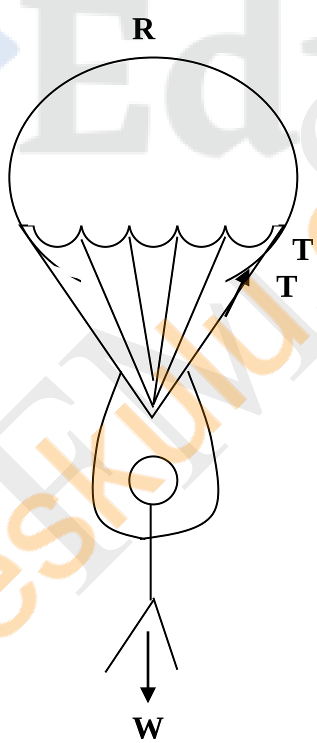
1. The amplitude of swing of a simple pendulum
2. The mass of the bob

Precautions when using a simple pendulum

1. The location of the pendulum should be in a place where there's less or no wind blowing.
2. Provide small amplitude to reduce effects of air resistance.
3. Use length of pendulum to reduce its frequency and easy counting of oscillations

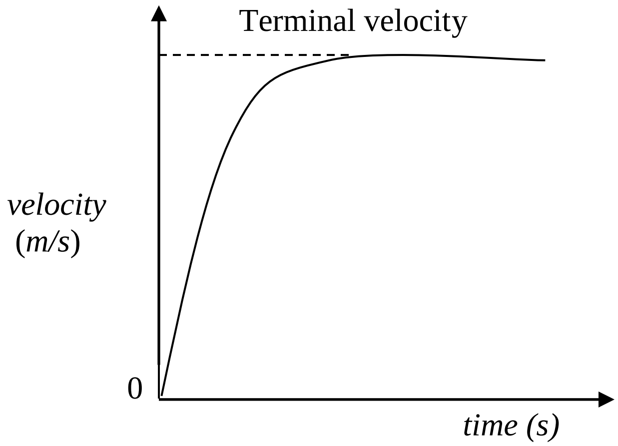
Air resistance and terminal velocity

Terminal velocity is a constant maximum velocity reached by a falling body when the air resistance acting upwards on it equals the downward pull (weight) on the object. Rain drops, parachutes, sky divers a terminal velocity. When an object falls in air, the air resistance (fluid friction) opposing its motion increases as its velocity increases, thus reducing its acceleration. Eventually, air resistance acting upward equals the weight of object acting downwards. At this point the resultant force on the object is zero (since two opposing forces balance) and the acceleration of the body is zero.



R = W , at terminal velocity

Graph of velocity against time



Motion Graphs

(A) - $Average\,speed = \dfrac{total\ distance}{total\ time}$ / $or\ Average\,velocity = \dfrac{displacement}{time}$

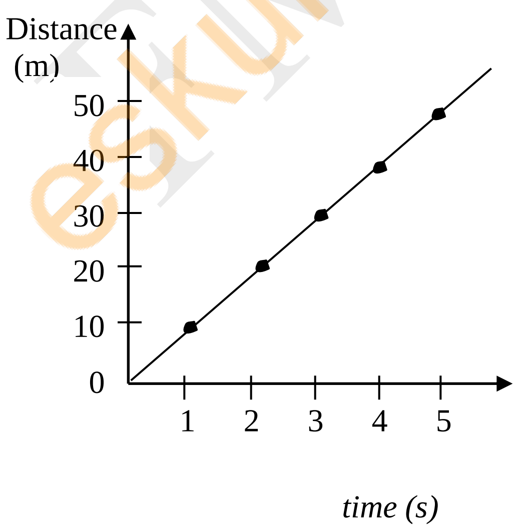
here with time on the *x-axis*, we get 2 graphs

1. Speed – time graph / or velocity – time graph
2. distance – time graph / displacement – time graph

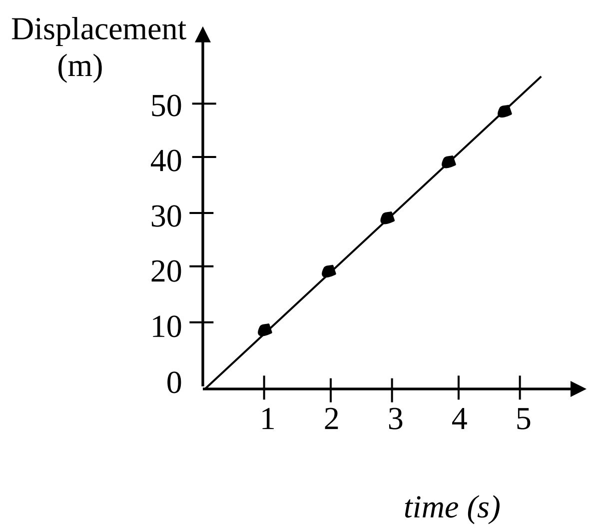
1. **Distance – time graph or displacement – time graph**

Distance or disp (m)	0	10	20	30	40	50
Time (s)	0	1	2	3	4	5

Distance – time graph



Displacement – time graph



Here the body is moving with uniform speed or uniform velocity equal to the slope (gradient) of the graph.

Speed or velocity = slope = $\dfrac{y_2 - y_1}{x_2 - x_1} = \dfrac{\Delta y}{\Delta x}$

$= \dfrac{(50-10)m}{(5-1)s}$

$= \dfrac{40\,m}{4\,s}$

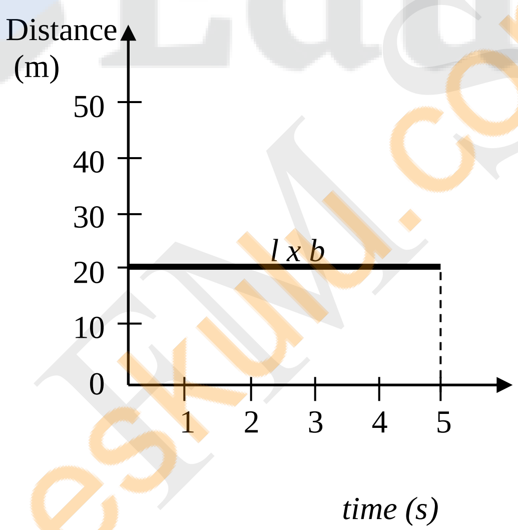
$= \underline{10\text{ m/s}}$

Note/interpretation:

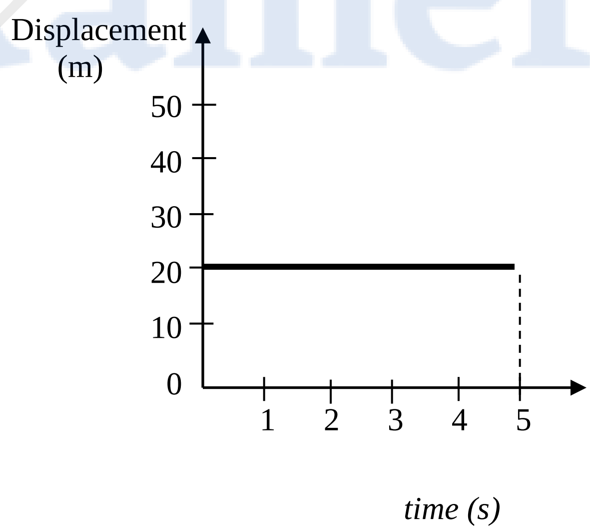
1. If equal distances are travelled in equal times, the graph is a straight line.
2. The **slope** or **gradient** of the graph gives the **speed**, which in this case is constant (uniform) or in the case of a displacement time-graph the slope gives **velocity**.

(b) **For an object at rest (stationary) at a fixed distance from the observer**

Distance – time graph



Displacement – time graph



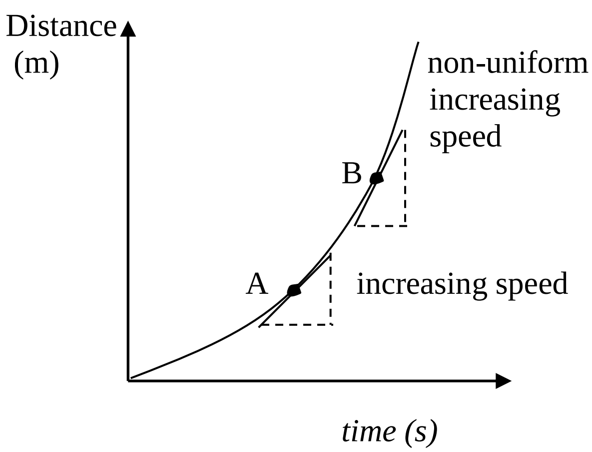
Here slope = $\dfrac{(20-20)m}{(5-1)s} = \dfrac{0\,m}{4\,s}$ = 0 m/s = speed

Note/interpretation:

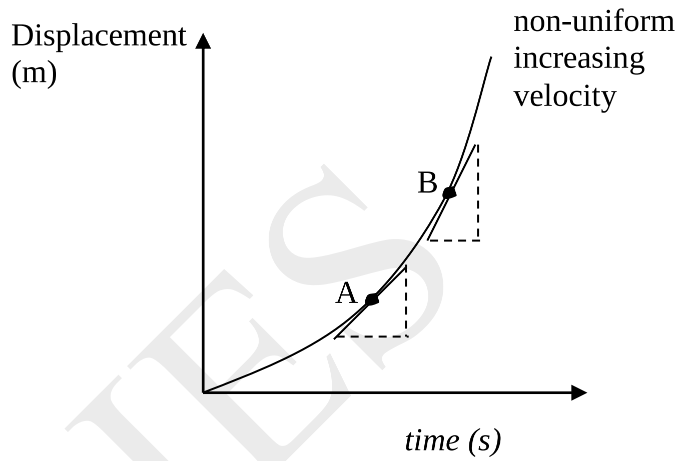
1. Slope is zero, therefore **speed** or **velocity** as the case maybe is zero

(i) **Non-uniform speed/velocity motion**

Distance – time graph

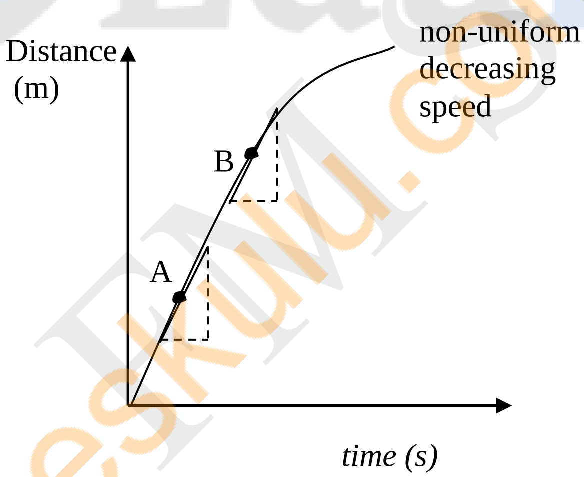


Displacement – time graph

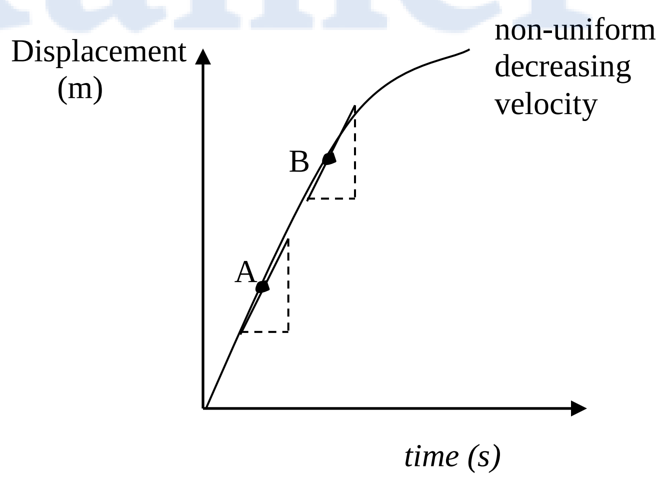


Slope of the tangent at any one point is equal to the speed or velocity at that point. Clearly, from the slope of the tangent at A and B, the slope is increasing, hence object is moving with **non-uniform increasing speed/velocity**.

Distance – time graph

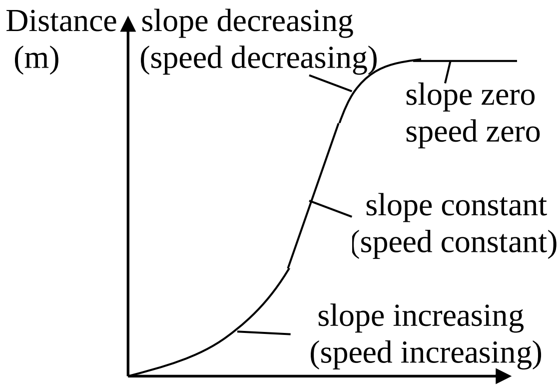


Displacement – time graph

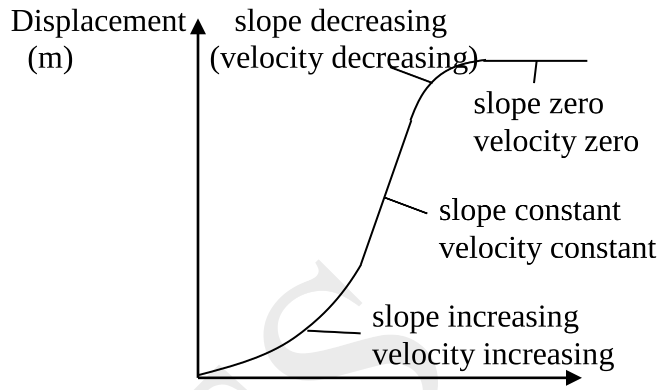


Slope of the tangent at any one point is equal to the speed or velocity at that point. Clearly, from the slope of the tangents at A and B, the slope is decreasing, hence object is moving with non-uniform decreasing **speed/velocity**.

Distance – time graph



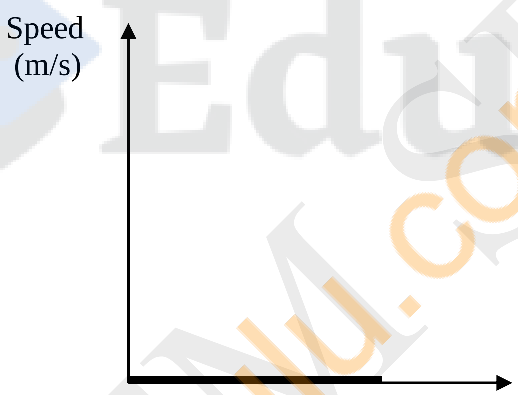
Displacement – time graph



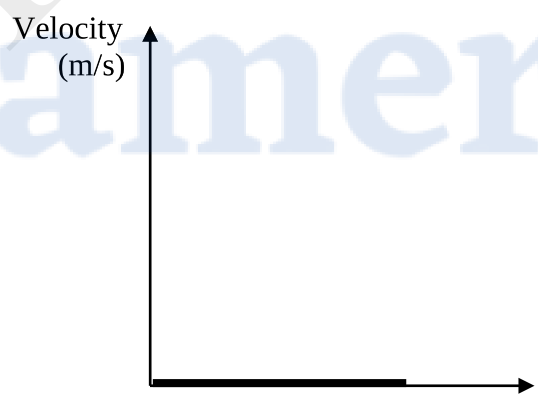
2. Speed – time graph/velocity – time graph

(a) **For a body at rest/stationary**

Speed – time graph



Velocity – time graph



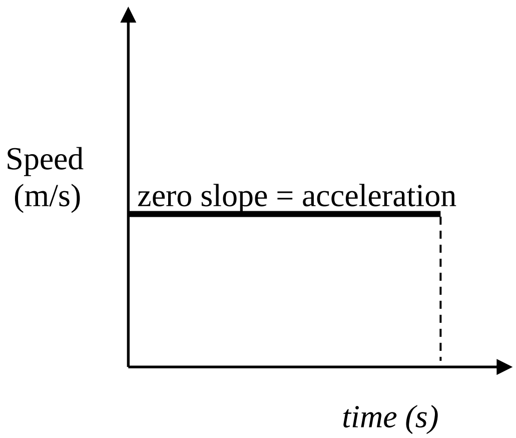
From the speed – time graph (or velocity – time graph)

Important information

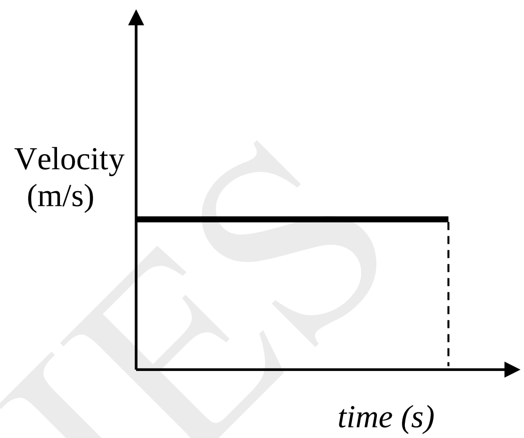
(ii) Slope of the graph = acceleration
(iii) Area under the graph = displacement (distance)

(b) **For a body moving with constant speed or velocity**

Speed – time graph



Velocity – time graph



The Area between the speed-time graph and the time axis

= distance travelled (in a speed-time graph)

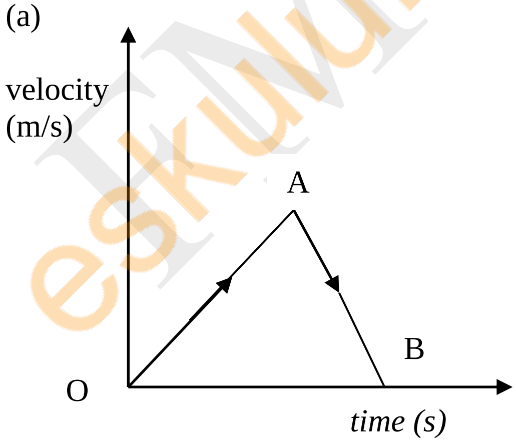
i.e. distance travelled = average speed x time

or = displacement (in a velocity-time graph)

i.e. displacement = average velocity x time

Other form of graphs

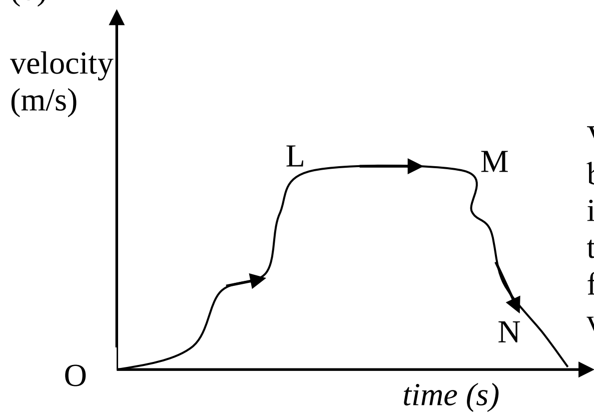
(a)



Velocity-time graph of a lift whose velocity increases uniformly along **OA** and then decreases uniformly along **AB** to rest.

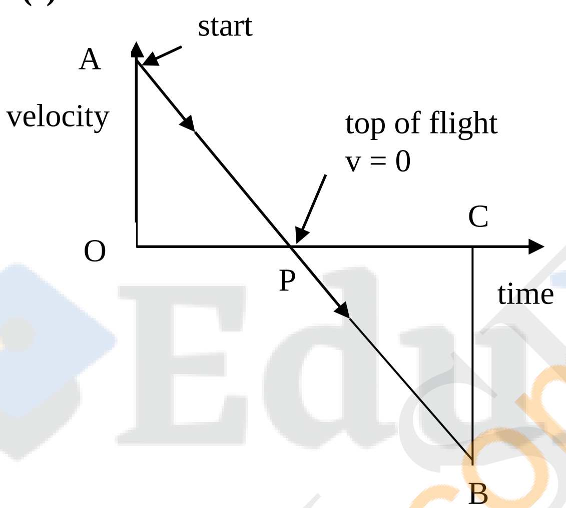
Displacement = Area of triangle **OAB**

(b)



Velocity-time graph of a body e.g. train between two stations. The train's velocity increased along **OL** as it left the station, then travelled with fairly uniform velocity for a time along **LM** and finally decreased in velocity and came to rest at **N**.

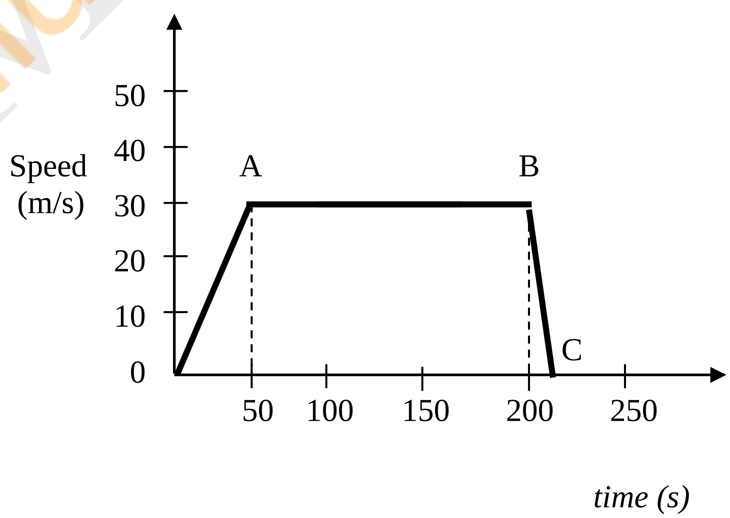
(c)



Velocity-time graph of a cricket ball thrown vertically upwards. The velocity decreases uniformly from **OA** to zero at the top of its flight in a time **OP** and then increases in velocity uniformly as it returns to the hand of the thrower at **B**.

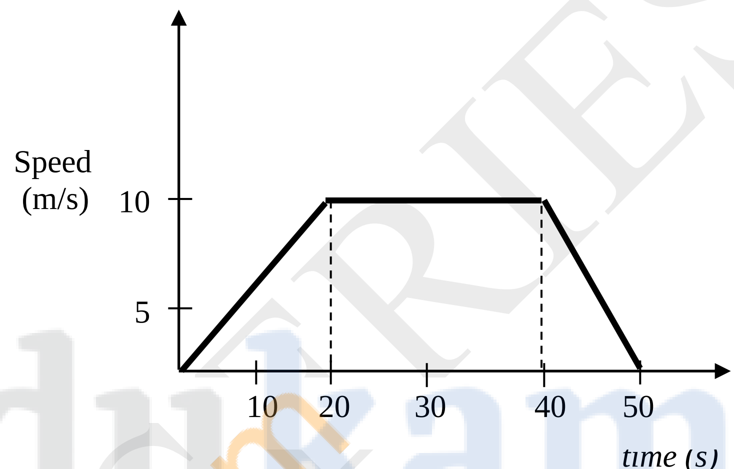
Exercise

1. The graph below shows a journey made by a train. Its speed is measured in metres per second (m/s) and time in seconds (s).



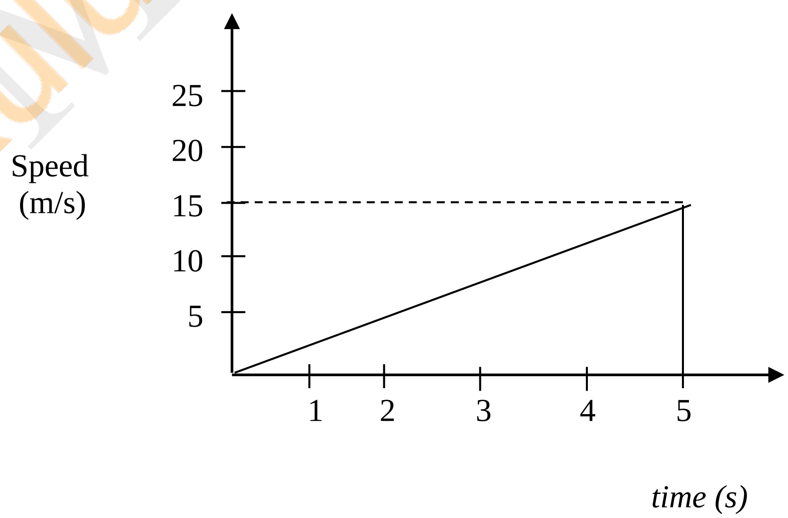
(a) What is the maximum speed of the train?
(b) What is the train doing when its motion is represented by the line AB?
(c) What is the train doing when its motion is represented by the line BC?
(d) Which of the points O, A, B or C represents the stage at which the breaks are applied.
(e) The line BC is steeper than the line OA. What does this tell you about the rates at which the train speeds up and slows down?
(f) Calculate how far the train traveled between the stages in its journey represented by the points O and A.

2. The graph below shows the movement of a car over a period of 50 seconds.



What is the distance traveled by the car while its speed was increasing?
½ b h
½ x 20 s x 10 m/s = 100 m

3. The graph below shows how the speed of a car changed as it started to travel along a straight road.



What was

(i) the acceleration of the car

$$\text{slope} = \frac{v}{x} = \frac{15m}{5s.s} = 3m/s^2$$

(ii) the distance traveled during the first 5 sec

½ b h

½ x 5 s x 15 m/s = 37.5 m

SCALAR AND VECTOR QUANTITIES

Quantities measured in physics can be classified as either **scalar** or **vector** quantities.

SCALARS

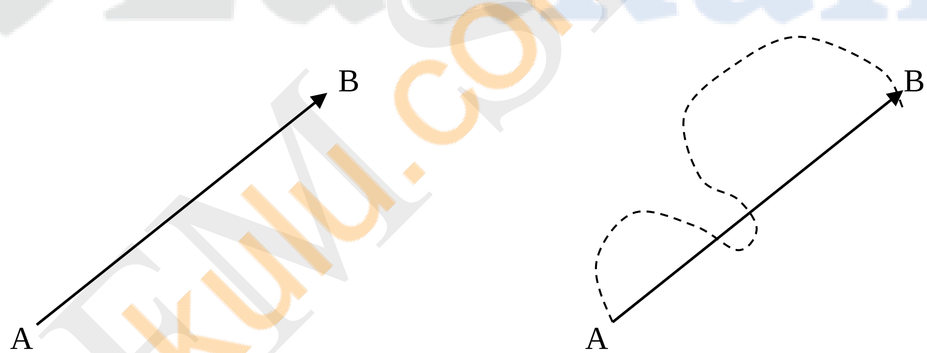
Definition; A scalar quantity is one which has magnitude (size) only (has no direction). Scalar quantities can thus be completely specified by a number with a unit.
Examples of scalar quantities include length (distance), mass, time, density, speed, work, energy, power, temperature, distance, volume, charge

Scalars are added by ordinary rules of arithmetic, e.g. a mass of 50 g added to a mass of 100 g gives a mass of 150 g; 5 kg added to 2 kg makes 7 kg; 25 books added to 10 books makes 35 books and so on.

VECTORS (vector ≡ 'carrier' in Latin)
which suggests a displacement

Definition: A vector quantity is one which has both size (magnitude) and direction. For example, displacement, velocity, acceleration, force (weight), the electric field, the magnetic field, momentum, impulse, torque (moment of force).

Vectors can be represented by (in a particular direction), straight line with an arrow on a diagram. The length of the arrow is proportional to the magnitude (size) of the vector (that is, we chose a scale) while the direction of the arrow is the direction of the vector.



A change of position of a particle is called a displacement. If a particle moves from positions A to B its displacement can be represented by drawing a line from A to B with an arrow head at B indicating the displacement was from A to B.

A is the tail (starting point) of a vector
B is the head (terminal point) of a vector

Hence, the actual path of the particle is not necessarily a straight line from A to B; the arrow at B represents only the net effect of the motion, not the actual motion.

Addition of Vectors

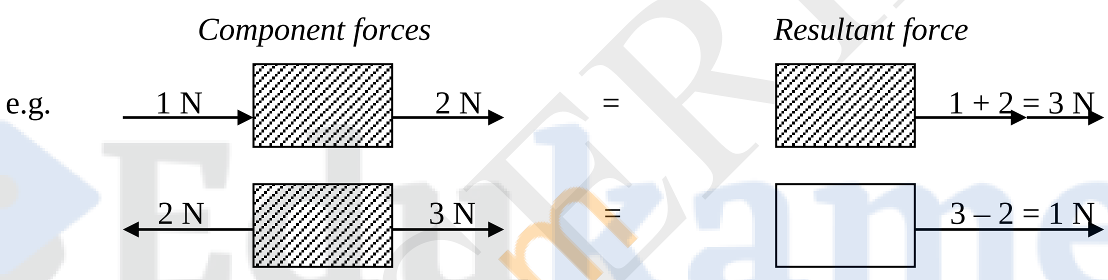
Vectors combine according to certain rules of addition. Addition of vectors is not simply additive unless the vectors act in the same or directly opposite directions.

The sum (combined effect) of two or more vectors is a single vector called their resultant, R. Thus a **resultant of vectors** is a single vector which produces the same effect as all the original vectors combined.

A **component of a vector** is its effective value in a given direction. Thus, several vectors which when added end to end give a single vector are said to be components of the vector.

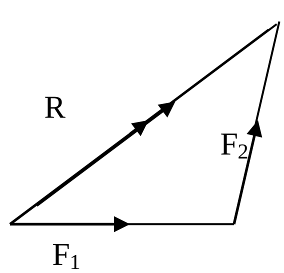
(a) **Simple addition or subtraction**

If the vectors e.g. forces act in the same straight line the resultant is found by simple addition or subtraction.



(b) **Addition by graphical method (polygon of vectors)**
Finding the resultant vector (magnitude and direction) by use of ruler and protractor is called the graphical method. For the graphical method as well as for the simple addition or subtraction, the rule is

- To add several vectors graphically, place them end to end, with the tail of the second on the head of the first, then the tail of the third on the head of the second and so on.
  The resultant vector is an arrow with its tail at the tail of the first and its head at the head of the last vector.

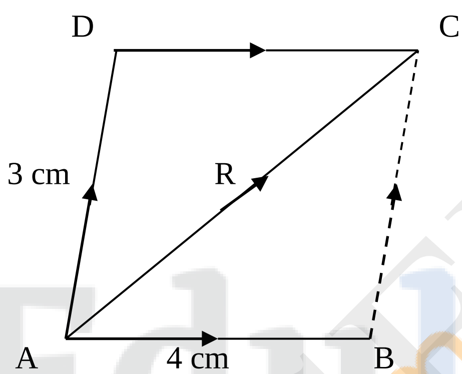


Parallelogram of forces

The parallelogram law for adding two forces is :
If two forces F_1 and F_2, acting at a point, are represented to scale in both size and direction by the two adjacent sides of a parallelogram, then the diagonal from their point of intersection to the opposite corner of the parallelogram represents the resultant force R in both magnitude and direction.

Examples

1. Find the resultant of force of 3 N and 4 N acting at right angles to each other.



Solution

Using a scale of 1.0 cm = 1.0 N
$\Rightarrow$ 3 cm = 3 N
4 cm = 4 N

Draw a parallelogram (rectangle) ABCD with AB = 4 cm, AD = 3 cm. By the parallelogram law, the diagonal AC represents the resultant in magnitude and direction.
Measuring AC = 5 cm, angle BAC = 37^o

(Tan $\theta = \frac{opp}{adj} = \Rightarrow \frac{3}{4} \Rightarrow \theta = Tan^{-1}\frac{3}{4} = 37^o$)

$\therefore$ Resultant force R = 5 N acting at an angle of 37^oC to the force of 4N.

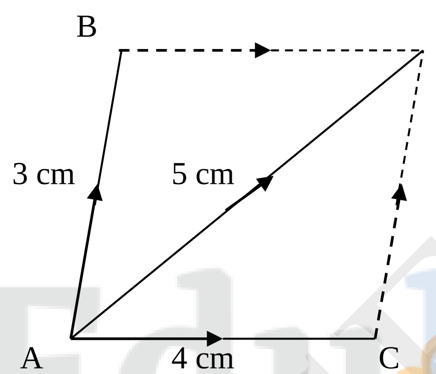
Exercise

2. Using a scale of 1 cm to represent 10 N find the size and direction of the resultant of forces of 30 N and 40 N acting at

   (a) Right angles to each other
   (b) 60^{o}C to each other

Solution

(a)



1 cm = 10 N
3 cm = 30 N

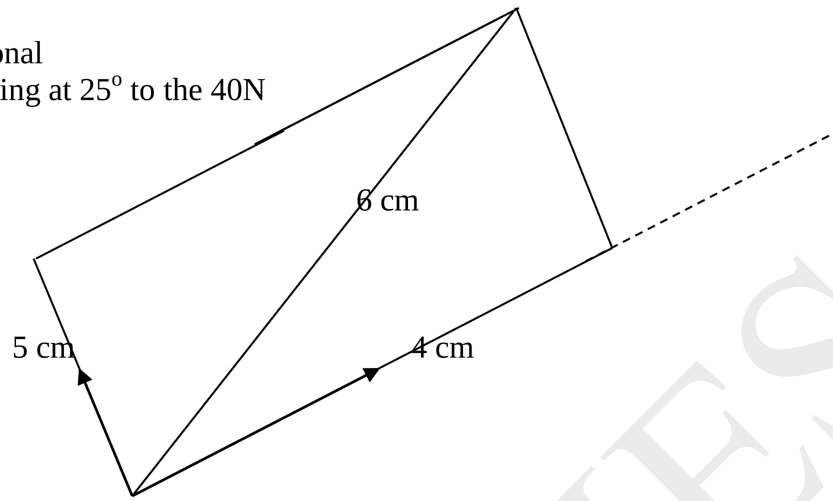
1 cm = 10 N
4 cm = 40 N

BC = 5 cm

Resultant force, = 50 N, acting at 37^o to the 40 N force

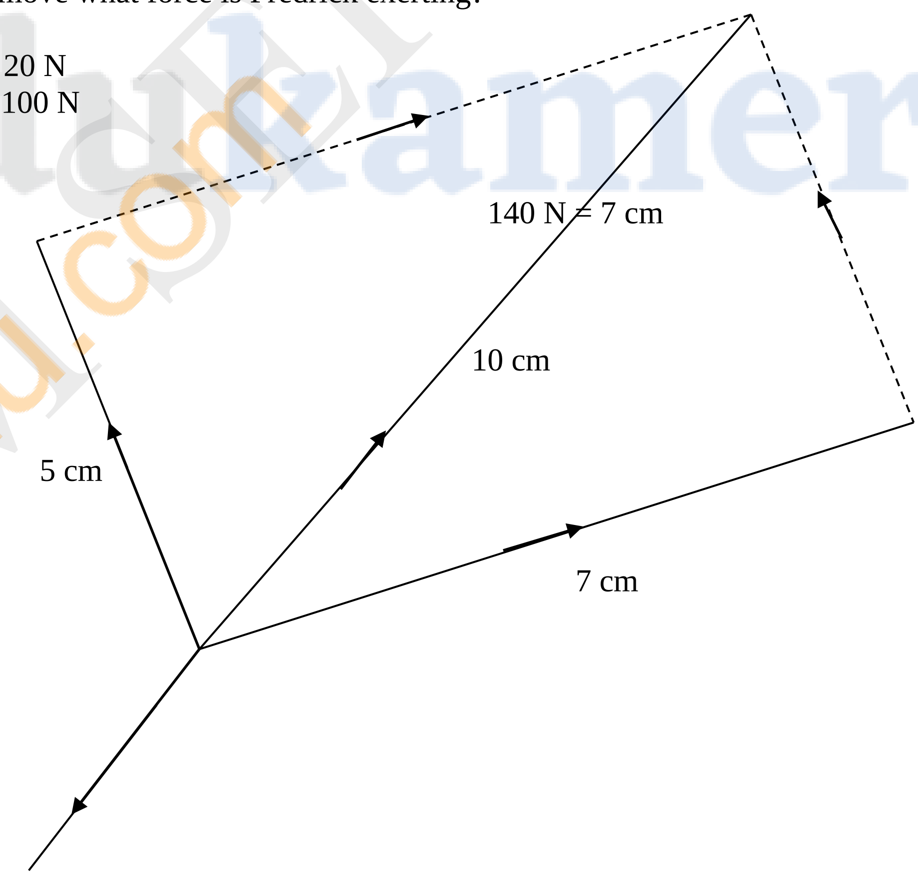
(b)

6 cm = diagonal
R = 60 N acting at 25° to the 40N Force.



3. Kenneth, Nelson and Fredrick are pulling on a metal ring. Kenneth pulls with a force of 100 N and Nelson with a force of 140 N at an angle of 70° to Kenneth. If the ring does not move what force is Fredrick exerting?

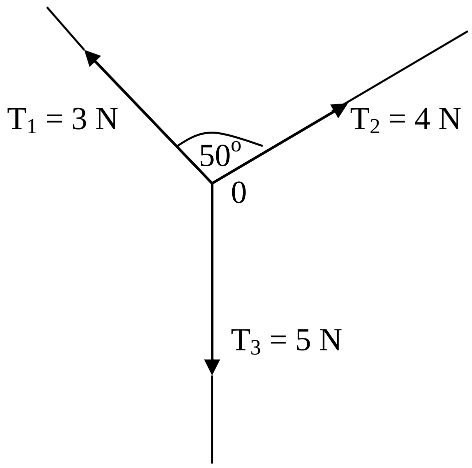
Solution: let 1 cm = 20 N
5 cm = 100 N

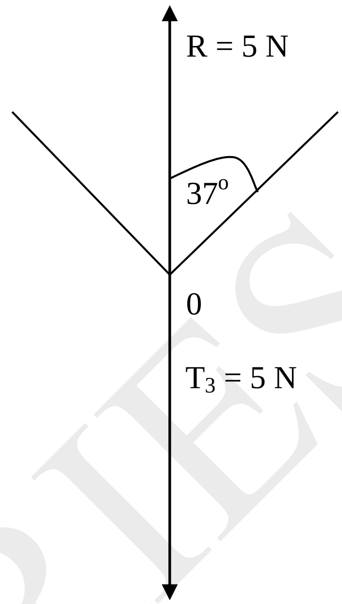


Diagonal = 10 cm
1 cm = 20 N
10 cm = 200 N

$\therefore$ Resultant = 200 N, acting at 38° to the 140 N force

Equilibrant: In the last example, the three forces acting at a point O exactly balance one another since point O is at rest. The forces 100 N, 140 N, 200 N are in equilibrium and any one of the these forces is said to be the **equilibrant** of the other two.
e.g.

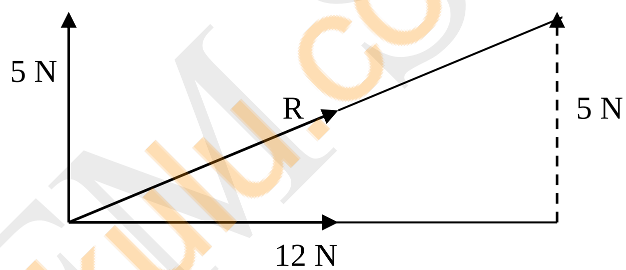




3. Find the resultant of forces of 5 N acting at right angles to a force of 12 N.

Solution:

1. By scale drawing

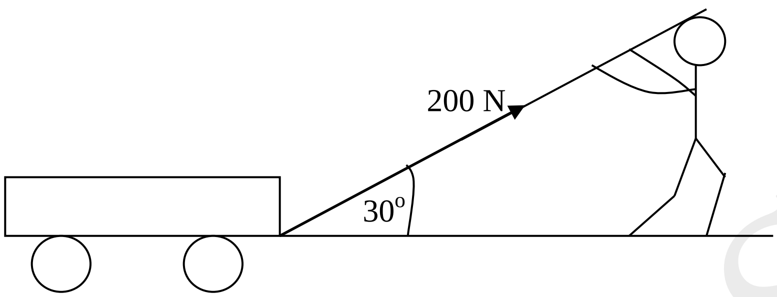


2. By Pythagoras theorem

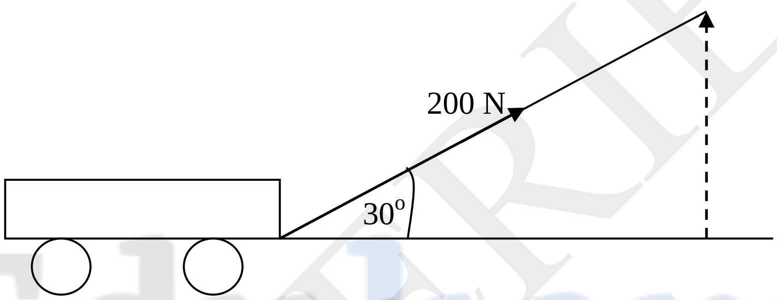
$$R = \sqrt{5^2 + 12^2}$$

$$R = \sqrt{169} = \underline{13\ N}$$

4. A boy pulls a friend on a trolley by means of a rope inclined at 30^oC to the horizontal. If the tension, T, in the rope is 200 N, find the effective force pulling the trolley along.



Solution



$$\text{Cos } \theta = \frac{Add}{Hyp} = \frac{R}{200\,N}$$

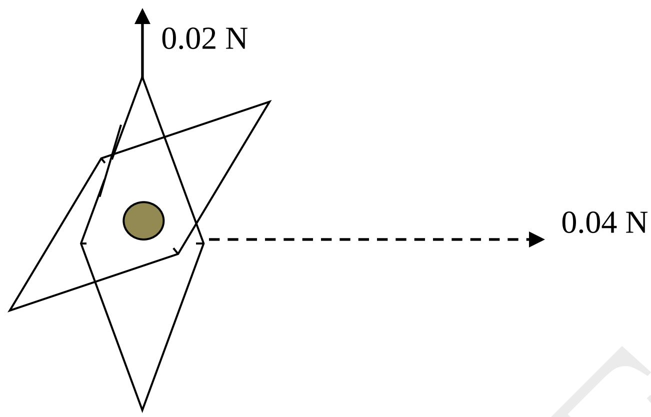
$$\text{Cos } 30^oC = \frac{R}{200\,N}$$

$\Rightarrow$ R = Cos 30^o x 200 N = <u>173.20508 N</u>

1. (a) Define a
   (i) Scalar quantity
   (ii) Vector quantity

   (b) Give 4 examples of
   (i) Scalar quantities
   (ii) Vector quantities

2. A magnetic compass needle is subjected to a force of 0.02 N acting north and a force of 0.04 N acting east as shown below:



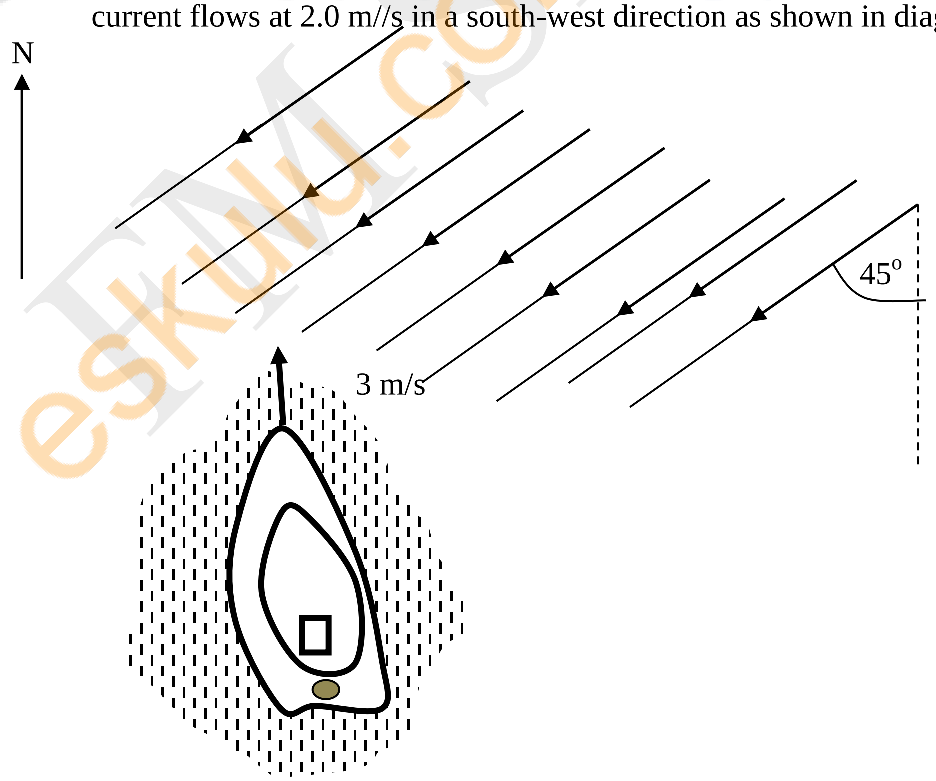
Calculate the resultant force on the needle and the direction in which it sets.

3. Two forces of magnitude 8 N and 6 N act on the same body. The angle between the directions of the forces is 90^o. Find the magnitude and direction of the resultant of the two forces.

4. A body is in equilibrium under the action of three forces. One force is 60 N acting due east and one is 3.0 N in a direction 60^o north of east. What is the magnitude and direction of the third force?

Exercise (combing vectors and speed, velocity)

1. A motor boat travels due north a steady speed of 3 m/s through calm water in which there is no current. The boat then enters an area of water in which a steady current flows at 2.0 m//s in a south-west direction as shown in diagram below:



Both the engine power and the course setting remain unchanged.

(a) Explain how the above diagram gives information not only about the speed of the boat but also about its velocity.

(b) Draw a vector diagram showing the velocity of the boat and the velocity of the current. Use the diagram to find

(i) The magnitude of the resultant velocity of the boat

(ii) The angle between due north and the direction of travel of the boat.

(c) Calculate the distance the boat now travel in 5 minutes

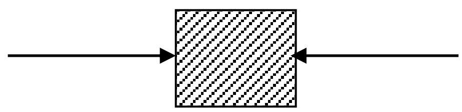
FORCES

In everyday language, the word force is used to mean a push or a pull. In science, however, the word force is defined in such a way that it can be practically understood.

Defn: Force is that which changes or tends to change the body's state of rest or uniform motion in a straight line.

Thus, when a force is applied to an object, the object will speed up (accelerate) or slow down (decelerate) or change its direction of motion. A force (unbalanced) or net or resultant force) therefore produces an acceleration.

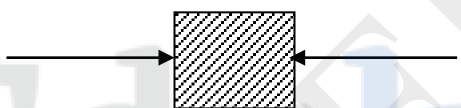
(a) F = 10 N
at rest



F = 10 N

unbalanced force 0 N

(b) F = 10 N



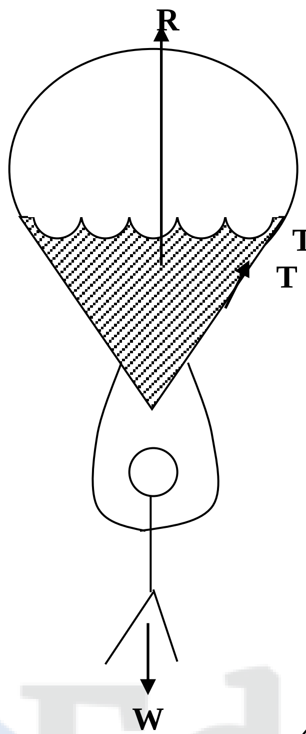
F = 2 N

- Object in (b) will move to the right due to the unbalance force, F
  F = 10 N – 2 N = 8 N

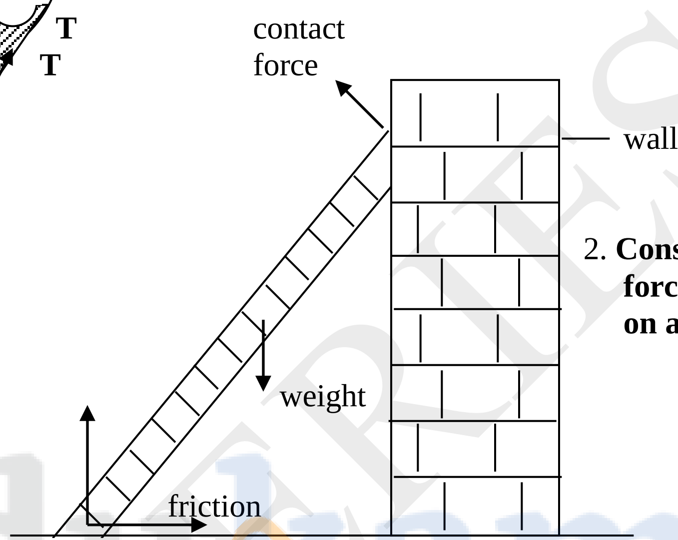
Examples of force include weight, reaction (normal forces), tension, friction, air resistance etc.

A fluid is any substance which flows e.g. air, water, etc.
Usually more than one force acts on an object.

1. **Consider the forces on a parachutists**



R = air resistance
T = tension in the ropes
W = weight of the parachutists

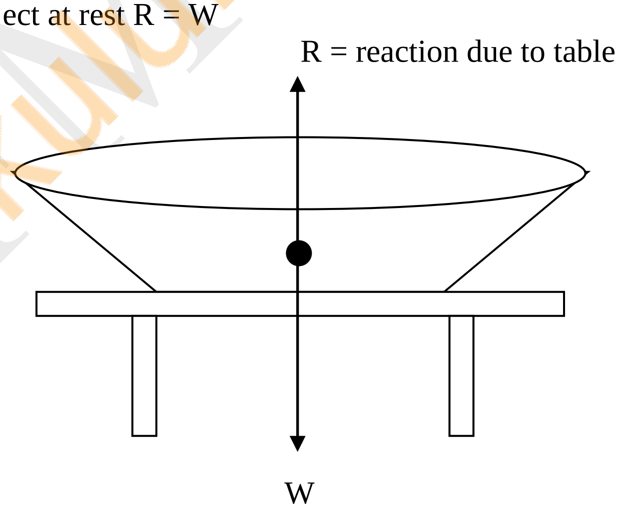


2. **Consider the forces acting on a ladder**

3. Consider the forces acting on object resting on a table.

W = weight of object
R = reaction due to table

for object at rest R = W

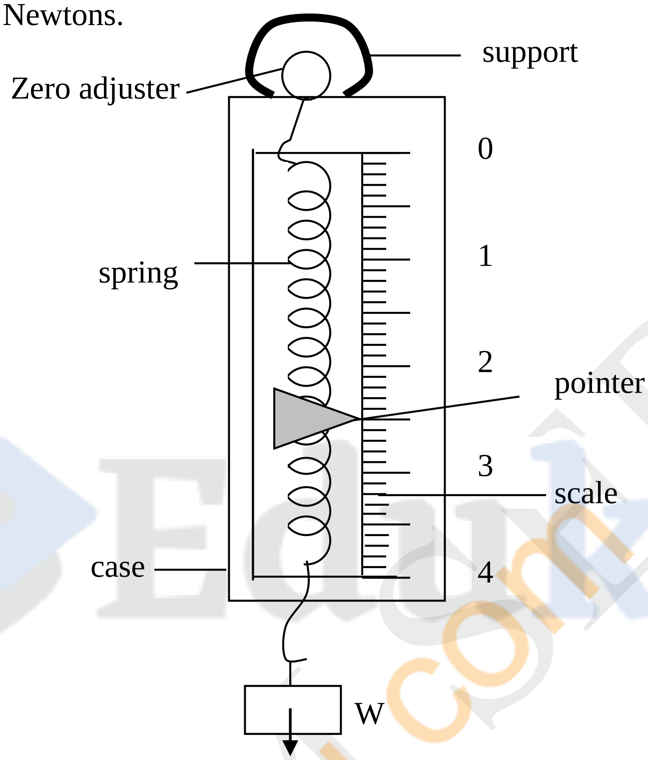


When a body is stationary (at rest) or is not accelerating it means either:

1. There is no force acting on it. or
2. Several forces acting on it balance each other and so there is no resultant force to produce an acceleration. Such a body is said to be in equilibrium under the action of several forces.

Measurement of Force

The instrument used to measure force is a spring balance (forcemeter or Newton meter). Force is measured in Newtons (N), hence, the scale of a spring balance is calibrated in Newtons.



When a force pulls on the hook, the spring balance stretches to counter balance the force until the spring provides an equal, balancing force.

By Definition: 1 Newton is the force which produces an acceleration of 1 m/s^2 in a mass of 1 kg.

1 N produces an acceleration of 1 m/s^2 in mass 1 kg
1 N produces an acceleration of 2 m/s^2 in mass ½ kg
10 N produces an acceleration of 5 m/s^2 in mass 2 kg

$\therefore$ Force = mass x acceleration
$F = ma$

Where F = force in Newtons
m = mass in kg
a = acceleration (m/s^2 or N/kg)

1. $F = m\,a\ (kg\ m/s^2)$
2. $m = \dfrac{F}{a}(N/m/s^2)$
3. $a = \dfrac{F}{m} = (N/kg)$

Examples

What force is needed to cause a train of mass 500 000 kg to accelerate at 0.04 m/s^2?

Solution

Given: m = 500 000 kg
a = 0.04 m/s^2
F = ?

$\therefore F = m\,a$
$F = m \times a$
F = 500 000 kg x 0.04 N/kg
F = 20 000 N

Exercise 1

1. A 900 kg car is to be accelerated from rest to a velocity of 12 m/s in 8 second. How large should be the force required to accelerate it in this way?

2. An electrical railway locomotive of mass 50 000 kg starts from rest and after 20 seconds. It has accelerated to a velocity of 25 m/s. Calculate

   (a) The acceleration of the locomotive
   (b) The horizontal driving force
   (c) The distance traveled in 20 s.

Exercise 2

1. A car of mass 1 200 kg traveled at 72 km/hr is brought to rest in 4 seconds. Find

   (a) Deceleration
   (b) Braking force
   (c) Distance moved during deceleration

Effects of force on a body

Since no one has ever seen, tasted or felt a force before, the only meaningful way to look at forces is by considering effects of a force.

Whenever a force acts on an object one or more of the following effects can be observed:

1. a force may produce or cause a change in the motion of a body.
2. a force may produce or cause a change in the size and shape of a body (more so for elastic materials).
3. a force may produce or cause a turning effect on a body.

(A) **Effect of a force on motion**

If an unbalanced force is applied to an object:

(i) It will cause an object, if at rest, to move or
(ii) If the body is already moving, it can change its speed or velocity (i.e. accelerate or decelerate) or
(iii) The object can change its direction of motion.

The whole of our treatment of effect of a force on motion is based on Sir Isaac Newton's studies of bodies in motion. **Sir Isaac Newton (1642 to 1727)** studied motion and its causes for many years and summarised his findings in three (3) laws of motion (Newton's laws of motion).

(i) ***Newton's 1st law of motion*** (also called the **law of inertia**) states that: an object will remain at rest (if at rest) or will continue in its state of uniform motion (i.e. uniform velocity), if moving, unless it is compelled by some external (unbalanced or opposing) force to act otherwise (i.e. to change that state of motion).

INERTIA

The property of a body to remain at rest or to continue its motion in a straight line is called **inertia** (from the Latin word for mechanical "laziness"), hence Newton's first law of motion is sometimes called "the law of inertia".
The first law therefore suggests that all matter (i.e. objects/bodies) has in-built opposition or reluctance or resistance to change its state of motion or rest.

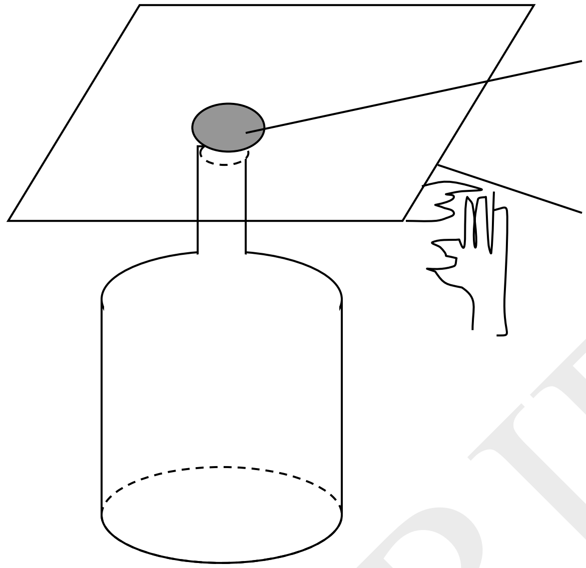
Due to inertia we recognize that:

- a moving car is much more difficult to stop moving than a bicycle moving with same speed.
- a truck is in turn much more difficult to stop moving than a small car at the same speed.

Clearly, inertia depends on the mass of the body. The larger the mass of a body the greater its inertia i.e. the more difficult it is to move the body when at rest and to stop it when in motion. Thus, the mass of a body is a measure of its inertia (objects with large mass also have large inertia).

Evidence (demonstration) of inertia

(a)



A small coin put on a card and placed over the mouth of a bottle or tumbler drops neatly into the bottle (tumbler) when the card is flicked sharply. Here, the coin shows reluctance to move along with the card.

(b) Occupants of a car which stops suddenly lurch forward in an attempt to continue moving (this is why seat belts are needed).

(ii) ***Newton's 2nd law of motion***.

States that: An unbalanced force, F, acting on a body of mass, m, causes the mass to move with an acceleration, a, which is directly proportional to the applied force but inversely proportional to the mass, in the direction of the force.

$a \propto F$ (i.e. acceleration, a, is directly proportional to force, F) *and*

$a \propto \frac{1}{m}$ (*acceleration is* inversely proportional to the mass)

Combining the two proportions, we obtain:

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

$a = \frac{kF}{m}$, where k = constant of proportionality

$kF = ma$

Let $a = 1$, $F = 1$, $m = 1$ (by definition, 1N is the force which gives a body of mass 1kg an acceleration of 1 m/s^2).

Then, $k = 1$

the equation can be written as

$F = ma$

Where F = resultant or net or unbalanced force in Newtons
m = mass of the body in kg
a = acceleration in m/s^2 or N/kg

NB: 1. An unbalanced force produces an acceleration in a body (hence, velocity changes with time).
2. If no unbalanced force acts on a moving body, the body does not accelerate, hence moves with uniform or constant velocity.

Newton's 2nd law of motion may be restated in terms of momentum (the product of mass and velocity).

Consider a force, F, acting on a body of mass, m, for a time, t, and changing its velocity from u to v.

$F \propto ma$

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

$F \propto m\left(\frac{v-u}{t}\right)$ or $F \propto \frac{mv-mu}{t}$

since, momentum, P = mass x velocity,

therefore, initial momentum = mu
final momentum = mv
change in momentum = mv-mu

and rate of change of momentum = $\frac{mv-mu}{t}$

Hence, ***Newton's 2nd law of motion*** also states that the **rate of change of momentum** of a body is directly proportional to the applied force, F (i.e. resultant force or unbalanced force) and takes place in the direction of that force.

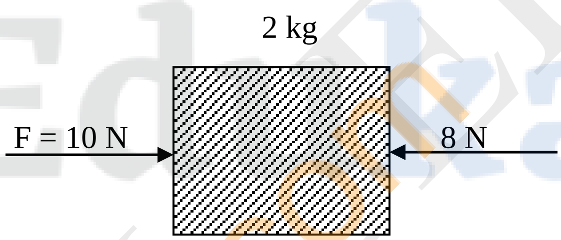
Exercise

1. A crate of mass 4 kg is pushed along the floor with a constant speed by a force of 10 N. When the push is increased to 18N, what is the

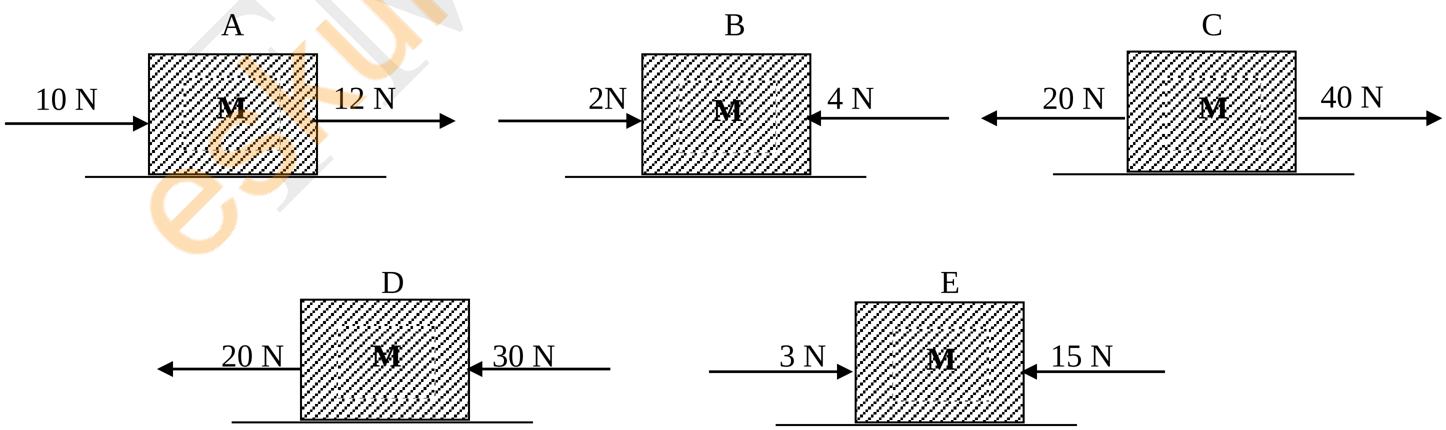
   (a) resultant (unbalanced) force
   (b) acceleration

ASSIGNMENT / EXERCISE (FORCES AND MOTION)

1. Calculate the acceleration produced in the following arrangement.



2. Which one of the diagrams below shows the arrangement of forces which gives the block **M** the greatest acceleration?



Object	*Resultant force*
A	10 N + 12 N = 22 N to the right
B	4 N – 2 N = 2 N to the left
C	40 N – 20 N = 20 N to the right
D	20 N + 30 N = 50 N to the left
E	15 N – 3 N = 12 N to the left

3. In the diagram if **P** is a force of 20 N and the object moves with **constant velocity**, what is the value of the opposing force, F?

4. (a) What resultant force produces an acceleration of 5 m/s^2 in a car of mass 1 000 kg?

   (b) What acceleration is produced in a mass of 2 kg by a resultant force of 30 N?

(iii) ***Newton's 3rd Law of motion*** (**action–reaction law**)
States that: to every action there is always an equal and opposite reaction.

The mutual actions of two bodies upon each other are always equal and are directed oppositely. Whenever object **A** exerts a force on object **B,** object **B** will exert a return force back on object **A.** The two forces are equal in magnitude but opposite in direction.
This law is often called the **action-reaction law.**

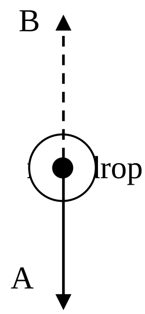
Examples of action–reaction forces

Action	*Reaction*
- gas is pushed out behind a rocket	- rocket moves forward
- a car hits a tree	- tree pushes the car
- foot pushes on the ground	- ground pushes on foot
- tyre pushes on road	- road pushes back on tyre

Exercise 2 (Action-reaction law)

1. A book of mass 1.5 kg exerts a downward force on a table. What is the
   (a) size of the force exerted by the table on the book?
   (b) Direction of this second force?

2. The diagram shows the forces acting on a raindrop which is falling to the ground.



(a) (i) **A** is the force which causes the raindrop to fall. What is this force called?

(ii) **B** is the total force opposing the motion of the drop. State one possible cause of this force.

(b) What happens to the raindrop when force **A** = force **B**?

FRICTION FORCES

While it seems common sense, from Newton's first law, that a body will remain at rest until an unbalanced force sets it in motion, it is not so easy to accept that a uniformly moving body would continue to move with constant velocity in a straight line if left to itself. This is because in practice we cannot eliminate all the forces which would retard the motion. One of the most commonly encountered types of force is the force of friction, encountered with every use of Newton's 2^{nd} law. Friction is the resistance which must be overcome whenever one surface moves over another.

By definition, friction is a force which opposes the relative sliding motion of two surfaces in contact with one another.

Friction always acts in the direction opposite to the movement and so always opposes any attempt to do mechanical work.

Friction is both useful and also a nuisance.

Usefulness of Friction

- provides a grip between the feet and ground, thus stops us from sliding.
- Provides a grip between the tyre and the road and also helps braking.
- Helps nails and screws to hold in wood, keeps nuts on bolts and also helps clothes to hold on the body.

Thus, we would be unable to walk if there were no friction between the soles of our shoes and the ground. Cars and bicycles could not be stopped if there were no friction between the brake pads and the rims or discs.

Friction as a nuisance

- causes wear and tear in moving parts of machines and produces heat on sliding surfaces of machines.
- causes machines to decelerate and to move stiffly and so waste some of the energy put in machines (as sound and heat).

Reducing Friction

- by lubricating moving parts of machines using lubricants e.g. oil, grease etc.
- by using ball bearings or roller bearings.

Motion in a curved path and the centripetal force (due to a perpendicular force)

It is not natural for an object to travel in a circle. If an object is to move on a circle, a force directed along a radius is needed. Thus an object moving in a circle requires a force directed towards the centre to keep it from moving along the tangent path. This force needed to bend the normally straight path of the particle into a circular path is called the **centripetal** (or **centre-seeking**) **force**. The centripetal force is a pull on the body and it is directed towards the centre of the circle.

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

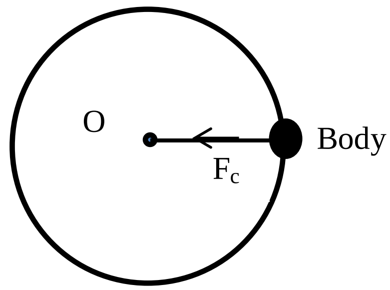
where, F_c = centripetal force

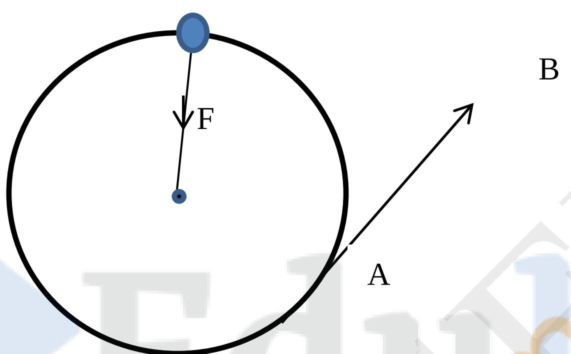
m = mass of body moving round a circular path
v = velocity of body
r = radius of circular path.

Clearly, a larger force is needed if

(i) the speed of the object is increased.
(ii) the radius of the circle is decreased.
(iii) the mass of the object is increased.

Consider a mass, m moving in a circular path.





Centripetal force provided by the tension, F in the string holds the ball in a circular path. If the string breaks when the ball is at A, the ball will continue in a straight line towards B, provided gravity is neglected.

An object moving in a circular path is said to have an acceleration even its speed is constant. Its direction of motion is constantly changing, hence its velocity changes and thus has an acceleration.

B] **Effects of a force on the shape and size of a body**

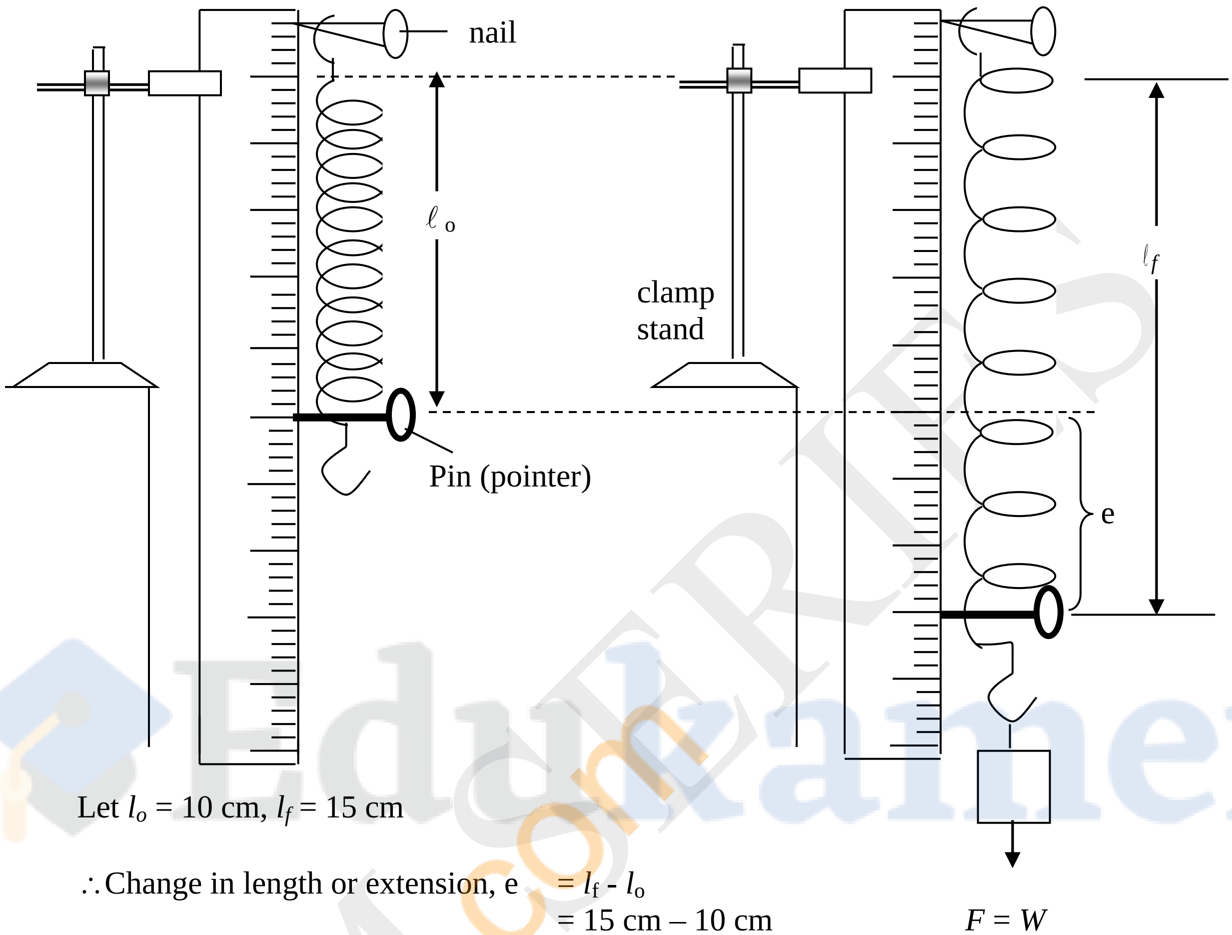
A part from producing a change in motion, a force may also produce a change in size and shape of a body (deform the body). This is more so for elastic objects e.g. rubber, rubber compounds, springs, etc.
Different bodies behave differently when subjected to a force which is later removed.

Elasticity of a spring

The use of a spring balance to measure forces depends on its ability of being elastic.
A substance is said to be elastic if when stretched or compressed or bent or twisted, it recovers its original shape and size when the applied force is removed.

Experiment: To discover the relationship between applied force, F and extension, e.

Set up the apparatus as below:



Let l_o = 10 cm, l_f = 15 cm

$\therefore$Change in length or extension, e $= l_f - l_o$
= 15 cm – 10 cm
= 5 cm

Hence, the difference in length between the stretched length, l_f of the spring and its unstretched length, l_f is called the extension.

Experimental procedure

- measure the original length of spring coil, l_o (when no force or load is applied on to the lower end of springs.)
- Add a known mass, say 50 g (0.5 N) to the lower end of the spring and record the new length of spring coil as l_f.
- Continue adding 0.5 N loads at a time and take the corresponding l_f for each total load.

Exercise

The following are typical experimental results obtained when various loads were added to the lower end of a spring.
Copy and complete the table by finding the extension, e produced by each load.

Load	*l/cm*	*$L_f - l_o = e/cm$*
0	10	
0.5	12	
1.0	13	
1.5	16	
2.0	18	

Experimental procedure

- measure the original length of spring coil, l_o (when no force or load is applied on to the lower end of springs.)
- Add a known mass, say 50 g (0.5 N) to the lower end of the spring and record the new length of spring coil as l_f.
- Continue adding 0.5 N loads at a time and take the corresponding l_f for each additional load.
- Table of results (as in the exercise)

NB: the pointer readings can also be taken as the weights are removed (unloading). After unloading the weights, check the original length, l_o of the spring to ensure that the elastic limit was not exceeded.

Analysis of results

Using the results of the experiment, plot a graph of extension e/cm on y-axis and load F/N on the x-axis.

The extension–force graph will be a straight line passing through the origin.

This shows that:

- the extension, e is directly proportional to the load, F (provided the elastic limit is not exceeded). Thus.

$e \propto F$

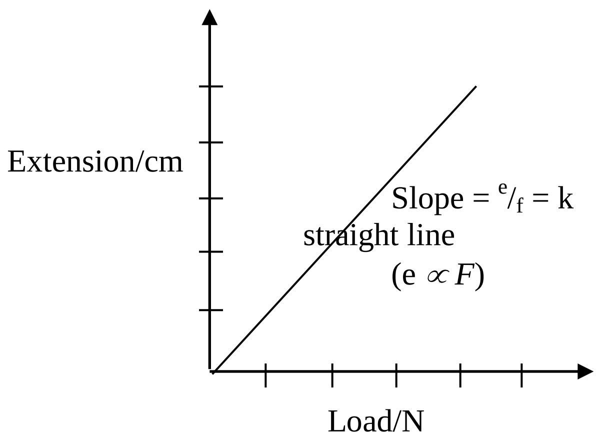
$e = KF$

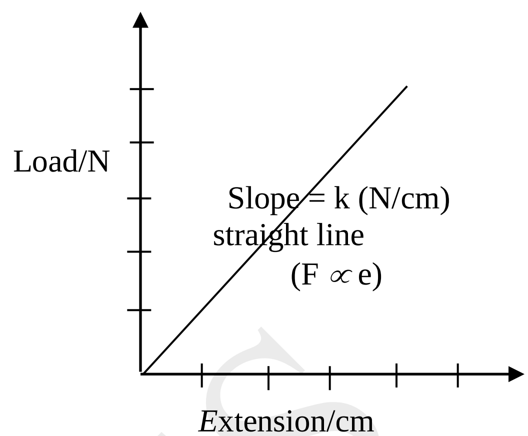
$K = \frac{e}{K}$ K = spring constant

e = extension caused by limit force

Graph of Extension/cm against the load/N

F/N	*l_o*	*l_f*	*extension*
0	10 cm	10	0
1	10 cm	12	2
2	10 cm	14	4
3	10 cm	16	6



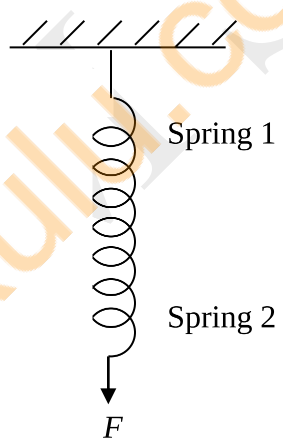


Exercise

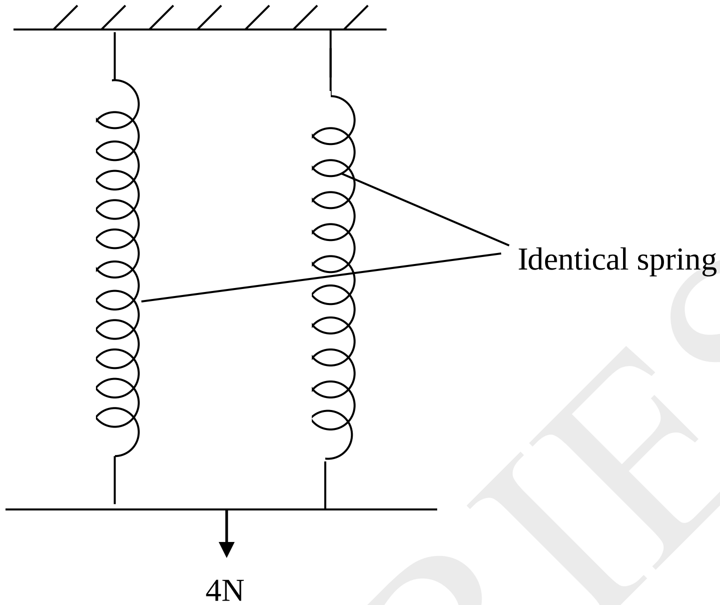
1. A spring is stretched 10 mm (0.01 m) by a weight of 20 N. Calculate
   (a) spring constant, K
   (b) the weight, W of an object which causes an extension of 80 mm (0.08 m)

2. What is the spring constant of a spring which is stretched
   (a) 2 mm by a force of 4 N
   (b) 4 cm by a mass of 200 g

3. A 2 N load causes a 10 cm extension of a spring.
   (a) When two such identical springs are joined end to end (in series) to form one continuous spring and a load of 4 N is applied, what is the next extension?



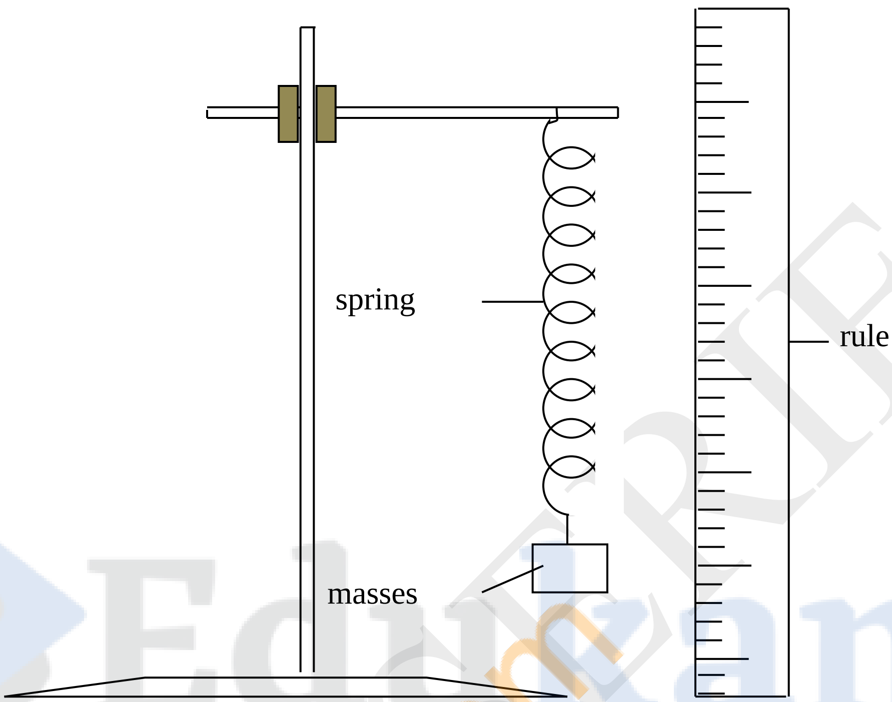
(b) If the two identical springs in (a) are now connected side by side (in parallel) and the load of 4 N is applied, what will the new extension be?



ASSIGNMENT: ELASTICITY AND HOOKE'S LAW

The effect of force on the shape and size of a body

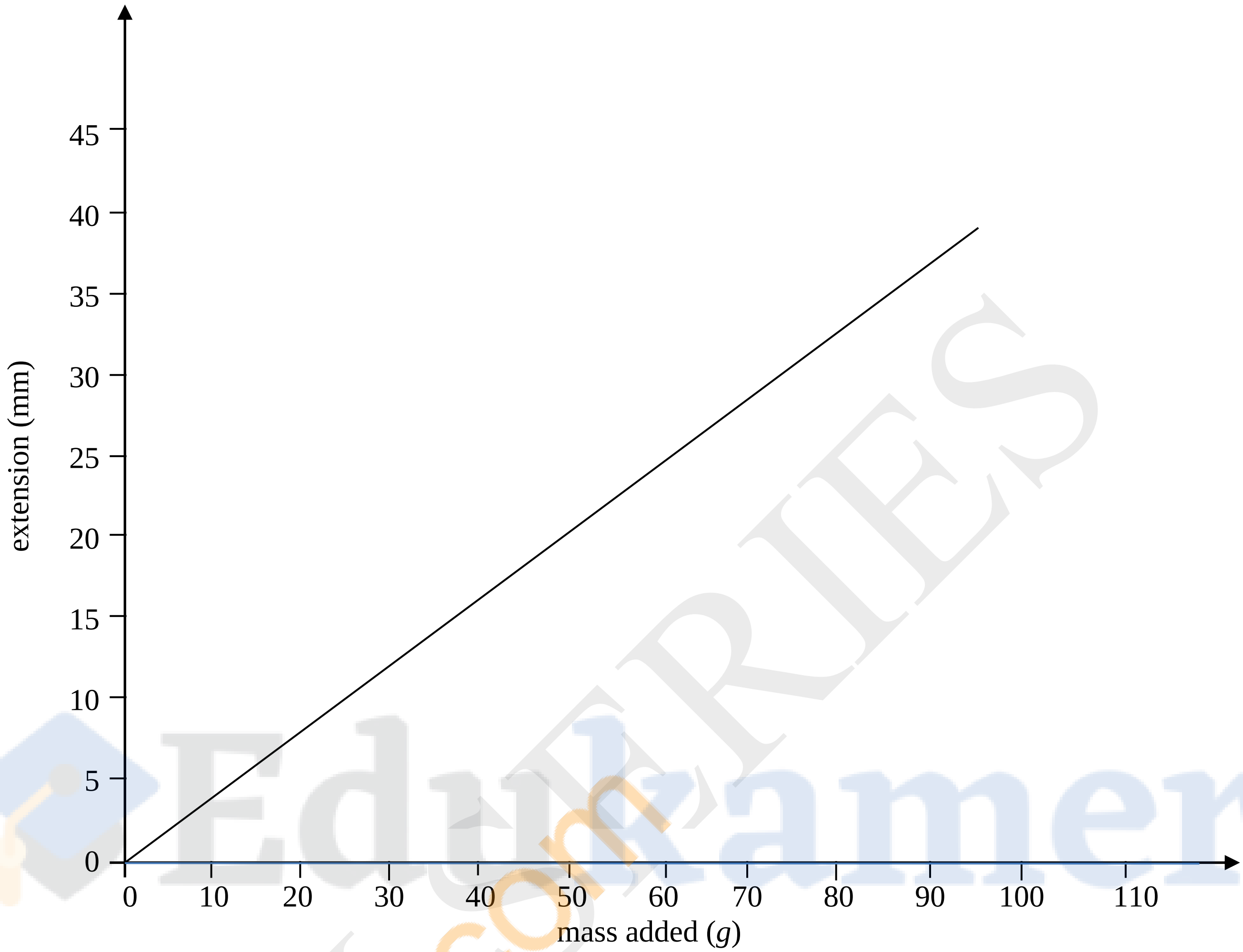
The apparatus below was used to investigate the stretching of a spring.



The table shows the results of the investigation

Mass added (g)	*Scale reading (mm)*	*Extension (mm)*
0	596	
10	601	5
20	606	10
30	610	14
40	615	19
50	621	25
60	625	29
70	630	34
80	635	39
90	638	42
100	640	44
110	641	45

The graph shows the results of the extension (mm) against the mass added (*g*).



Using the information provided answer the following questions:

1. How is the extension related to the load?
2. In the straight line region, what is shown by the slope of the line?
3. What extension of this spring would you expect from a load of 35 g?
4. What extension of this spring would you expect from a load of 150 g?

C] **Turning Effects of a force**

When two or more forces act at different points on a body, the forces tend to make that body rotate. Each of the forces produce a turning effect about a point on the body. Force thus, can produce **turning effects** or **moments** about a point. The point about which the moment acts is called the pivot or the fulcrum or axis.

Definition: The moment or turning effect of a force about a point or pivot or axis is the product of the force F, and the perpendicular distance, d from the pivot to the line of action of the force.

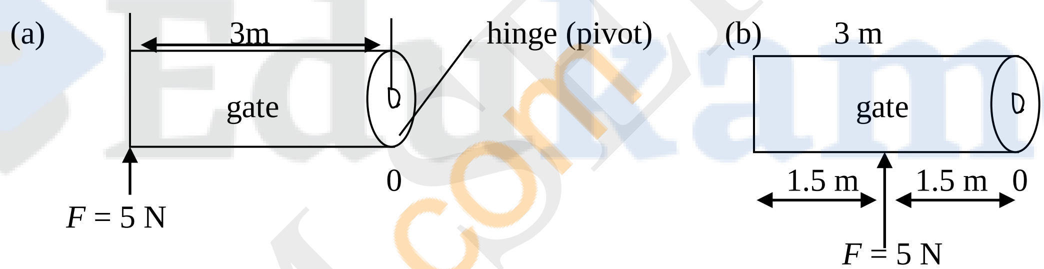
Moment of a force = F x $\perp d$

The unit for moment of a force is the Newton-metre (Nm). The moment has both magnitude and direction, hence is a vector quantity. Closing and opening of gates, doors etc are all examples of a turning effect or rotation of a force.

The turning effect depends on

1. The size of the force applied
2. The distance from pivot to point of application of force

Consider the two gates below:



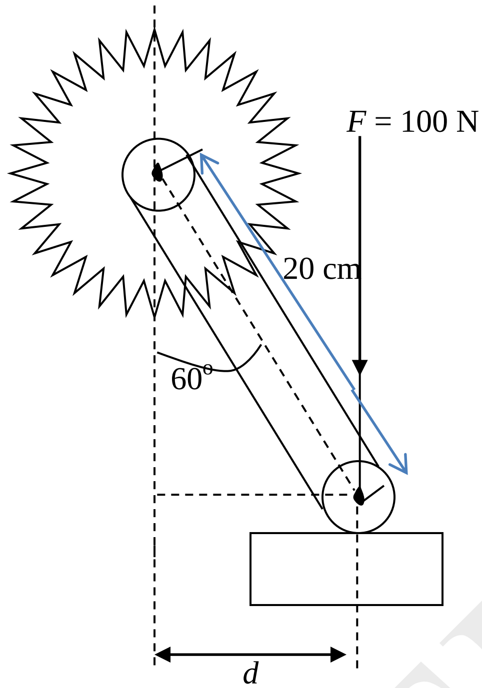
In (a) a force F acts on the gate at the edge, in (b) at the centre.

(a) moment of force F about 0 = F x 1d
= 5 N x 3 m = 15 Nm

(b) moment of force about 0 = F x $d\perp$
= 5 N x 1.5 m = 7.5 Nm

Thus the turning effect of F is greater in (a) and gate opens most easily when it is pushed or pulled at the edge than in (b).

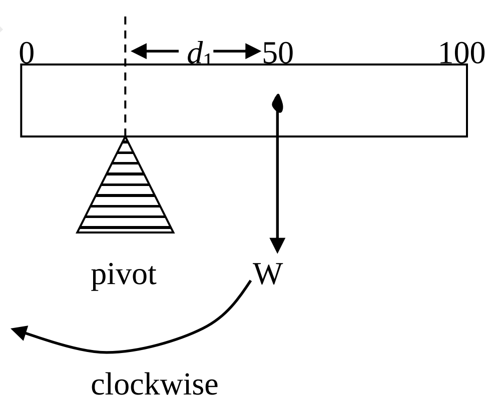
Example
Calculate the moment produced by a force of 100 N applied to a bicycle pedal as shown below:



Solution
Moment = F x d
= 100 N x 0.2 x sin 60° m
= 17.32 Nm (clockwise)

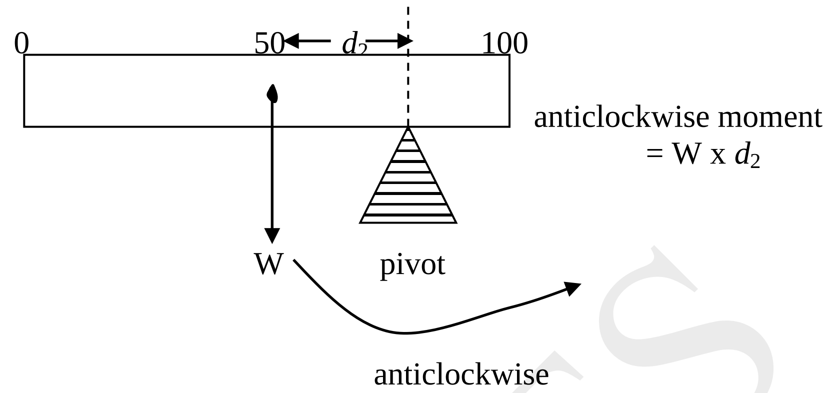
Clockwise and anticlockwise moments
The turning effect or rotation about a point can either be clockwise or anticlockwise.

(a) Clockwise moments



Clockwise = W x d_1

(b) Anticlockwise

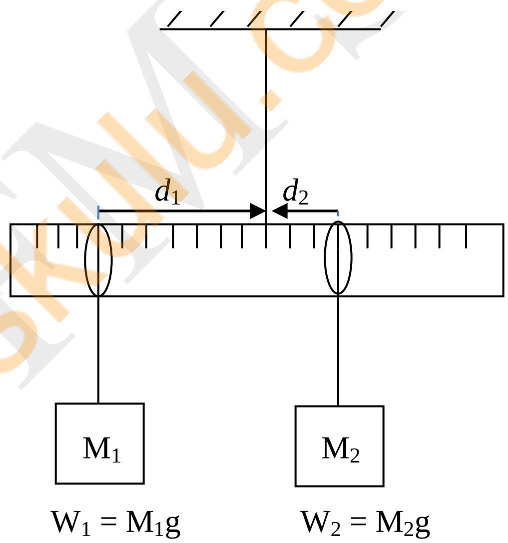


The principle of moments state that:

When a body is in equilibrium, the sum of the clockwise moments about a given point equals the sum of the anticlockwise moments about the same point

Clockwise moments = anticlockwise moments

Experiment: To verify the principle of moments
Balance a metre rule with a hole drilled at its centre (at 50 cm mark) on a spring tied to a rigid support.



Hang unequal loads m_1 (weight, W_1) and m_2 (weight, W_2) from either side of the hole at the centre and move the string loops holding m_1 and m_2 until the ruler balances horizontally once more. Read and record the distances d_1 and d_2.

Again move m_1 and m_2 to other positions until the ruler balances as before and record the results. Calculate W_1d_1 and W_2d_2.
Record the results in a table and repeat the experiment for other loads and distances.
Table of results

m_1(kg)	W_1(N)	d_1(m)	W_1d_1(Nm)	m_2(kg)	W_2(N)	d_2(m)	W_2d_2(Nm)

W_1 is trying to turn the ruler anticlockwise and W_1d_1 is its moment. W_2 is trying to cause clockwise turn and its moment is W_2d_2.

Results
At equilibrium, the anticlockwise moment W_1d_1 equals to the clockwise moment W_2d_2.

Conclusion: Within the limits of experimental errors anticlockwise moments equals clockwise moments.

Conditions for equilibrium of a body
(i) The sum of the forces in one direction must equal the sum of the forces in the opposite direction (i.e. resultant force must be zero).

(ii) Resultant moment must be zero (the principle of moment must apply).

Example
1. Consider a see-saw balanced by two people with different weights sitting at different distances from the pivot or fulcrum.
   The one on the left is 2 m from the pivot and weighs 300 N while the one on the right is 3 m from the pivot and weighs 200 N.

   (a) Using the principle of moments shows that the beam is in equilibrium.
   (b) If the person on the left moves to a position 2.5 m left of the pivot, where must the other person move in order to keep the beam balanced?

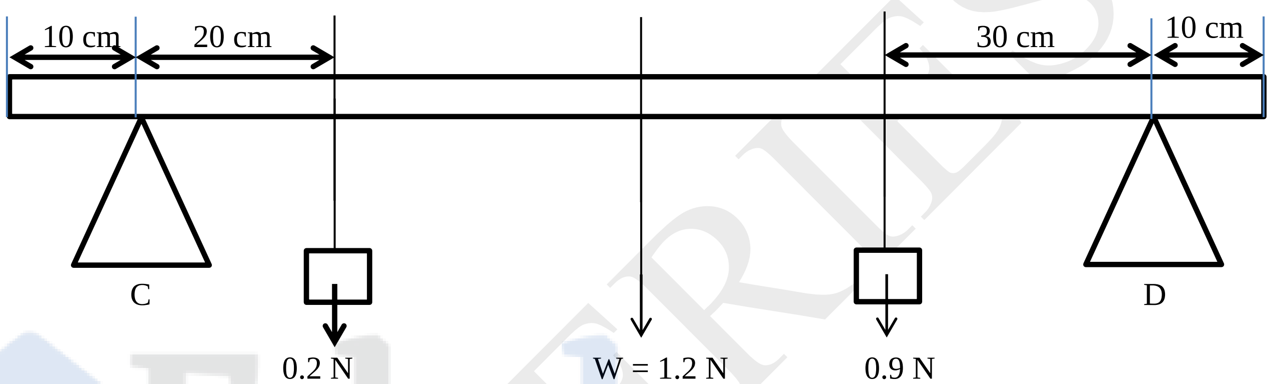
Solution
(a) If the principle of moments apply (i.e. beam balances)
Clockwise moment = anticlockwise moment
$F_1 \text{ x } d_1 = F_2 \text{ x } d_2$
200 N x 3 m = 300 N x 2 m
600 Nm = 600 Nm
Hence beam is in equilibrium

(b) In order to keep the beam balanced, principle of moments must hold.
Clockwise moment = anticlockwise moment
$F_1 \text{ x } d_4 = F_2 \text{ x } d_3$
200 N x d_4 = 300 N x 2.5 m

$$d_4 = \frac{200\,N\ x\ 2.5m}{200\,N} = \frac{7.5m}{2}$$

d_4 = 3.75 m (to the right of pivot)

2. A uniform wooden beam AB, 120 cm long and weighing 1.2 N rests on two sharp-edged supports C and D placed 10 cm from each end of the beam respectively. A 0.2 N weight hangs from a loop of thread 30 cm from A and a 0.9 N weight hangs similarly 40 cm from B. Find the reactions at the supports.



Solution:
For a body at rest (i.e. in a state of equilibrium) under the action of several parallel forces, the sum of all forces in one direction is equal to the sum of the forces in the opposite direction.

Hence

Total upward forces = total downward forces
$F_C + F_D = 0.2\text{ N} + 1.2\text{ N} + 0.9\text{ N} = 2.3\text{ N}$
(F_C and F_D being the reactions, R, at the points of support).

If we take moments about C (hence, eliminating the moment due to reaction force at C):

Clockwise moments = anticlockwise moments
(0.2 N x 20 cm) + (1.2 N x 50 cm) + (0.9 N x 70 cm) = F_D x 100 cm

$$F_D = \frac{(0.2\,N \times 20\,cm) + (1.2\,N \times 50\,cm) + (0.9\,N \times 70\,cm)}{100\,cm}$$

$$F_D = \frac{4\,Ncm + 60\,Ncm + 63\,N\,cm}{100\,cm} = \frac{127\,Ncm}{100\,cm}$$

F_D = 1.27 N (reaction at support D)

but $F_C + F_D = 2.3$

$\therefore$ F_C = 2.3 N – F_D

= 2.3 N – 1.27 N

F_C = 1.03 N (reaction at support C)

Alternatively,

Taking moments about D (hence eliminating the moment due to the force D)

Clockwise moments = anticlockwise moments

F_C x 100 = (0.2 x 80) + (1.2 x 50) + (0.9 x 30)

F_C x 100 = (16 + 60 + 27) = 103

$$F_C = \frac{103\,Ncm}{100\,cm} = 1.03\,N(reaction\ at\ support\ C)$$

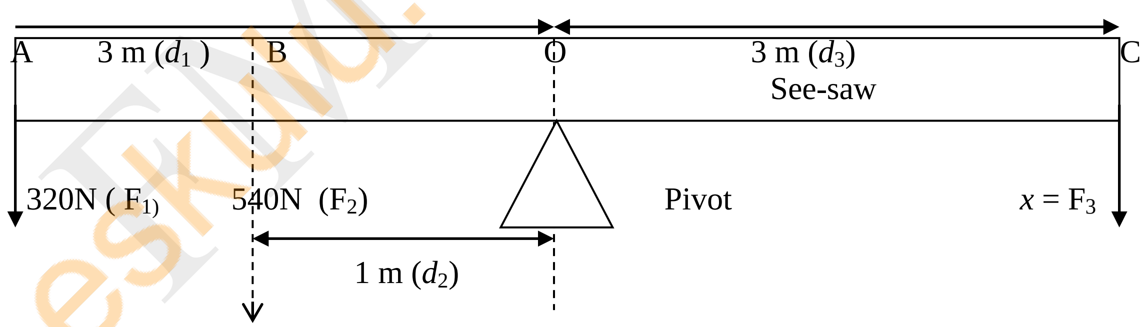
but $F_C + F_D$ = 2.3 N

$\therefore$ F_D = 2.3 N – 1.03 N

F_D = 1.27 N (reaction at support D)

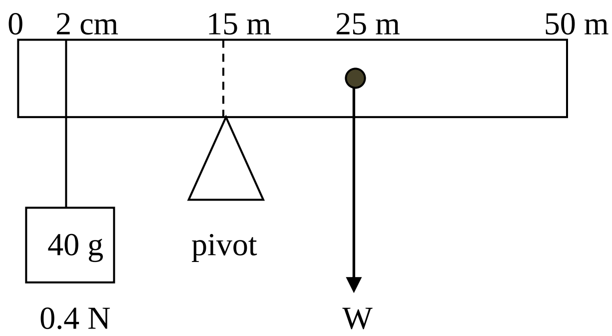
Exercise

1. A see-saw balances when a girl of weight 320 N is at **A** and a boy of weight 540 N is at **B** and another boy of weight **x** (N) is at **C**. If 3 people are positioned on the see-saw as shown below find the weight **x.**



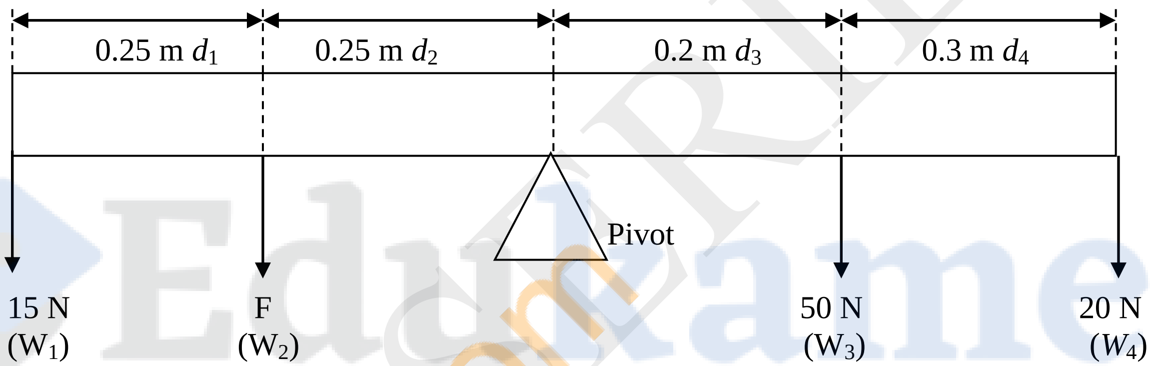
2. A uniform half metre rule is freely pivoted at 15 cm mark and it balances horizontally when a body of mass 40 g is hung from the 2 cm mark.

   (a) Draw a clear force diagram of the arrangement.



(b) Calculate the weight of the rule.
(c) Mass of the rule

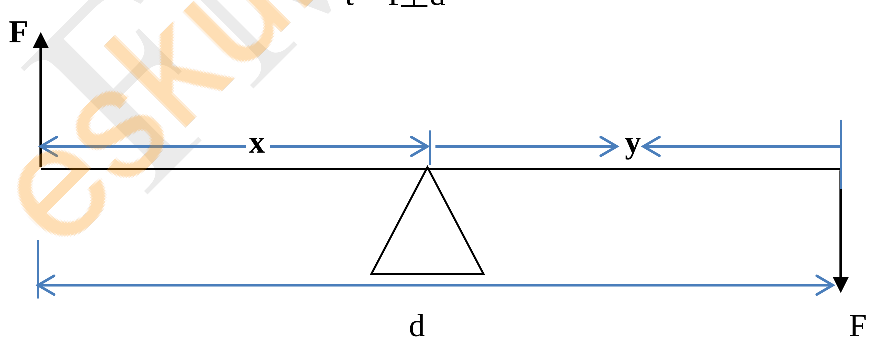
3. For the diagram, calculate the force, *F* needed 25 cm from the left hand end of the beam so that it will be in equilibrium.



Couples

Two, equal and opposite parallel forces acting on opposite sides of a pivot form a couple**.** The moment of the couple is called its TORQUE, t.

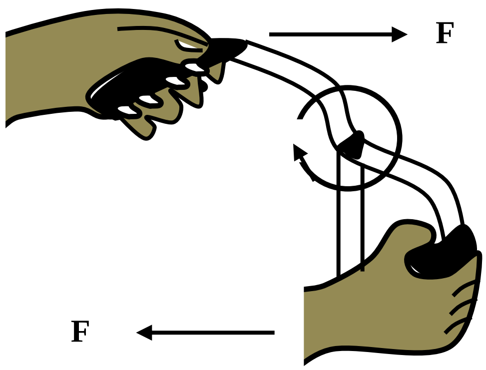
$$t = F \perp d$$



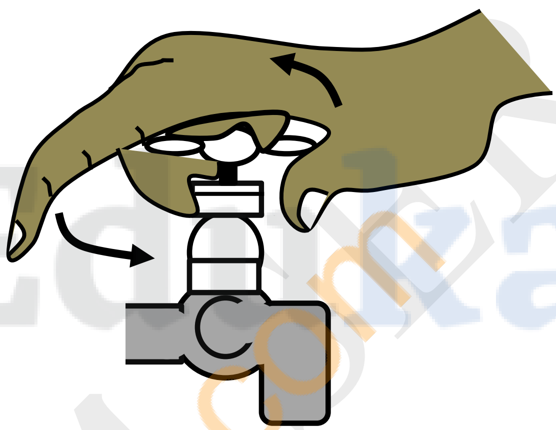
$$t = Fx + Fy = F(x+y) = Fd$$

Examples of couples include:

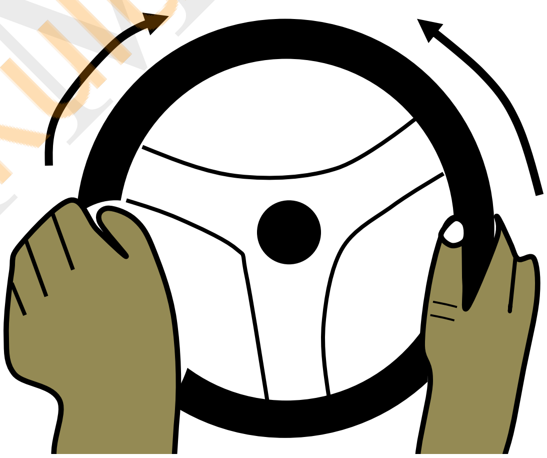
(a) when you use two hands to turn the handlebars of a bicycle



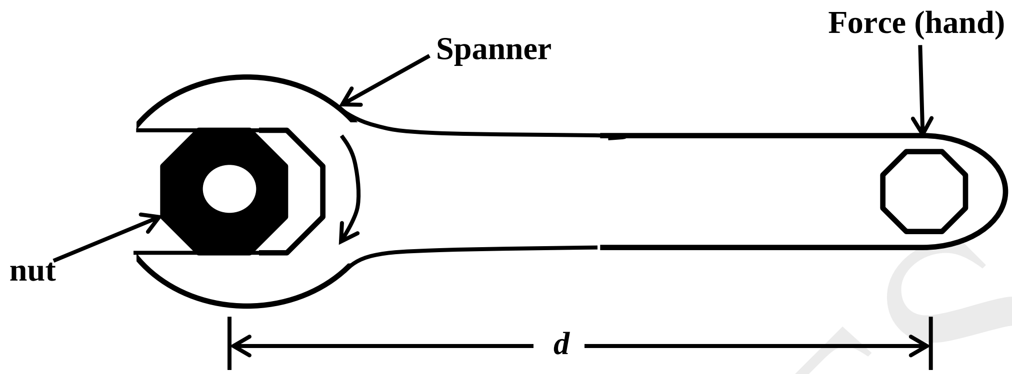
(b) turning a water tap (with a couple consisting, say the index finger and the thumb).



(c) turning the steering of a car (with a couple of the left hand and right hand).



(d) when a spanner tightens a nut or a bolt (the force is actually applied to the two opposite faces of the nut, hence producing a couple).



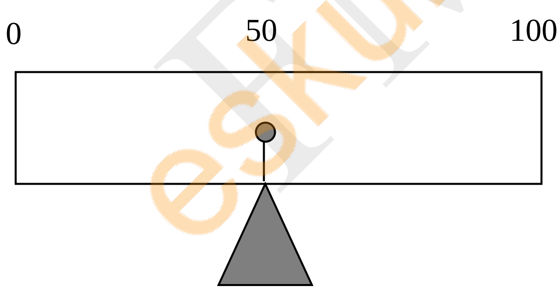
The principle of moments is applied in devices called simple machines (i.e. the levers), as we shall see later under work, energy and power.

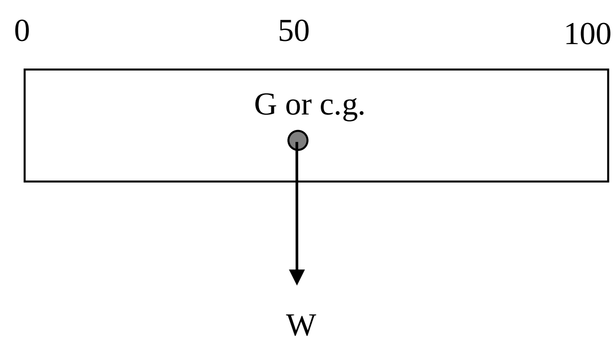
CENTRE OF MASS (AND CENTRE OF GRAVITY)

The centre of mass of an object is the point where the whole mass of the body is concentrated or appears to be concentrated. The centre of gravity of an object is the point where the whole weight of the body is concentrated or appears to be concentrated. For simplicity, we will consider the centre of mass and the centre of gravity to coincide in position.
The centre of gravity of an object is regarded as the point where the object balances. Thus the centre of gravity of objects can be found by balancing a body on a knife-edge or by hanging it with a plumb-line from several points.

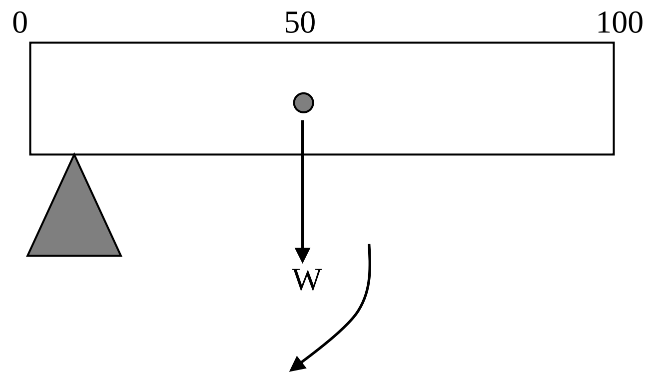
It follows that:

- the centre of gravity a uniform rod or rule is at its centre (mid point) and when supported there it balances.





If it is supported at any other point it topples because the moment of its weight W about the point of support is not zero



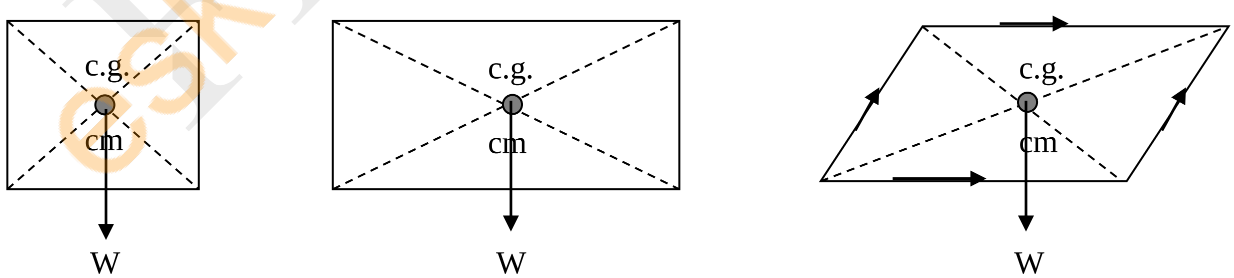
Locating the centre of gravity
The centre of gravity can be located by

1. Simple geometry (for regular shaped bodies)
2. Experiment (for irregular shaped bodies)

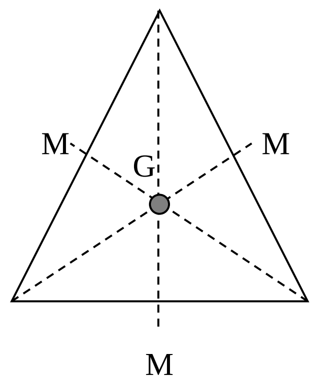
1. ***Simple geometry***

- a uniform disc and ring both have the centre of gravity at the centre.

- a uniform regular thin sheet (or lamina) such as a square, rectangle, parallelogram etc have the centre of gravity at the intersection of the diagonals.



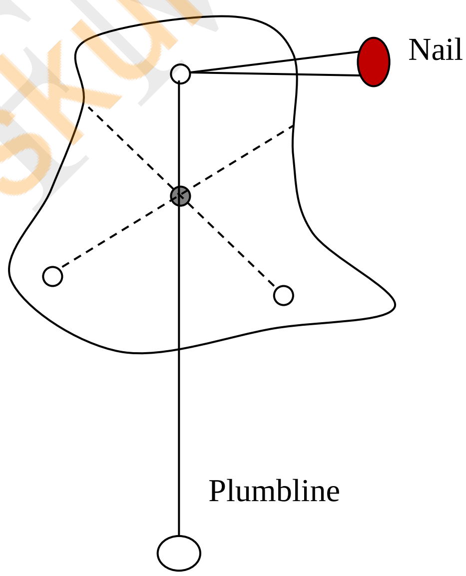
For a triangle or triangular lamina, the centre of gravity is where the medians, M intersect.



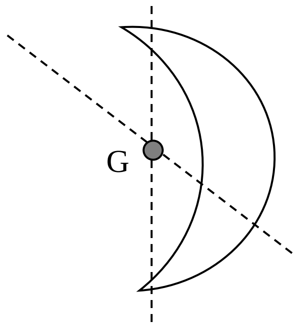
Thus, we see that the centre of gravity or centre of mass of a regularly shaped body of same density all over is at its centre.

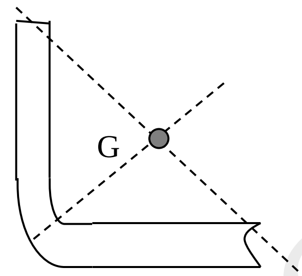
2. ***Centre of gravity, G, by experiment***
   The centre of gravity (or centre of mass) of an irregularly shaped body can be found experimentally.

   Experiment: To find the centre of gravity of a sheet of cardboard (by plumbline method- best accurate method).
   1. Cut the cardboard to any shape e.g. a crescent.
   2. Make 3 well-spaced holes near the edge of the cardboard.
   3. Hang the end of one hole on a nail. Make sure that the card swings freely and then come to rest.
   4. Hang a weight on a string (plumbline) from the same nail and mark the vertical line formed by the string on the cardboard.
   5. Repeat this for the two other holes.
   6. Where the vertical lines from each hole intersect on the cardboard, marks the position of the centre of gravity.



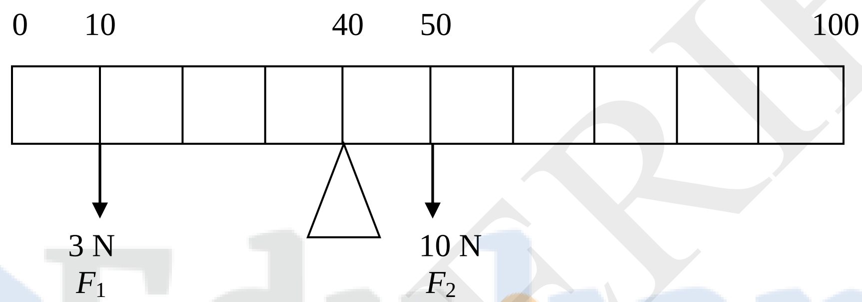
NB: Note that the centre of gravity may be either inside the actual material or outside a body (i.e. in the air nearby) e.g. for an iron tripod, laboratory stool etc.





Exercise

1. The weight of the uniform bar shown below is 10 N.

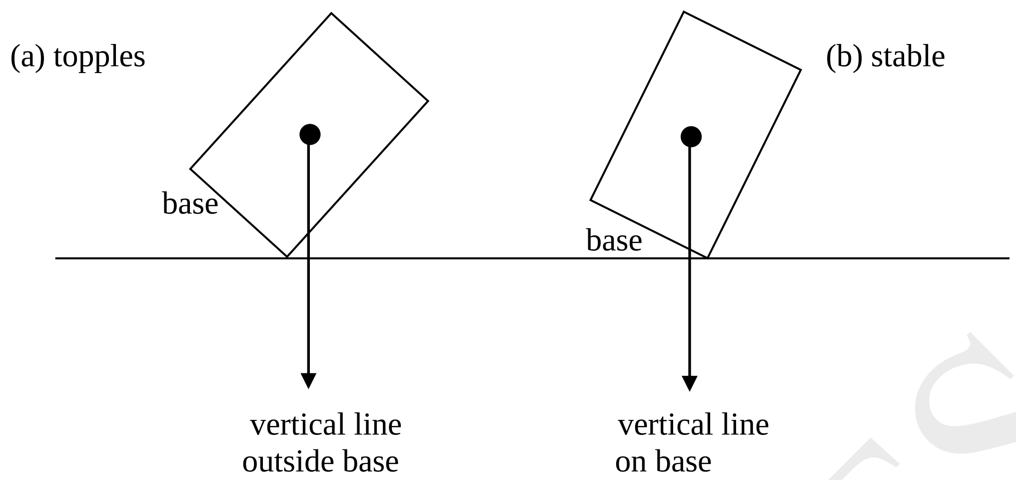


Does the bar balance, tip to the right or tip to the left? Show any calculation used, hence how you arrive at the answer.

Centre of gravity as related to the stability of an object

An object is said to be stable if it does not topple easily. If it does topple easily then it is unstable. The position of the centre of gravity of a body determines whether or not the body topples easily. This fact is important in the design of tall vehicles (which tend to overturn when rounding a corner), racing cars, reading lamps, drinking glasses, double-decker buses etc.

As a simple rule, a body topples when the vertical line through its centre of gravity falls outside its base, otherwise it remains stable.



Thus the stability of an object is related to the
(1) position of the centre of gravity of the object
(2) moment its weight exerts about an axis

The stability of an object can therefore be increased by
1. Lowering its centre of gravity (i.e. keeping its centre of gravity low).
2. Increasing its base area (making its base wide)

Racing cars have low centre of gravity and wide wheel base for stability in going round bends.

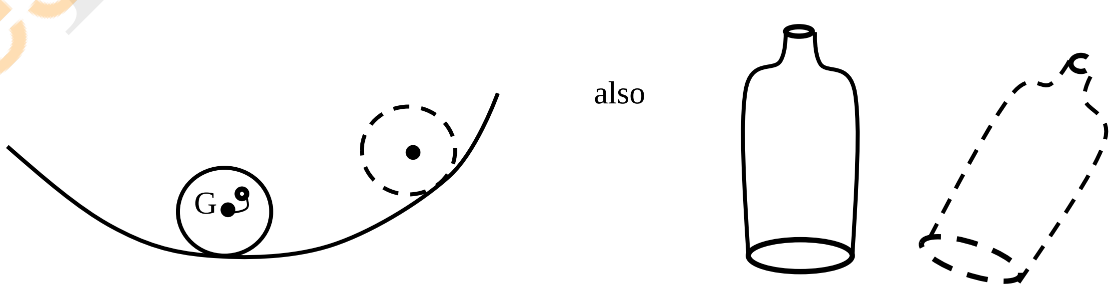
There are three (**3**) different states of stability:

- stable equilibrium

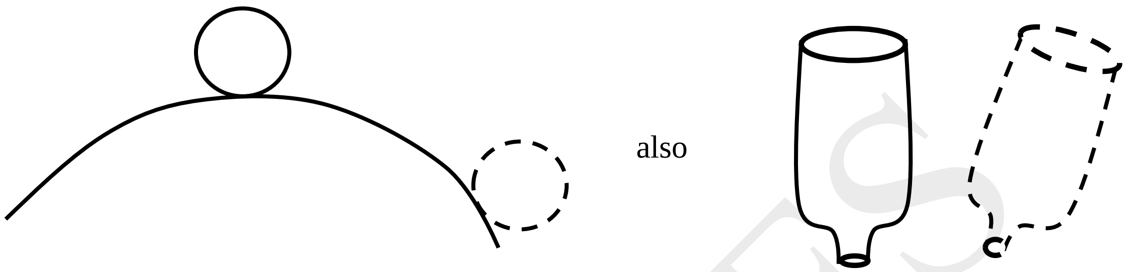
- unstable equilibrium

- neutral equilibrium

(a) <u>Stable equilibrium:</u> A body is said to be in 'stable equilibrium' if when slightly displaced and then released, the object returns to its original position (as this is the position of low centre of gravity).



(b) Unstable equilibrium: A body is said to be in 'unstable equilibrium' if when slightly displaced and then released, the object moves further away from its original position (position of high centre of gravity).



(c) Neutral equilibrium: A body is said to be in neutral equilibrium if when slightly displaced and released, the object remain at its new position (same centre of gravity position).

Exercise (Centre of gravity/ centre of mass):

1. What is meant by the centre of gravity of an object?
   Describe how you would find by experiment the centre of gravity of a thin, irregularly shaped sheet of metal.
   Explain why a minibus is more likely to topple over when the roof-rack is heavily loaded than when the roof rack is empty.

WORK, ENERGY AND POWER

(a) WORK

In everyday language ‘work’ means almost any kind of physical or mental activity that people do. In science however, the word has a more precise meaning.

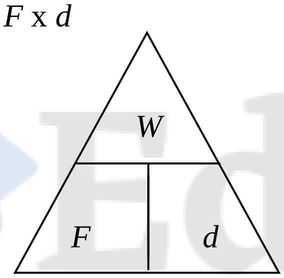
Mechanical work is done whenever anything is moved against a force or resistance. Notice that two factors are involved, i.e. there must be movement and the movement must be against a resistance. The greater the force and the greater the distance moved, the more work is done.

A locomotive pulling a train does work, so does a man who is employed to carry bricks up a ladder and onto a scaffold platform or an inclined plane (a ramp or slope).

Defn: Work is said to be done when a force is applied and moves a distance in the same direction as the force.

Work done = force x distance

$W = F \times d$

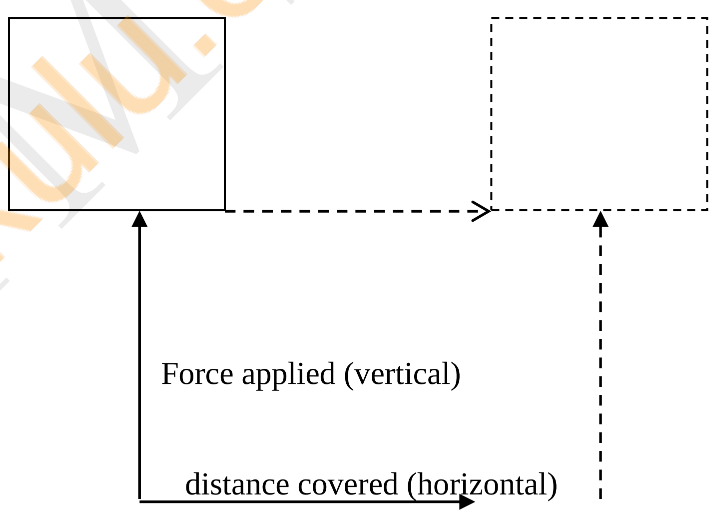


F is force in Newtons

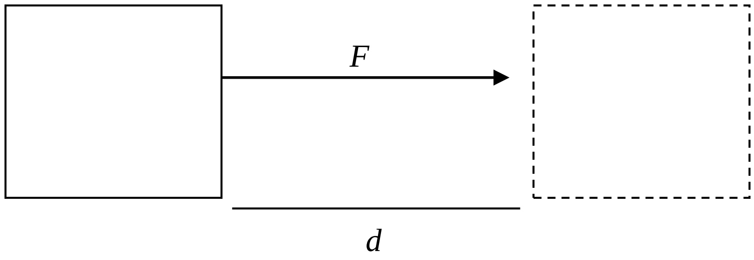
d is the distance in metres

W is work in Nm or Joule (J)

(a) here, no work is done



(b) here, work is done



The S.I. unit of work is the joule (J); if the force F is measured in newtons (N) and displacement s in metres (m).

Since W= F x d

1 joule = 1 Newton x 1 metre

Thus, 1 joule of work is done when a force of 1 Newton moves through a distance of 1 metre measured in the direction of the force.

Larger units of work in common use are the kilojoule (kJ) and the megajoule (MJ).

1 KJ = 1 000 J (10^3 J)
1 MJ = 1 000 000 J (10^6 J)

Note: Work done is a scalar quantity.

Example

1. How much work is done by an engine force of 5 000 N pulling a train 100 m?

   Soln: Work done = force F x displacement s
   = 5 000 N x 100 m = 500 000 J

2. A crane lifts a crate of mass 500 kg through a height of 20 m.

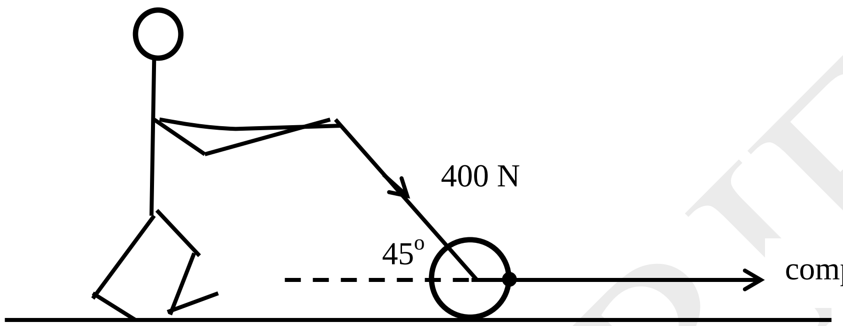
   (a) Calculate the work done by the crane in lifting the crate?

   Work done = F x d
   = mg x h
   $= 500 \text{ kg x } \frac{10\,N}{kg} \; x \; 20 \; m = 100\;000\,J$

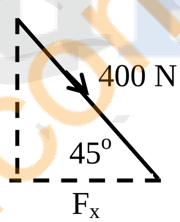
3. A block of mass 2 kg is lifted through a vertical height of 2 m from the earth's surface. Find the work done.

   Soln: Work done = force F x displacement s
   but F = upward force equal and opposite to the block's weight = mg
   s = vertical height, h
   $\therefore$ Work done = mgh = 2 kg x 10 N/kg x 2 m = 40 Nm = <u>40 J</u>

4. Calculate the work done by a man pushing a lawn roller with a force of 400 N at an angle of 45^{o} to the lawn if the roller is pushed along a distance of 20 m.



Soln: The force acting along the ground = 400 cos 45^{o} = 283 N
displacement s = 20 m



$$\text{Cos } 45^{o} = \frac{F_x}{400}$$

F_x = 400 cos 45^{o}

$\therefore$ Work done = 283 N x 20 m = <u>5 660 J</u>

(a) **ENERGY**

In order to do work we must have a source of energy. In the case of mechanical work, the source of energy produces the force which produces the movement.

Defn: Energy is the capacity (or ability) to perform work.

Energy, like work, is measured in joules (J).

Energy is also a scalar quantity.

Energy exists in a variety of different forms:

Some Different forms of Energy

(i) Mechanical energy (potential energy and kinetic energy)
(ii) Chemical / fuel energy (a re-grouping of atoms)
- energy stored in food, fuels and batteries
(iii) Sound energy
- e.g. from drum, loudspeakers etc
(iv) Nuclear energy
- released from the nucleus of certain atoms
(v) Thermal energy or heat energy or internal energy
- Often all other forms of energy end up as heat energy.
(vi) Electrical energy
- involves an electric current and is produced by energy transfers at power stations and in batteries. It is the commonest form of energy used in homes and industry because it is easy to transmit and to transfer to other forms.
(vii) Light energy
- from the sun, light bulbs etc

MECHANICAL ENERGY

Mechanical energy can be divided into two kinds called *potential energy* and *kinetic energy*.

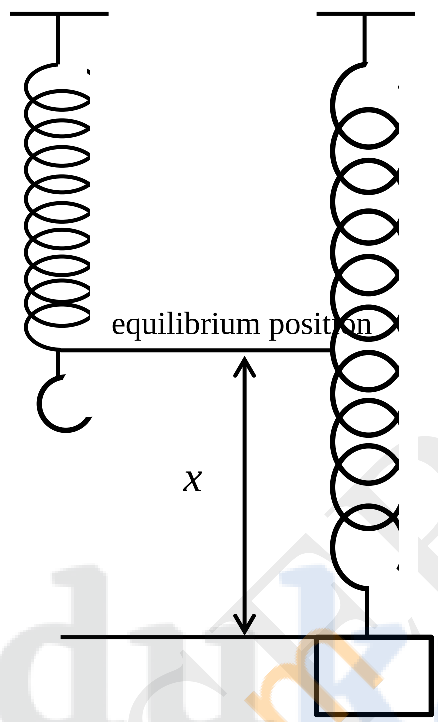
Potential Energy

Defn: Potential energy is the energy a body has by reason of its position (height above the ground) or state.

Potential energy is further divided into two; *Gravitational potential energy* and *elastic (strain) potential energy*.

Elastic (strain) potential energy is the energy a body has by reason of its state of condition such as the object may be bent, twisted, stretched or compressed.

e.g. A wound (coiled) clock-spring possesses elastic potential energy.

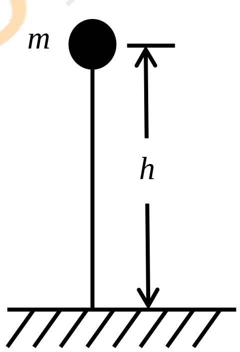


Elastic spring stretched by distance, x has stored potential energy.

Elastic P.E = $\frac{1}{2}kx^2$ where k = elastic or spring constant

x = extension

Gravitational potential energy is the energy a body has by reason of its position or height above the ground caused by gravity. Thus when anything is lifted against the pull of gravity, work has to be done. This work is stored in the lifted body as gravitational potential energy.



a mass m at a height h above the ground has stored gravitational potential energy.

e.g. The water in a reservoir above a hydroelectric power station has gravitational potential energy which is used to drive the turbines and produce electrical energy.

Gravitational potential energy = work done to lift the mass, m through a vertical height h above the ground.
= force F (equal and opposite to weight of mass m) x height h.

Gravitational potential energy = $\underline{mgh}$
where m = mass of body in kg
g = acceleration due to gravity in N/kg
h = height above ground in m.

Unit of potential energy is the joule (J).

Example

1. A crane lifts a crate of mass 500 kg through a height of 20 m.

   (a) What is the gravitational potential energy of the crate?

   GPE = work done
   $= F \text{ x } d$
   $= mg \text{ x } h$
   $$= 500 \text{ kg x } \frac{10\,N}{kg} \; x \; 20\, m = 100\,000\, J$$

   (b) What is the work done by the crane?
   (Take g = 10 N/kg)

   Work done by the crane = Gravitational PE gained by the crate
   = 100 000 J

2. Calculate the potential energy of a 5 kg mass when it is

   (a) 3 m
   (b) 6 m
   above the ground

   (Take g = 10 N/kg)

Soln: (i) $PE = mgh$ = (5 x 10 x 3)J = $\underline{150 \text{ J}}$
(ii) $PE = mgh$ = (5 x 10 x 6)J = $\underline{300 \text{ J}}$

Kinetic Energy

Defn: Kinetic energy is the energy a body gas by reason (virtue) of its motion.

When a force acting on a body produces movement, the force does work and the body possesses kinetic energy because of its motion.
If a force *F* (N) moves an object of mass *m* (kg) through a displacement *s* (m), then

Work done = Force *F* x displacement *s*

W = F.s

but F = ma

$\therefore$ W = m.a.s. but displacement *s* = average velocity x time *t*

and average velocity $= \left(\dfrac{u+v}{2}\right)$

acceleration $= \dfrac{v-u}{t}$

$$W = m\left(\frac{v-u}{t}\right)\times\left(\frac{u+v}{2}\right)t$$

if body starts from rest $u = 0$

$$\therefore W = \frac{1}{2}mv^2$$

$\Rightarrow$ The work done by moving body = The gain in kinetic energy of the moving body

$= \frac{1}{2}mv^2$

$\Rightarrow$ Kinetic energy $= \frac{1}{2}mv^2$, where m = mass of body in kg

v = velocity in m/s

For a body accelerating from an initial velocity *u* to a final velocity *v* in time *t*:

Work done = F.s

W = ma x *s*

$$W = m\left(\frac{v-u}{t}\right)\times\left(\frac{u+v}{2}\right)t$$

W = $\frac{m}{2}(v-u)(v+u)$

$= \frac{1}{2}m(v^2 - u^2)$

$= \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ *where,* $\frac{1}{2}mv^2 = final\ kinetic\ energy$

$\frac{1}{2}mu^2 = initial\ kinetic\ energy$

The work done = $= \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ = change in kinetic energy.

SI unit of KE is joule (J)

Examples of bodies possessing KE are moving bullets, hammer heads, cars, arrows etc.

Examples

1. A 300 g stone is thrown with a velocity of 6 m/s. What is its kinetic energy?

   Soln:

   KE = ½ mv^2
   = ½ x 0.3 kg x $(6\ m/s)^2$
   = ½ x 0.3 kg x 18 m^2/s^2
   = 5.4 J

2. Calculate the KE of a 4 kg trolley travelling at 3 m/s.

   Soln:

   KE = $\frac{1}{2}mv^2 = \left(\frac{1}{2} \times 4 \times (3)^2\right)J = 18\,J$

3. A body of mass 5 kg falls through a vertical distance of 5 m near the earth's surface. What is its kinetic energy just before it hits the ground?

   (*Take g = 10 N/kg*)

   KE gained = PE lost
   PE = *mgh*

PE = (5 x 10 x 5) J = 250 N.m
= 250 J

Alternative Soln:

$$KE = \frac{1}{2}mv^2$$

$$but\ \ v^2 = u^2 + 2gh$$

$$if\ \ from\ rest\ u = 0\ and\ u^2 = 0$$

$$\therefore v^2 = 2gh = 2 \times 10 \times 5\ m^2/s$$
$$= 100\ m^2/s^2$$

$$\therefore KE = \left(\frac{1}{2} \times 5 \times 100\right) J$$

$$KE = 250\ J$$

4. What is the velocity of an object of mass 1 kg which has 200 J of KE?

Soln:

$$KE = \frac{1}{2}mv^2$$

$$\Rightarrow v^2 = \frac{2KE}{m}$$

$$\therefore v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2 \times 200}{1}}\ m/s = \sqrt{400}\ m/s = 20\ m/s$$

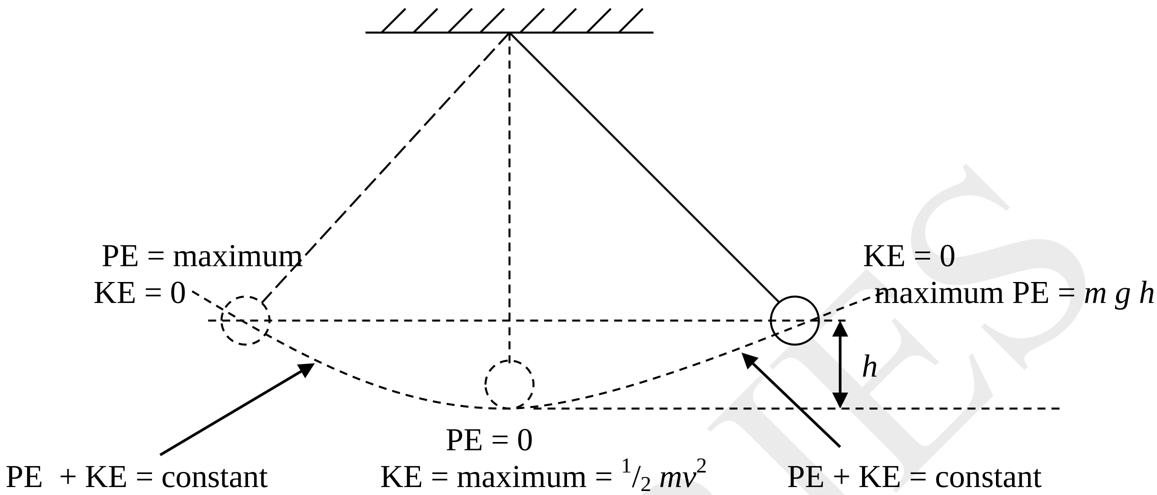
ENERGY CONVERSION AND CONSERVATION

Energy can be changed (transformed) from one form to another. Energy is therefore only useful when it is converted (changed) from one form to another. For people, computers, machines and many devices to be able to work energy must be transferred.

The **law of conservation of energy** states that energy can neither be created nor destroyed but can only be changed from one form to another. Hence, the total energy in the Universe is always constant (same).

Examples of energy conversions

1. ***Energy changes in a swinging pendulum***
   In a simple pendulum KE and PE are interchanged continuously as it swings.



When a pendulum bob swings backward and forward, energy changes from *PE* to *KE* and back again repeatedly. It we neglect air resistance the sum of the PE and KE at any point is constant. Once again, energy is conserved.

When a pendulum bob is drawn back to one side the bob rises a vertical height *h* above its rest position and gains potential energy equal to *mgh*. When the bob is released this potential energy is converted into KE. At its lowest height, the bob is moving at its maximum speed and momentarily all the energy is kinetic. As the bob rises on the other side of the swing it loses KE and gains PE. Once again when it gains the height *h* on this side, it has all PE and no KE (since it is momentarily at rest).

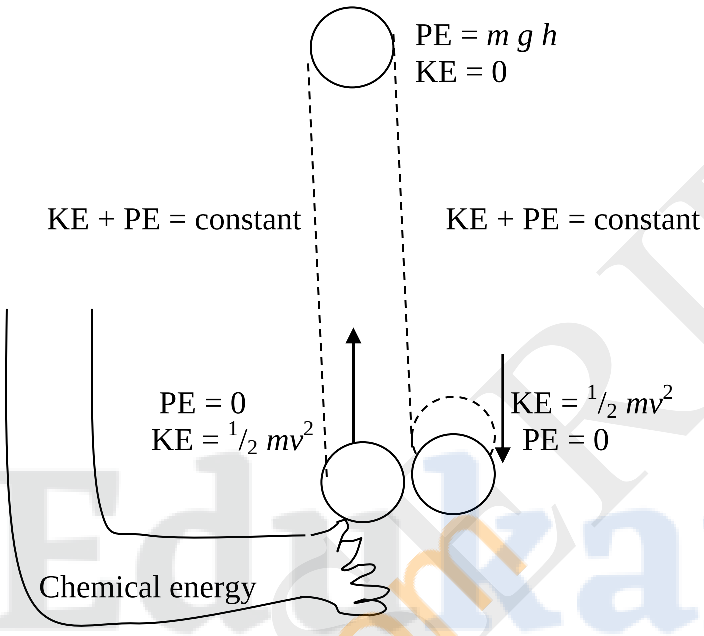
Exercise
A pendulum bob of mass 0.1 kg is raised to a height of 0.4 m above its lowest point. It is then released.

(a) What is its *PE* at this height?
(b) What is its *KE* at its lowest height?

2. *Interchange of energy* between *PE* and *KE* also takes place in a ball of mass, *m* thrown vertically upwards from the ground.

Consider energy changes in a ball of mass, *m* thrown vertically up from the ground. The initial throw of the ball gives it kinetic energy (i.e. the chemical energy stored in your body is transferred to the ball as kinetic energy).
The ball loses speed (slows down) as it gains height, and its kinetic energy is being changed into potential energy. At its maximum height its velocity is momentarily zero (⇒ KE = zero).

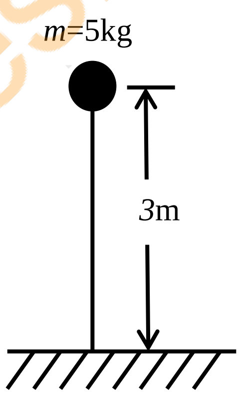
As the ball begins to fall vertically downwards its potential energy is being changed back into kinetic energy (when ball loses height it loses PE while as it gains speed during the fall it gains kinetic energy). If air resistance is negligible, the ball returns to the ground with the same kinetic energy as it had when it left the ground. Part of the way up or down the ball had some KE and some PE and their sum (KE + PE) was equal to the total mechanical energy (i.e. was equal to the PE = mgh before the fall or KE = $\frac{1}{2}mv^2$ just before the ball hits the ground or when the ball was just thrown with velocity, v).



However, when the ball finally hits the ground and stops moving, all its original energy is changed into thermal (heat) energy and sound energy.

Example
A 5 kg body falls freely through a vertical height of 3 m near the earth's surface. Find its kinetic energy as it hits the ground and show that it equals the potential energy before falling.

Soln:



$$KE = \frac{1}{2}mv^2$$

Reasoning: As the ball falls 3 m, its velocity increases and it therefore gains kinetic energy at the expense of its potential energy. If it starts falling from rest, $u = 0$ (i.e. at maximum height, velocity is momentarily zero), then its final velocity v on reading the ground is given by:

$\therefore v^2 = u^2 + 2\,gh$

but $u = 0 \Rightarrow u^2 = 0$
$g = 10$ N/kg
$h = 3$ m

$\therefore\ v^2 = (2 \text{ x } 10 \text{ x } 3)\text{m}^2/\text{s}^2 = 60\ \text{m}^2/\text{s}^2$

$\Rightarrow$ Kinetic energy as it hits the ground is

$$KE = \frac{1}{2}mv^2 = \left(\frac{1}{2}\times 5\times 60\right)J = \underline{\underline{150\,J}}$$

P.E. before falling is given by:
P.E = mgh
= (5 x 10 x 3)J
P.E. = 150 J

$\therefore$P.E. before falling = 150 J = kinetic energy as the ball hits the ground.
$\Rightarrow$ Loss of P.E. = gain in K.E.

From this example we clearly see that energy was just changed from P.E. to K.E. so that;

Total mechanical energy = P.E. + K.E. = mgh + ½ mv^2 is constant.

This illustrates the principle (law) of <u>conservation of energy</u> which states that energy can neither be created nor destroyed but can only be converted from one form to another, hence the total energy in the universe is always constant (same).

3. Energy conversions in a hydroelectric power station/scheme.

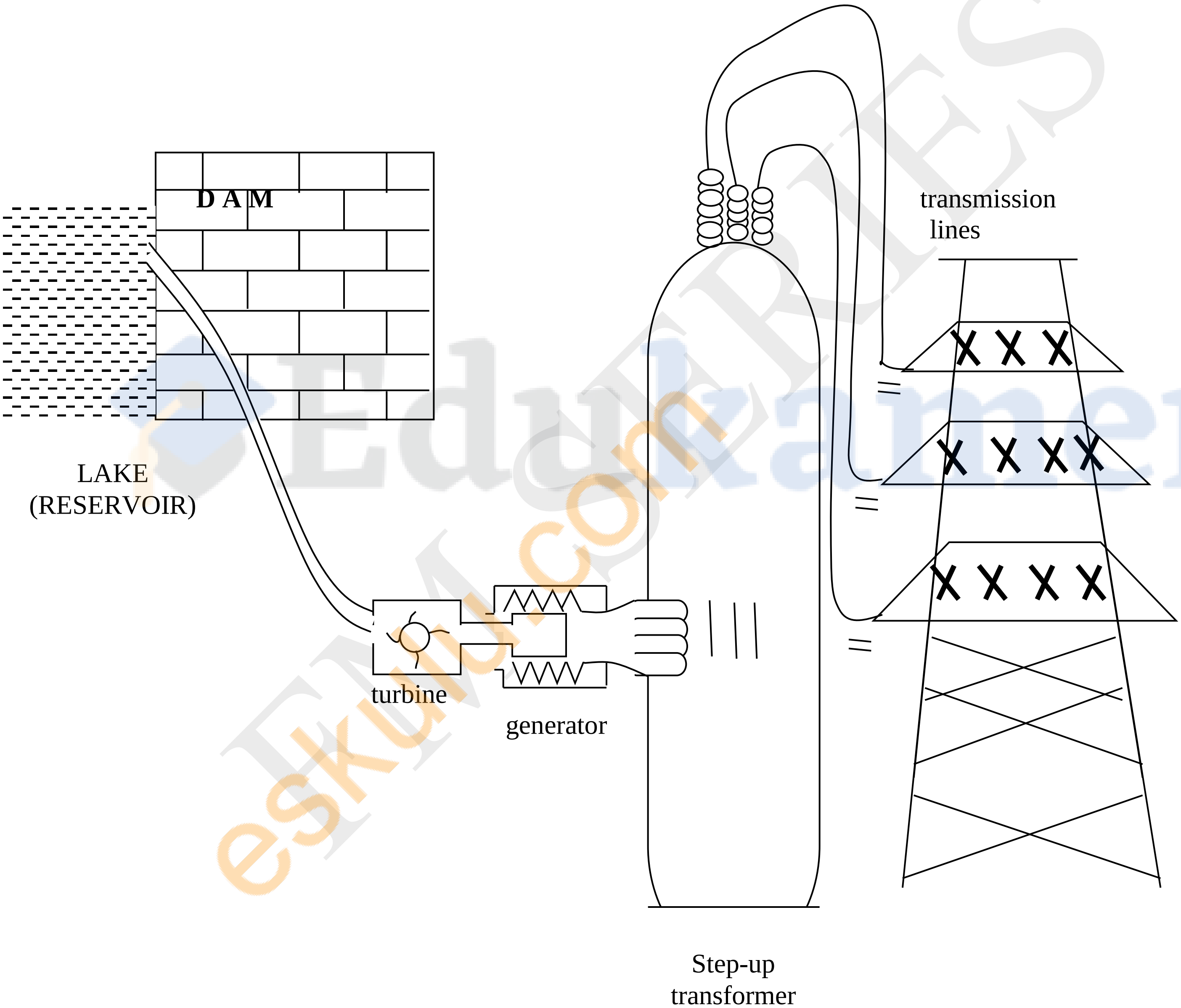
In a hydroelectric power scheme a river is dammed to form a lake. The water which is normally stored at a higher level/reservoir in the dam possesses potential energy. The flow of water from a higher to a lower level (the kinetic energy of the falling water) from behind tha dam turns the water turbine (water wheel) which in turn drives a generator. The generator then produces electrical energy.

The energy which originally lifted the water to the high reservoirs came from the sun when evaporated water from the sea and lakes later fell as rain.

In the case of a pumped storage scheme, when the demand for electricity is low the power station can use some of the power generated to pump water up to the high reservoir in serve for when the demand increases.

Thus, in a HEP scheme:

Potential Energy (of high-level reservoir water)	$\rightarrow$	Kinetic Energy (of falling water and rotating turbine)	$\rightarrow$	Electrical Energy (of generator)



4. Energy conversions in a coal-fired (thermal) power station.

In a coal-fired power station coal (or any fuel) is burnt in a furnace to produce heat. The heat converts the water in the boiler into steam at high pressure. The steam drives turbines which in turn drive the generators that produce electrical energy.

Thus in a coal-fired power station:

Chemical Energy →	Heat Energy →	Kinetic Energy →	Electrical Energy
(from coal)	(of steam)	(of rotating turbine)	(of generator)

Summary of some Energy Conversions

Energy conversions occurs between other types of energy

(a) In an electric light bulb

Electrical energy →	light energy +	(heat energy)
	Useful energy	*wasted energy*

(b) In an internal combustion engine of a car

Chemical energy → Heat energy → Mechanical energy

(c) In a torch battery

Chemical energy → Light energy

(d) In a generator

Mechanical energy → Electrical energy

(e) In an electric motor:

Electrical energy → Kinetic energy (+ heat energy)

(f) In a microphone

Sound energy → Electrical energy

(g) In a loudspeaker

Electrical energy → Sound energy

(h) In a hydroelectric power scheme (HEP)

Potential energy $\rightarrow$ Kinetic energy $\rightarrow$ Electrical energy

(i) In a wind mill/turbine

Kinetic energy $\rightarrow$ Electrical energy

(j) In a coal-fired power station

Chemical energy $\rightarrow$ Heat energy $\rightarrow$ Kinetic energy $\rightarrow$ Electrical energy

(k) In a solar panel

Light energy $\rightarrow$ Heat energy

(l) In a solar cell

Light energy $\rightarrow$ Electrical energy

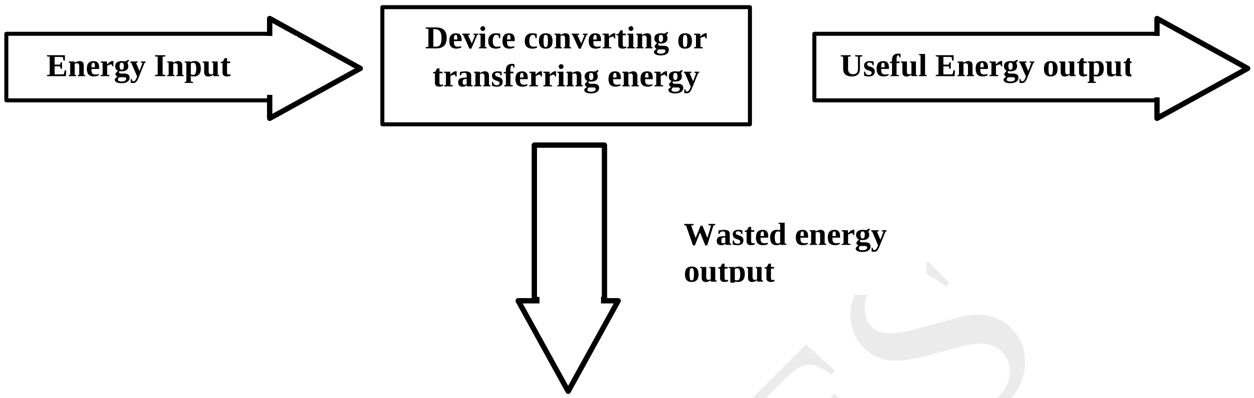
Efficiency of a device

In a machine, the useful work done (work output) is always less than the work input. Total energy is conserved but some of the energy input is wasted in form of heat due to friction in moving parts, sound etc.
No real machine can have an efficiency of 100%.
In general, when one form of energy is converted into another form, some energy is wasted.

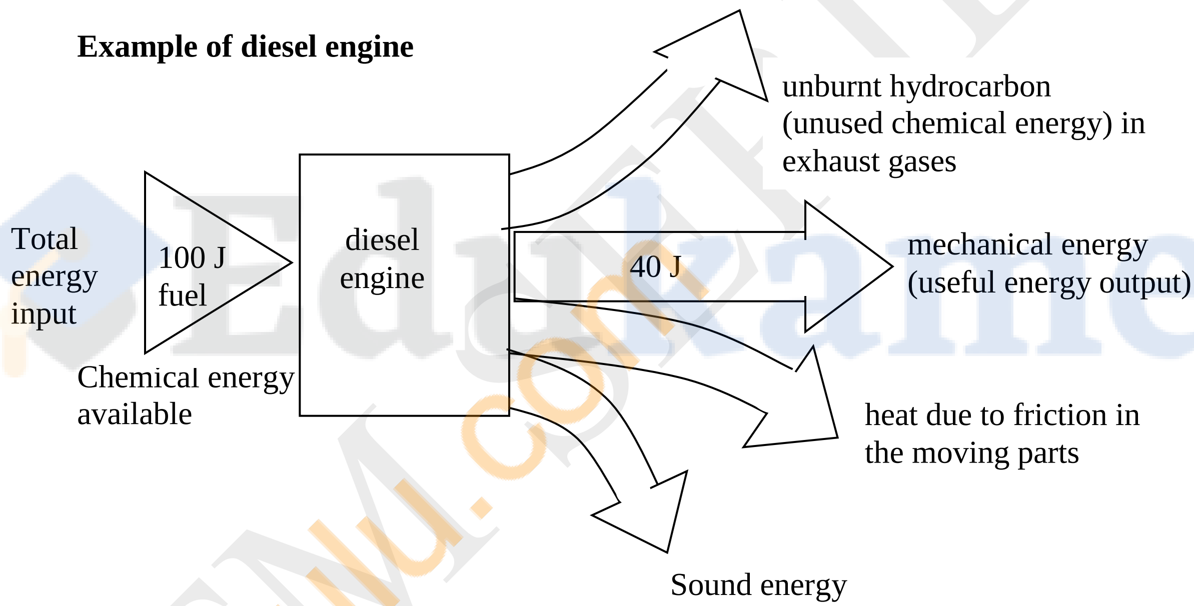
When an electric bulb, for example, is in use the useful energy output is light. The heat energy produced is wasted energy. Hence the useful energy output (in the form of light) is less than the energy input (in the form of electrical energy).

In the motor car engine, we supply the energy in the form of chemical energy in the petrol. The useful energy that is given out is mechanical energy. But some energy is wasted as heat in the radiator and exhaust system, more heat is produced by friction in moving parts of the car and some energy is wasted as sound.

In general when one form of energy is converted into another form, some energy is wasted



Example of diesel engine



Wasted energy
- Heat
- Sound
- Unburnt fuel
- Sound energy

Defn: The efficiency of a machine or device is the ratio of the useful work (energy) output to the total work (energy) input.

$$Efficiency = \frac{useful\ work\,(energy)\,output}{total\ work\,(energy)\,input}$$

Or $Efficiency\ \% = \frac{useful\ work\,(energy)\,output}{total\ work\,(energy)\,input}\ x\,100\%$

The efficiency of a device, being a ratio, has no units. Its value will always be less than 1. To express efficiency as a percentage, multiply by 100.

$$Efficiency\ \% = \frac{useful\ work\,(energy)\,output}{total\ work\,(energy)\,input}\ x\,100\%$$

Efficiency is usually less than 1 or less than 100%. It is important to cut down energy wasted so that the useful work obtained from the device is as high as possible.

Exercise/Example

1. Find the efficiency % of an electric motor that is capable of pulling a 50 kg mass through a height of 15 m after consuming 30 kJ of electrical energy.

Soln:

Work output = mgh = (50 x 10 x 15) J = 7 500 J

Energy input = 30 kJ = 30 000 J

$\therefore$ Efficiency % = $\frac{\text{Work output}}{\text{Work input}}$ x 100 % = $\frac{7\,500\text{ J}}{30\,000\text{ J}}$ x 100 % = 25 %

2. A man uses a pulley system to lift a car of weight 2 000 N a height of 1 metre. He pulls the rope a distance of 8 m. A force of 300 N is used. Calculate the efficiency of the pulley system.

Soln:

Solution

Useful work output = Fs = 2 000 N x 1 m = 2 000 J

Work input = Fs = 300 N x 8 = 2 400 J

$$Efficiency = \frac{2\,000\,J}{2\,400\,J} = 0.83\ (\%\ efficiency = 83\%)$$

Sources of energy

The raw materials from which energy can be produced are called energy sources. There are 2 major energy sources.

1. Renewable energy sources
2. Non-renewable energy sources

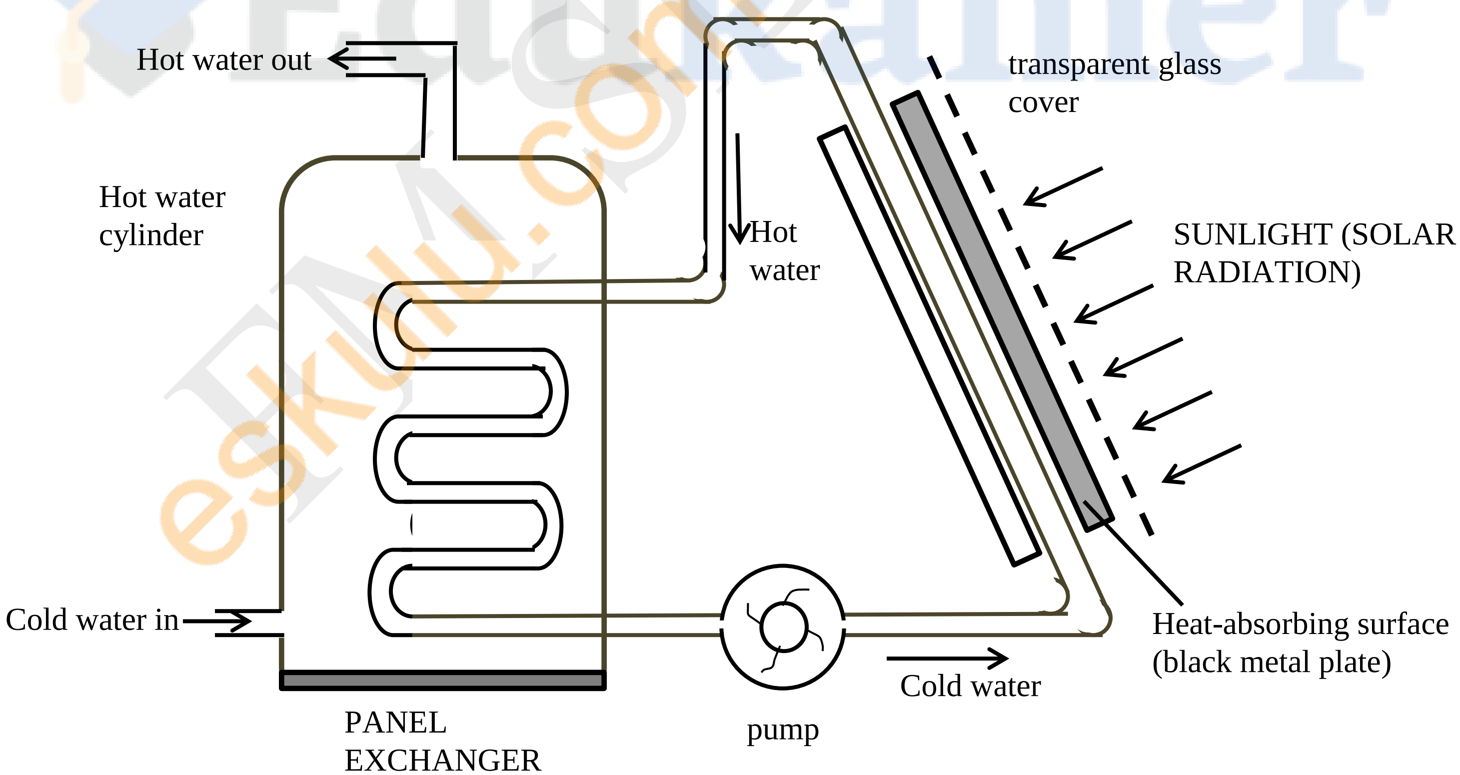
Renewable energy sources: are those that can be used over and over again. They do not deplete as cannot be exhausted e.g. wind energy, solar energy, geothermal energy, water energy etc.

Advantage: Clean source of energy and are non-polluting
Disadvantage: Requires large energy transfer devices

(a) **Solar energy (nuclei of atoms in the sun)**

Energy from the sun (mostly in form of sunlight). However, its low density requires large collecting devices and its availability varies.

In sunny regions, Solar cells convert solar energy directly into electricity. These solar cells are used in watches and calculators and to power satellites. Solar panels use solar radiant energy to provide hot water. Water is pumped through the panels, and absorbs energy radiated from the sun before it passes through the house's main heating system. A transparent cover traps the solar radiation (like the green house does). A black surface helps absorb the radiation.



Solar energy is mostly used in:

(i) Solar panels – for heating water (light $\rightarrow$ heat energy)
(ii) Solar furnace – to generate electricity
(iii) Solar cells – to supply electricity in remote areas and to electronic communication equipment and other satellites.

In nature, solar energy is absorbed by green plants to bring about the conversion of carbon dioxide and water into sugars and later into starch and cellulose. Large crops of vegetable fuels e.g. green algae may also be grown which can either be dried and burnt as a fuel or fermented to produce alcohol for use as fuel in engines. Fuels are storehouses of solar energy which is set free when the fuel burns.

Advantages: solar energy is free, non-polluting, and available in large quantities (especially in hot countries).
Disadvantages: low energy density, requires large collecting devices, its availability varies.

(b) **Wind energy**

- Energy of the moving air
- Can be used in sailing ships, water pumps, windmills for milling grain and wind turbines for generating electricity.

e. g. in a wind turbine:
Wind energy $\rightarrow$ Mechanical energy $\rightarrow$ Electrical energy

(c) Water energy
The energy of moving water is used in

(i) ***Hydroelectric schemes***
River water is dammed to form a lake and in turn the water falls from a high level (reservoir) to a lower level to drive a turbine (water wheel) which drives the generator to produce electricity. In a HEP scheme:

PE $\rightarrow$ *KE* $\rightarrow$ Electrical energy (+ heat + sound)
(stored in water reservoir/dam) (of moving/falling water and in turbines)

(ii) ***Tidal energy***

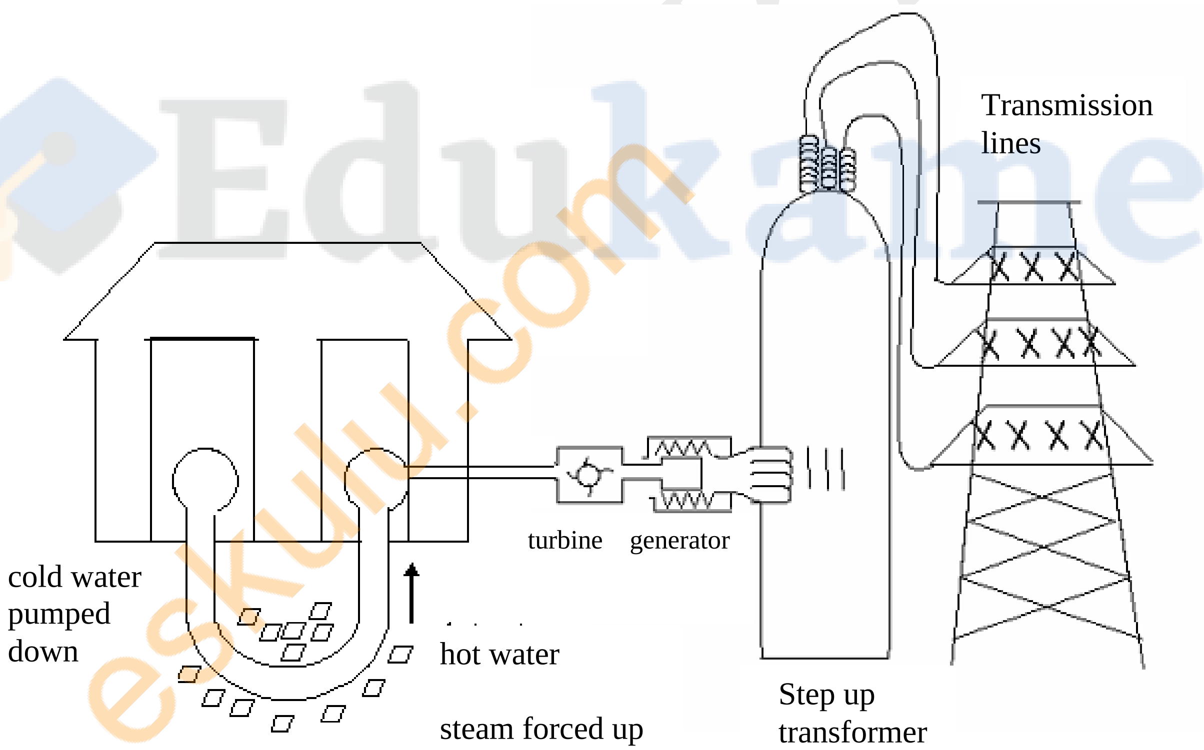
The flow of water from a higher to a lower level from behind a tidal barrage (barrier) is used to drive water turbine connected to a generator. Tides are caused by the gravitational attraction of the moon and the sun pulling the sea about.

(iii) ***Water waves***

Large amounts of energy exists in waves. Sea waves are generated by weather conditions over the oceans. Efficient way can be used to change the waves energy into electrical energy.

(d) **Geothermal energy**

Energy from hot rocks in the Earth's crust is called geothermal energy. The heat is given off by radioactive atoms which are naturally present in the Earth's rocks.
The hot rocks deep in the earth can be used to heat water and the steam can be used to drive a turbine and generate electricity or to heat buildings.



2. ***Non-renewable energy sources***

- Are those sources which if used up cannot be easily replaced i.e. are limited sources e.g. coal, natural gases (fossil fuel) and nuclear energy

  - Fossil fuel were formed from remains of plants and animals that died million of years ago.
  - Nuclear energy comes from the nucleus of certain radioactive atom e.g. ^{235}U.

Advantages

- they have high energy density (store large amounts of energy in a small volume, i.e. are concentrated sources).
- require small size energy transfer device
- readily available

Disadvantages

- causes pollution
- nuclear fuels pose a danger of radioactive waste material disposal as well as risk of radiation leakage.

(a) Fossil fuels

The main modern sources of energy are the fuels coal, oil and natural gas formed from the remains of plants and animals which lived millions of years ago and obtained energy originally from the sun. The fossil fuels contain chemical energy which can be released as heat on combustion (burning) in power stations and in cars.

e.g. In the steam engine:

Chemical energy $\rightarrow$ Heat energy $\rightarrow$ Kinetic energy $\rightarrow$ Electrical energy
(from coal or oil or natural gas) (of steam which turns turbines)

(b) Nuclear energy

This is the energy that is stored in the nucleus of an atom and can be released through a nuclear reaction (as opposed to chemical reaction). Two types of reactions are responsible in producing nuclear energy; **nuclear fission** and **nuclear fusion.**

(i) Nuclear fission

Fission means 'splitting up' of heavy atoms. Fission of heavy atoms release a lot of heat energy.

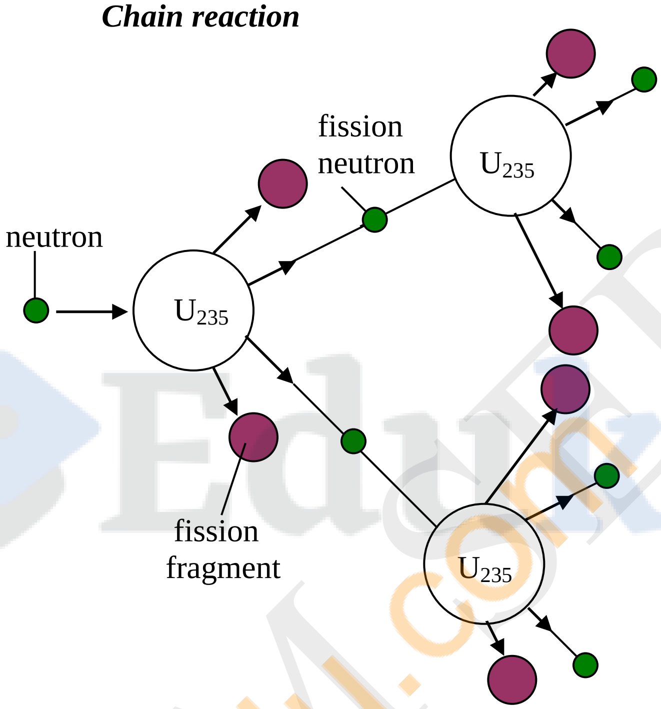
When the nuclei of large/heavy (i.e. unstable or radioactive) atoms such as uranium – 235 $^{235}_{92}U$ are split by bombarding them with neutrons a very large amount of energy in form of heat is released. The heat energy produced can then be converted to other forms of energy, e.g. electrical energy. This (nuclear fission) is the source of energy in a nuclear power station to produce electrical energy and in nuclear engines to drive submarines etc.

If the fission neutrons split other uranium 235 nuclei; a chain reaction is set up.

Uranium – 235 atoms release a very large amount of heat energy when bombarded by neutrons.

$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{144}_{56}Ba + {}^{90}_{36}Kr + 2{}^{1}_{0}n + heat\ energy$$

Chain reaction



The chain reaction occurs at a steady rate (is controlled) in a **nuclear reactor**.

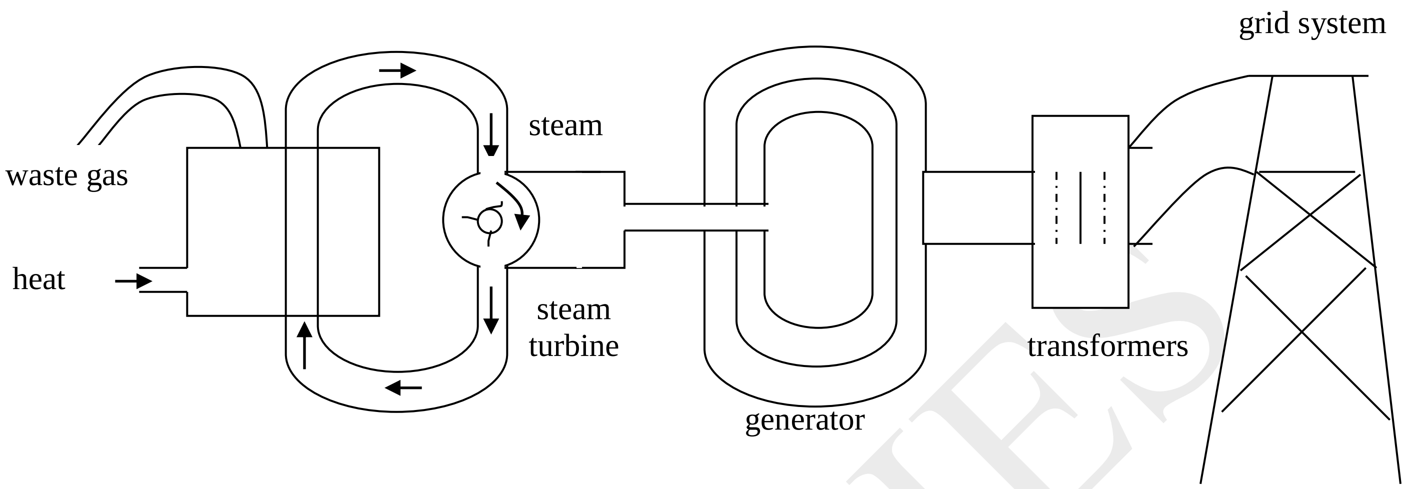
(ii) **Nuclear fusion:**
This is the joining together of two very light isotopes' nuclei to form a heavier one. In doing so, a very large quantity of energy in form of heat is released. This is the process taking place in the sun (source of the sun's energy) and in the hydrogen bomb.

$${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n + energy$$

deuterium tritium helium

The heat energy so produced can be converted to other forms of energy e.g. electrical energy in nuclear power station.

In general, the heat energy produced from nuclear energy and fossil fuel is used to heat water and produce steam, which in turn is used to generate electricity.



Energy changes in nuclear reactions

In nuclear transformations (i.e. both fission and fusion) it is found that the combined mass of the products is less than that of the original material (i.e. there is a mass defect). This **mass defect** or **mass decrease**, **Δm**, is converted into energy according to Albert Einstein's equation (the mass-energy equivalence equation).

$E = \Delta mc^2$; where E = energy produced (J)

Δm = mass decrease (kg)

c = speed of light = 3.0 = 3.0×10^8 m/s

Δ = delta (a change in a value or difference between two numbers)

The implication is that matter or mass can be converted into energy, hence any reaction in which there is a decrease of mass (mass defect), is a source of energy. It appears that mass (matter) is a very concentrated form of energy and that matter and energy are convertible.

The energy and mass changes in physical and chemical changes are very small; those in some nuclear reactions, e.g. radioactive decay, are millions of times greater since there are extremely large numbers of transformations taking place.

Exercise/Examples

1. Calculate the amount of energy that would be liberated if 1 g of matter were to be all converted into energy.

   (Assume c = 3.0×10^8 m/s).

Soln:

$E = mc^2$

Given: $m = \frac{1}{1000}$ kg = 0.001 kg = $1.0 \, x \, 10^{-3}$ kg

$c = 3.0 \, x \, 10^8 \, m/s \Rightarrow c^2 = 9.0 \, x \, 10^{16}$ m^2/s^2

$\therefore$ E = ($1 \times 10^{-3} \times 9 \times 10^{16}$) J

= $\underline{9 \times 10^{13} \text{ J}}$

2. Calculate the energy produced by a nuclear reactor when the mass of the fuel decreases by 2.0×10^{-6} kg.
   The speed of light is 3.0×10^8 m/s.

   Soln:

   $E = mc^2$

   Given: $m = 2.0 \, x \, 10^{-6}$ kg

   $c = 3.0 \, x \, 10^8 \, m/s \Rightarrow c^2 = 9.0 \, x \, 10^{16}$ m^2/s^2

$\therefore$ E = ($2.0 \times 10^{-6} \times 9 \times 10^{16}$) J

= 18×10^{13} J = $\underline{1.8 \times 10^{11} \text{ J}}$

POWER

When we speak of power we mean how quickly work is done.

Defn: Power is the work done per second, or the rate at which work is done or the amount of energy transferred per second.

$$Power = \frac{Work\ done\ (Joules)}{time\ taken\ (seconds)} \quad OR \quad \frac{energy\ transferred}{time\ taken}$$

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

Where P = power in J/s or watt

W = work done in Joules = E = energy transferred (J)
t = time in s

Also, $P = \frac{W}{t} = \frac{F \times s}{t} = \frac{F \times v \times t}{t} = F \times v$

The S.I. units of power are joules per second (J/s). One joule per second is called a watt (W).

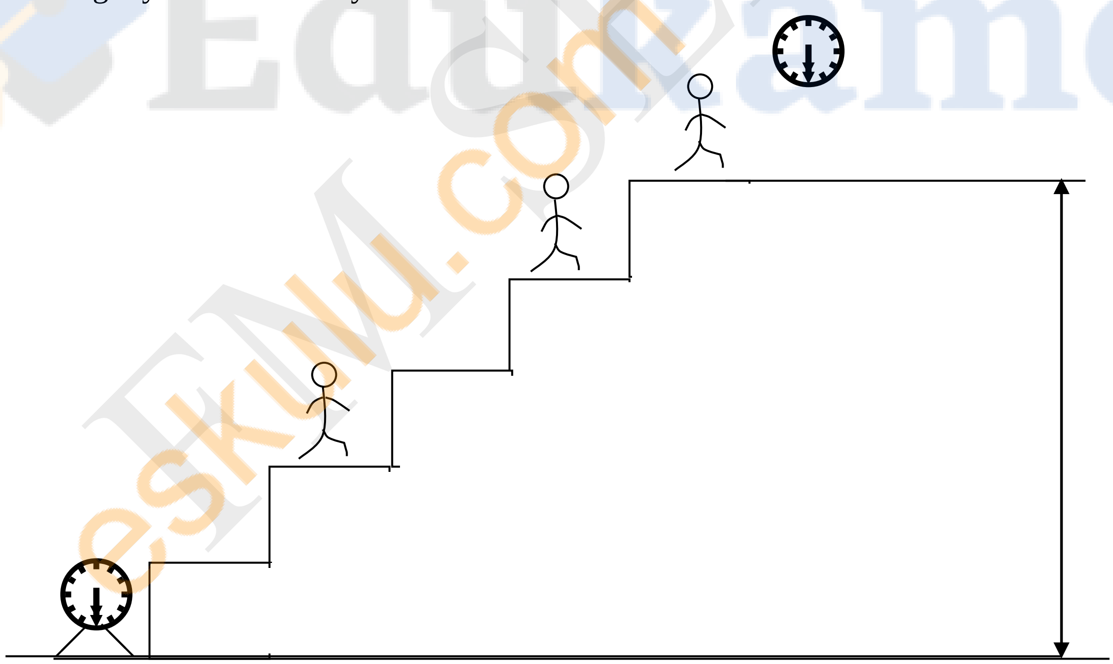
$\therefore$ 1 J/s = 1 W

Larger units for power are kilowatts and megawatts
1 Kw = 1 000 W (1 000 J/s)
1 Mw = 1 000 000 W (1 000 000 J/s)

Power is a scalar quantity, just like work and energy.

Measuring human power

To measure your own power, measure your weight, then get someone to time you with a stopwatch as you run up a flight of stairs as quickly as you can. Measure the vertical height you have raised yourself.



Work done in running up the steps = weight, W (N) x height, h (m).

$$\therefore Work\,done\ \ per\,\sec ond\ =\ power\ \ developed\ =\frac{weight\,(N)\times height\ \ (m)}{time\,(s)}$$

$$\therefore \text{average power}\ \frac{m\,g\,h}{t}$$

<u>Power and efficiency</u>

$$Efficiency\ \ =\frac{Power\ \ output}{Power\ \ input}$$

$$\%\ Efficiency\ \ =\frac{Power\ \ output}{Power\ \ input}\times 100\%$$