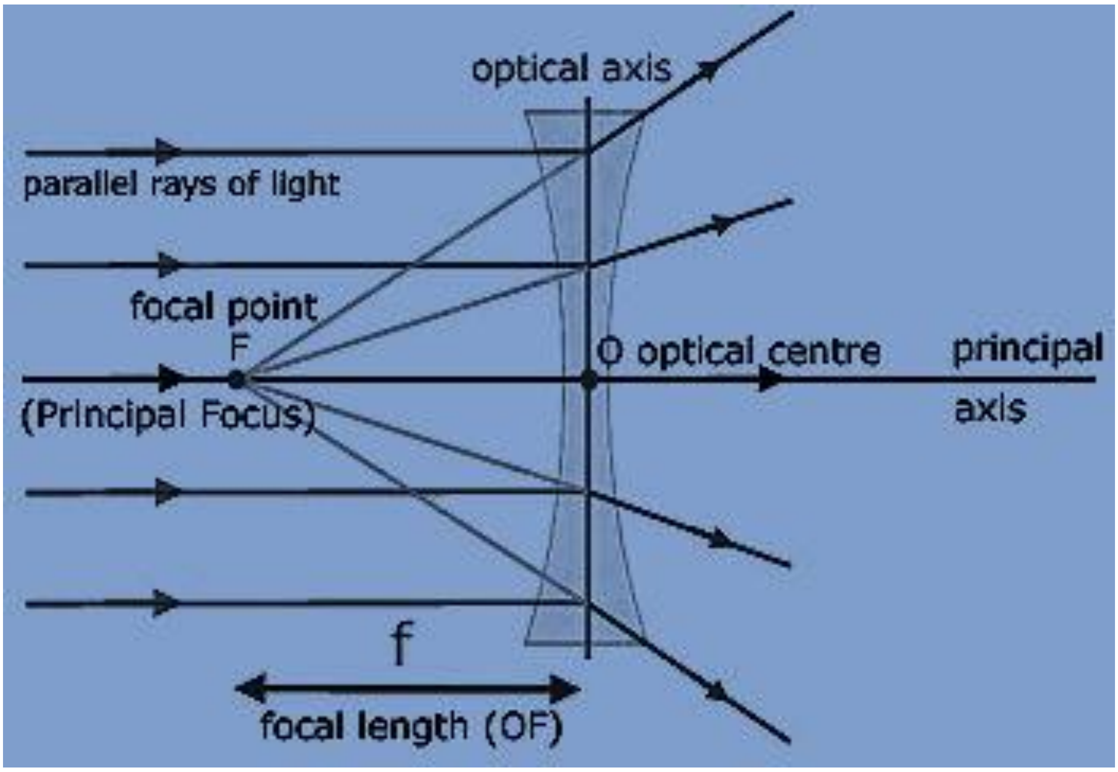
MINISTRY OF EDUCATION

YEAR 11 PHYSICS



ACKNOWLEDGEMENT

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CHAPTER 1: MEASUREMENTS

1.0 INTRODUCTION

Physics involves measurement, so a standard system of units is used to measure physical quantities. Physical quantities are physical properties of objects and other phenomena that have numbers and unit of measurements example, 2 kilograms, 1 meter etc.

1.10 INTERNATIONAL SYSTEM OF UNITS

International System of Units, abbreviated as *SI* (in French) units were established by international agreement. The fundamental units of SI base units are mass in kilogram, length in meter and time in seconds.

The other included base units are shown below.

Quantity	Unit Name	Unit Symbol
Mass	Kilogram	kg
Length	Meter	m
Time	Second	s
Temperature	Kelvin	K
Luminous intensity	Candela	cd
Amount of Substance	Mole	mol

1.20 DERIVED UNITS

SI units are divided into fundamental units and derived units. Derived units are products and or ratio of fundamental units. For example, velocity is the change in length per unit of time. The unit of speed is similarly the ratio of the unit of length to the unit of time (i.e. m/s).

$$\textbf{Speed} = \frac{\textbf{distance (m)}}{\textbf{time } (s)}$$

1.21 Examples Of Other Derived Quantities

1. *Area*

The amount of space covered by a body is called its area and is measured in square meters (m^2). Area is the product of length and width.

Area = Length x Width

2. *Volume*

The amount of space taken up by a body is called its volume and is measured in cubic meters (m^3). Volume of a rectangular body is the product of its length, width and height:

Note:

Volume = length x width x height

$1\ cm^3 = (1 \times 10^{-2}\ m) \times (1 \times 10^{-2}\ m) \times (1 \times 10^{-2}\ m)$
Therefore:
$1\ cm^3 = 1 \times 10^{-6}\ m^3$

A liter (L) is defined as 1000 cm^3, hence
$1\ cm^3 = 1\ mL$

1.30 UNIT PREFIXES

Unit prefixes are symbols placed before a unit to specify the order of magnitude of a quantity. For example “k” (kilo) is the unit prefix in the unit “km” (kilometer). These prefixes are useful for showing quantities that are either very big or very small. To be more precise, unit prefix stand for a specific positive or negative powers of 10.

For example: Three kilogram is equivalent to three thousand grams. The prefix “kilo” means that the value of the unit is multiplied by 10^3. (i.e. 3 kg = 3×10^3 g = 3000 g).

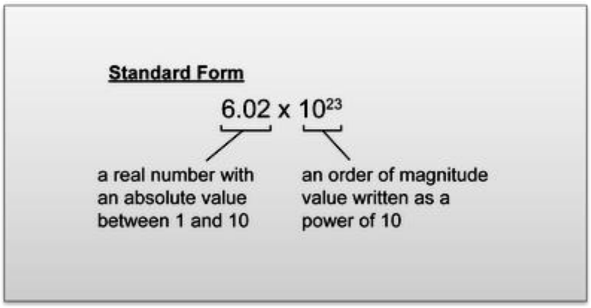
Common Unit Prefixes

Prefix	Symbol	Multiple of Unit
femto	f	10^{-15}
pico	p	10^{-12}
nano	n	10^{-9}
micro	µ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
deca	da	10^{1}
hecto	h	10^{2}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}
peta	P	10^{15}

Example 1
40 nanometer is equivalent to 40×10^{-9} m.

Example 2
3 megawatts is equivalent 3×10^{6} Watts

1.40 SCIENTIFIC NOTATION



Scientific notation is a way of expressing either very large or very small numbers as factors of the power of 10.

$$A \times 10^{y}$$

where A = number between 1 and 10 and
y = number in which the decimal point move

Example 1: Let's consider number 390000.

1. Decimal point is position on the right because it is a whole number, moving it towards the left to make A a number between 1 and 10. In this case it will be 3.9
2. The second step is to find the value of y. The value of y is found by counting the places to the right of the decimal point in A to the original decimal point.

3.9 0 0 0 0 0

Therefore 3.9 x 10^{6} (standard form)

Example 2: Now let's write 0.000 0024 in scientific notation.

1. Let A as a decimal number between 1 and 10. In this case it will be 2.4
2. Find value of y. From value of A in step 1 gives 2.4 so therefore y is found by counting the places to the left of the decimal point in A to the original decimal point.

0. 0 0 0 0 0 2 4

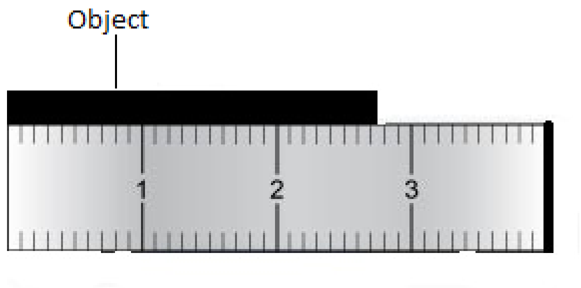
Moving to the left makes y = -6.
Therefore, 2.4 x 10^{-6} (standard form)

Note: If the original number is less than 1, then y is always negative and if the original number is greater than 1, then y is always positive.

1.50 SIGNIFICANT FIGURES

Every measurement in Physics should be recorded with some digits which are **certain** plus one digit that has been **estimated**. The estimated digit is always the **last digit** in a measurement. This estimated digit is found by estimating one digit between the finest markings on the scale.

Consider a ruler being used to measure the length of an object:



This measurement is best recorded as 2.75 cm. The value 2.7 cm is certain but the digit 5 has been estimated.

The number of digits written down for a measurement is called **significant figures.** It indicates the precision with which the measurement was taken.

1.51 Rules of Significant Figures

1. All **non-zero** digits are significant.

   (i) 14321 (5sf) (ii) 4129 (4sf) (iii) 312 (3sf)

2. Zeros placed between two non-zero digits are significant.

   (i) 5002 (4sf) (ii) 390075 (6sf) (iii) 1.0005 (5sf)

3. Zeros to the left of a non-zero digit are not significant.

   (i) 004 (1sf) (ii) 0.006 (1sf) (iii) 0.0025 (2sf)

4. Zeros placed to the right of a non-zero digit after a decimal point is significant.

   (i) 2.0 (2sf) (ii) 15.0 (3sf) (iii) 5.00 (3sf)

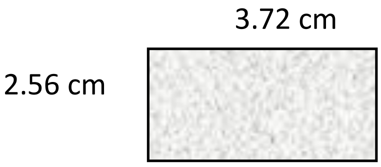
5. Zeros placed at the end of a number are **ambiguous**. Number of significant digits is indicated by writing the number in standard form.

(i) 1.5×10^3 (2sf) (ii) 1.50×10^2 (3sf) (iii) 1.500×10^3 (4sf)

1.52 Arithmetic with Significant Figures

Every recorded measurement has a **certain number** of significant digits. Calculations such as addition, subtraction, division and multiplication are often done on these measurements. It is important to note that the precision of an experiment cannot be improved by doing arithmetic with its measurements.

For instance, consider a rectangular glass slide with dimensions taken using a ruler.



The area of the slide can be calculated as follows:

$$A = L \times W$$

$$= 3.72 \text{ cm} \times 2.56 \text{ cm} = \underline{9.5232 \text{ cm}^2}$$

The measurements have **3** significant digits but the calculated answer has **5** significant digits. This shows that by doing the calculation we made the measurement more precise. This is not possible. When measurements are combined, the answer must be reported with the **same amount of precision.** Therefore, the area of the slide must be written as **9.52 cm²**.

The following rules can be used to determine the number of significant digits after a calculation:

1.53 Addition and Subtraction

When adding or subtracting quantities, the answer should have the same number of **decimal places** as the value with the **smallest number** of decimal place that we want to add or subtract.

Examples

Evaluate:

(i) 3.02 cm + 4. 1cm = 7.12 cm $\Rightarrow$ 7.1 cm [Answer rounded to 1 decimal place]

(ii) 7.62 - 0.0023 = 7.6177 $\Rightarrow$ 7.62 [Rounded off to 2 decimal place]

1.54 Multiplication and Division

When multiplying of dividing quantities, the answer should have the same number of **significant figures** as the quantity with the **lowest number** of significant figures.

Examples

(i) 10.45 x 0.03 = 0.3135 ⇒ 0.3 [Answer rounded to 1 significant figure]

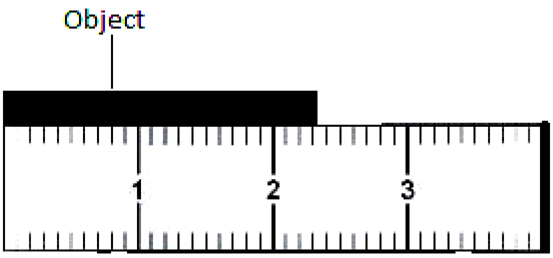
(Ii) 9.45 x 2.5 = 23.625 ⇒ 24 [Answer rounded to 2 significant figure]

(iii) 8.34 ÷ 4.2 = 1.986 ⇒ 2.0 [Answer rounded to 2 significant figure]

1.60 UNCERTAINTIES IN MEASUREMENT

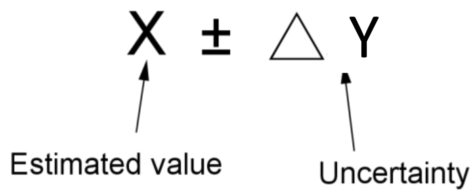
No measurement can be ‘exact’. The precision of a measurement is limited by the *markings* on the measuring instrument.

Let us look at one example, consider a ruler used for measuring the length of an object as shown:



The reading is close to 2.3 cm. The best reading a Physicist can give is 2.34 cm by estimating one more digit between the finest markings on the scale. It is not possible to obtain an ‘exact’ or ‘true’ value for the measurement. This would require a measuring instrument with marks infinitely close together.

Since we cannot obtain an exact value, Physicists usually specify the range of values in which the ‘exact value’ of the measurement lies. This is done by recording the estimated data with the uncertainty and writing the measurement in the form:

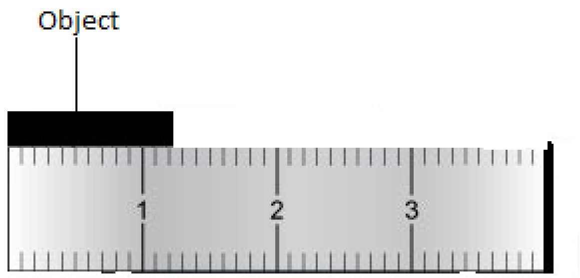


For instance, a measurement is recorded as (2.4 $\pm$ 0.1) m. This means that the true value of the measurement lies between 2.3 m and 2.5 m.

It should be noted that uncertainties are not mistakes. Uncertainties are caused because of the limitations of the instrument used to take the measurement. To get more precise measurement, a more precise instrument (a more expensive and complex one) is needed.

1.61 Estimating Uncertainties

Minimum Uncertainty = *Half of the smallest division on the scale*



Estimated value = 1.2 cm

Smallest division on ruler = 1 mm = 0.1 cm

$$\therefore \text{Uncertainty} = \frac{0.1}{2} = 0.05 \text{ cm}$$

Hence total uncertainties = 2 x 0.05 = 0.1 cm which is the same as the smallest division on a ruler.

The above measurement is best written as (1.2 $\pm$ 0.1) cm.

Note the form of the final answer.

1.70 EXERCISES

Express all answers in scientific notation and state their units clearly.

1. Given D = $\frac{m}{V}$, find D when *m* = 2.5 kg; *V* = 50 $m^{3.}$

2. Given P = $\frac{F}{A}$, find P when *F* = 6300N; *A*= 30 m^2

3. Given ΔH = *m*c Δt, find ΔH when *m* = 6000 g; c = 4.2 kJ /(kg°K)   Δ t = 80 °K

4. Convert the following to exponential notation.
   (i) 2.3
   (ii) 470
   (iii) 230
   (iv) 187

5. Write the following, using appropriate prefixes:
   (i) 4.2×10^{12} g.
   (ii) 7.9×10^{-6} m.
   (iii) 8.3×10^{-3} g.
   (iv) 9.56×10^{-10} m.

6. A box has dimensions 300 cm x 150 cm x 100 cm.
   Determine its volume in cubic meters (m^3).

9. How many significant figures are there in each of the following measurements?
   (i) 0.001
   (ii) 8.3×10^{-3}
   (iii) 215.52
   (iv) 0.0030
   (v) 3366090

CHAPTER 2: RELATIONSHIPS

2.0 INTRODUCTION

Graphs are very useful in experimental work because

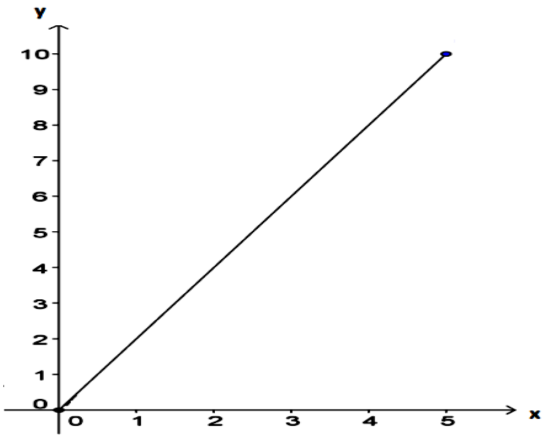
1. they provide a visual representation of the results,
2. they identify relationship between the quantities

2.10 DIRECT RELATIONSHIP

In a graph, the independent variables (variable manipulated in an experiment) are on the horizontal axis and the dependent variable (variable calculated using data values) and on the vertical axis.

The linear equation graph below shows that as the *x* value increases, so does the *y* value increase for the coordinates that lie on this line y = 2x

For instance, if $x = 2$, $y = 4$. If $x = 6$ (multiplied by 3), then $y = 12$ (also multiplied by 3).



This is a graph of direct relationship. If the value of *x* is increased, then *y* increases as well. Both variables change in the same manner. If *x* decreases, so does the value of *y*. We say that *y* varies directly with the value of *x*.

A direct variation between 2 variables, y and x, is a relationship that is expressed as:

$$\boldsymbol{y = kx}$$

where the variable *k* is called the *constant of proportionality.*

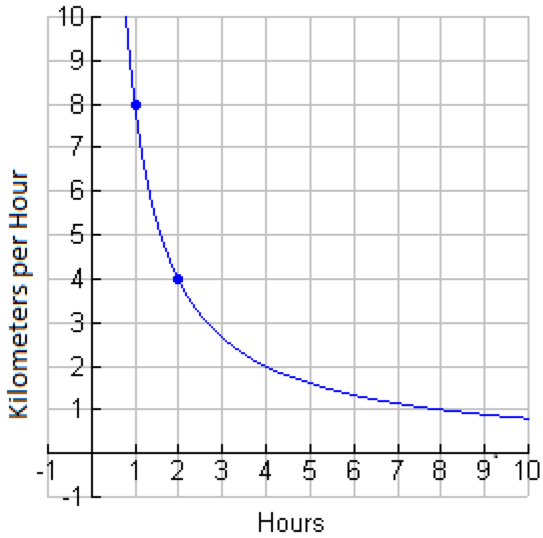
Direct relationships graphs should show three important properties

- Straight line graph
- As one quantity increase the other also increase
- The line should pass through the origin. (0,0)

2.20 THE INVERSELY PROPORTIONAL RELATIONSHIP

In an inverse variation, the values of the two variables change in an opposite manner, which is "as one value increases, the other decreases".

For instance, a biker traveling at 8 km/h can cover 8 km in 1 hour. If the biker's speed decreases to 4 km/h, it will take the biker 2 hours (an increase of one hour), to cover the same distance.



Notice the shape of the graph of inverse variation. If the value of x is increased, then *y* decreases. If x decreases, the *y* value increases. We say that y varies inversely as the value of x.

An inverse variation between 2 variables, y and x, is a relationship that is expressed as:

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

where the variable *k* is called the *constant of proportionality.*

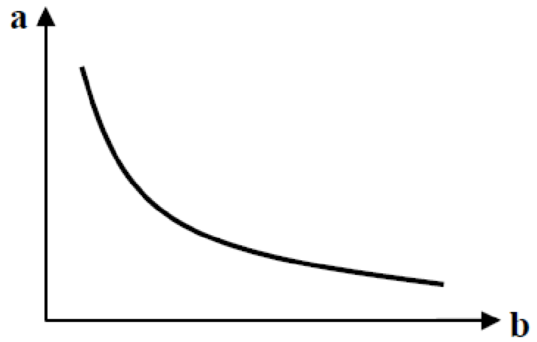
2.30 EXERCISES

1. Use the table below to answer the questions that follows

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

(i) Sketch the graph of velocity against time.
(ii) State the relationship of velocity and time.
(iii) Find the constant relating the variables.

2. The graph below shows the relationship between two variables **a** and **b**.



What kind of relationship does this graph represent?

3. A loaded trolley of mass **M** is accelerated along a smooth surface by a hanging mass with acceleration **a.** The acceleration for different masses is recorded below. (**M** includes mass of trolley, added masses and accelerating mass)

M (kg)	0.50	0.75	1.0	1.25	1.5	1.75	2.0
a (m/s^2)	5.0	3.3	2.5	2.0	1.7	1.4	1.3
1/**M**							

a) Sketch the graph of **a** (vertical) against **M**. (horizontal)
b) Describe the shape of the graph.
c) Calculate the reciprocal of the systems mass in the last row of the table.
d) Plot **a** versus 1/**M** on the same graph.
e) Describe the shape of the graph and the relationship between **a** and 1/**M**
f) Calculate the slope of the graph and state its unit
g) Write down the mathematical relationship between **a** and **M.**

4. A 100kg rock falls from a cliff. The speed it travels at the end of each second is recorded below.

Speed (m/s)	0	10	20	30	40	50	60	70	80	90	100
Time (s)	0	1	2	3	4	5	6	7	8	9	10

a) Sketch the graph of speed (v) versus time (t)
b) Describe the shape of the graph
c) Calculate the slope of the graph and include its unit
d) Write down the mathematical relationship between v and t
e) What (sensible) name would you give the slope? What is its value?

CHAPTER 3: SCALARS AND VECTORS

3.0 INTRODUCTION

We deal with many physical quantities in the natural world on a daily basis. For example, quantities like mass, weight, and force are some which we are all familiar with. We know that physical objects have mass. Bodies have weight due to gravity. We exert forces when we open doors and walk along the street.

There are many physical quantities in nature, and we can divide them up into two groups called **vectors** and **scalars**.

3.10 SCALAR

A **scalar** is a physical quantity that has a magnitude (size) only. Some scalars can take negative values but the sign does not imply directionality of any sort.

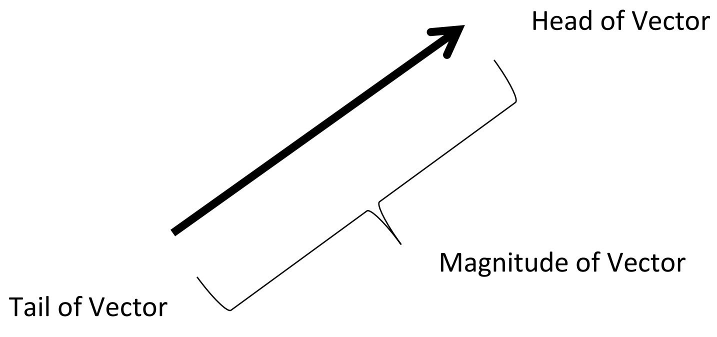
Length, charge, temperature, energy, speed and distance are scalar quantities.

3.20 VECTORS

A **vector** is a physical quantity that has both magnitude and direction. Vectors which take negative values, point in the direction opposite to that defined to be positive.

Displacement, velocity, acceleration and force are vector quantities.

A **vector** is represented graphically as an arrow pointing in a given direction.



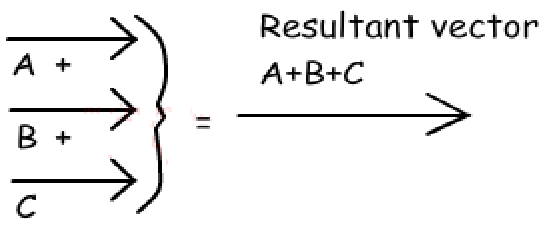
Head of the vector shows the direction and tail shows the starting point. We can change the position of the vector however, we should be careful not to change the direction and magnitude of it.

3.30 Examples of Vectors and Scalars

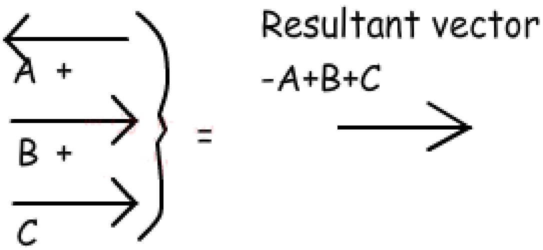
Scalars	Vectors
Mass	Force
Temperature	Displacement
Speed	Velocity
Distance	Momentum
Energy	Acceleration

3.40 ADDITION AND SUBTRACTION OF VECTORS

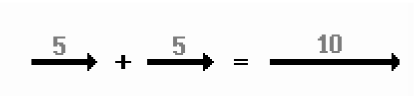
Look at the picture given below. It shows the classical addition of three vectors. We can add them just like they are scalars. However, you should be careful, they are not scalar quantities. They have both magnitude and direction. In this example their magnitudes and directions are the same thus; we just add them and write the resultant vector



Let's look at a different example. In this example as you can see the vector A has negative direction with respect to vectors B and C. So, while we add them we should consider their directions and we put a minus sign before the vector A. As a result our resultant vector becomes smaller in magnitude than the first example.

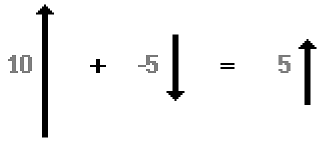


Example 1

(i) 

(ii) 

(iii) 

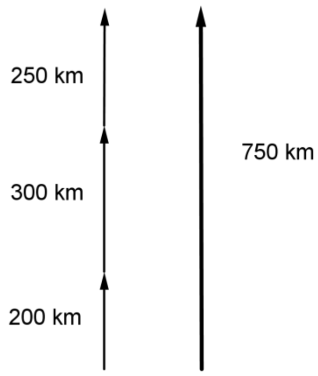
(iv) 

Example 2

If a car travels due north and cover 200 km on the first day, 300 km on the second day, and 250 km on the third day, draw a vector diagram of the trip and find the total displacement for the three-day journey.

Solution: Because the car continues to travel in the same direction throughout the entire trip, these vectors simply add together. This can be shown by placing the displacement vectors head to tail.

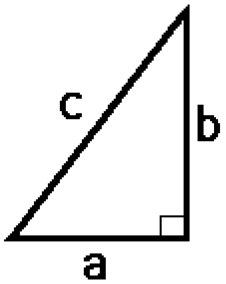
200 km + 300 km + 250 km = **750 km north**



3.50 THE PYTHAGOREAN THEOREM

Pythagorean Theorem is a mathematical equation that relates the length of the sides of a right angled triangle to the length of its hypotenuse.

Pythagorean Theorem

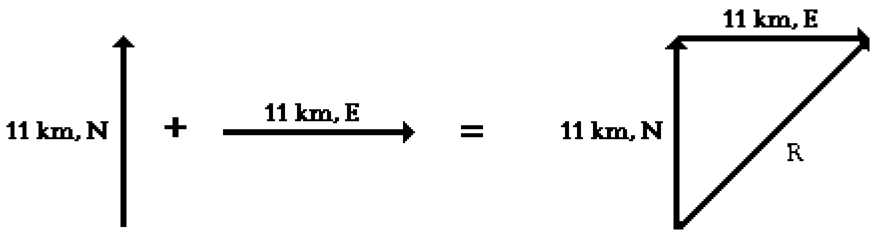


$$a^2 + b^2 = c^2$$

To see how the method works, consider the following problem:

Peter leaves home and walks 11 km north and then walks 11 km east. Determine Peter's resulting displacement.

This problem asks to determine the result of adding two vectors that are at right angles to each other. The result (or resultant) of walking 11 km north and 11 km east is a vector directed northeast as shown in the diagram below. Since the northward displacement and the eastward displacement are at right angles to each other, the Pythagorean Theorem can be used to determine the resultant (i.e., the hypotenuse of the right triangle).



$$11^2 + 11^2 = R^2$$

$$242 = R^2$$

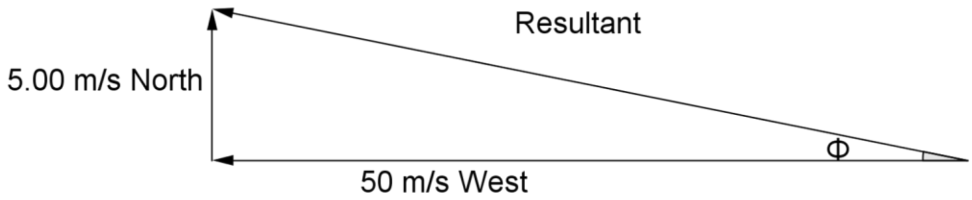
$$15.6 = R$$

The result of adding 11 km, north plus 11 km, east is a vector with a magnitude of 15.6 km.

Example

If the Lakeba cricket captain, Viliame, hit a cricket ball due west with a speed of 50.0 m/s, and the ball encountered a wind that blew it north at 5.00 m/s, what is the resultant velocity of the baseball?

Solution: Begin by drawing a vector diagram of the situation.



Solve using the Pythagorean Theorem:

$$a^2 + b^2 = c^2$$
$$(50.0\ m/s)^2 + (5.00\ m/s)^2 = c2$$

$$c = \sqrt{2500 + 25} = 50.2\ m/s \text{ toward northwest}$$

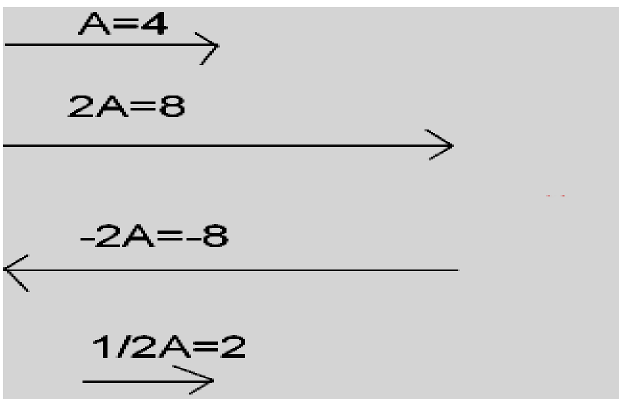
We can find the exact angle at which the ball travels by:

$$\text{Tan } \phi = \frac{opp}{adj} = \frac{5.00 m/s}{50.0 m/s} = 0.1 \qquad \text{so } \tan^{-1}(0.1) = 5.71^0 \text{ from west towards north.}$$

3.60 MULTIPLYING A VECTOR WITH A SCALAR

When we multiply a vector with a scalar quantity, if the scalar is positive than we just multiply the scalar with the magnitude of the vector. But, if the scalar is negative then we must change the direction of the vector. Example given below shows the details of multiplication of vectors with scalar.

Example: Find 2A, -2A and 1/2A from the given vector A.



3.70 EXERCISES

1. Which one of the following is a vector quantity?

   A. Mass B. Temperature

   C. Acceleration D. Work

2. If a man walks 17 m east and then 17 m south, the magnitude of the man's displacement is

   A. 17 m B. 24 m C. 30 m D. 34 m

3. Some Antarctic explorers heading due south toward the pole travel 50 km during the first day. A sudden snow storm slows their progress and they move only 30 km on the second day. With plenty of rest they travel the final 65 km the last day and reach the pole. What was the explorers' displacement?

4. Erica and Tory are out fishing in the lake on a hot summer day when they both decide to go for a swim. Erica dives off the front of the boat with a force of 45 N, and simultaneously Tory dives off the back with a force of 60 N.
   a) Draw a vector diagram of the situation.
   b) Find the resultant force on the boat.

5. Young race-horses are sometimes reluctant to enter the starting gate for their first race. Astro Turf is one such horse, and it takes two strong men to get him set for the race. Sam pulls Astro Turf's bridle from the front with a force of 200 N and San push it from behind with a force of 150 N, while the horse pushes backward with a force of 300 N.
   a) Draw a vector diagram of the situation.
   b) What is the resultant force on Astro Turf?

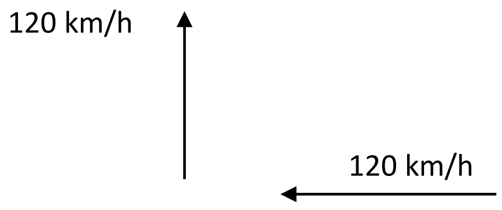
6. Akeneta finds that when she drives her motorboat with a constant speed upstream, she can travel with a speed of only 8 m/s, while she moves with a speed of 12 m/s when she heads downstream. What is the speed of the current of the river on which Akeneta is traveling?

7. The diagram below represents a 5 N force and a 12 N force acting on point *P*.

The resultant of the two forces has a magnitude of

A. 5.0 N B. 7 N C. 13 N D. 17 N

8. A car traveling at 120 km/h towards West makes a right turn and travels north without changing its speed.



Using a vector diagram, find the magnitude and direction of the resultant velocity of the car.

CHAPTER 4: FORCES

4.0 INTRODUCTION

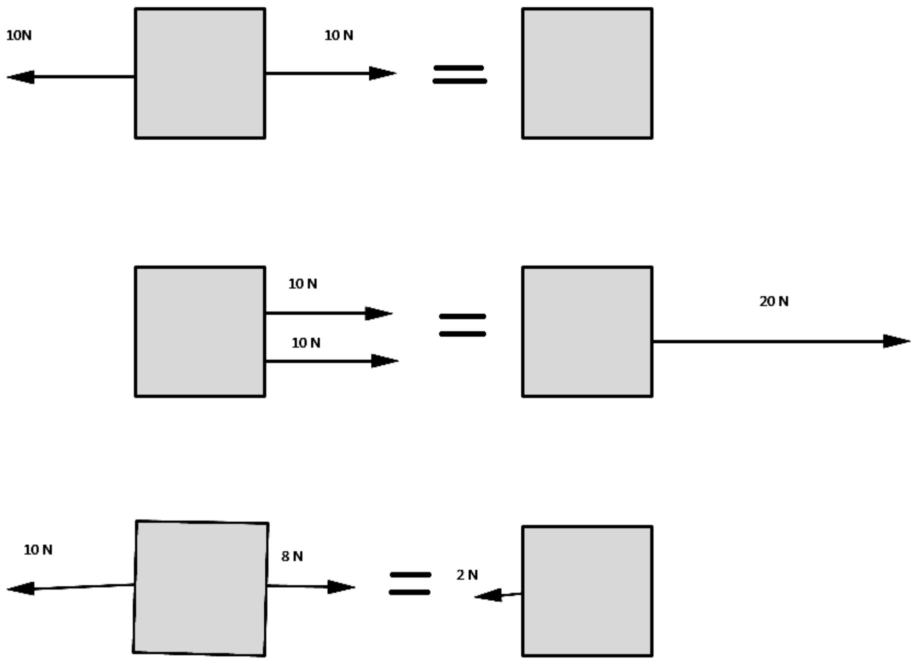
Force changes the shape or position of an object. When kicking a ball, force is applied so giving speed to the ball and also changes its position. Force is a vector quantity having both magnitude and direction. Force will cause motion.

4.10 UNIT OF FORCES

The unit of force is Newton (N) or kgm/s^2. A *Newton* is the force required to give a mass of 1 kilogram (1 kg) an acceleration of 1 meter per second per second (1 m/s^2). This unit of measurement is in the metric or SI system and is used in scientific work more than other units of force.

4.20 UNBALANCE FORCE

What we mean by a word "unbalanced force"? Look at the given picture to understand what we mean.

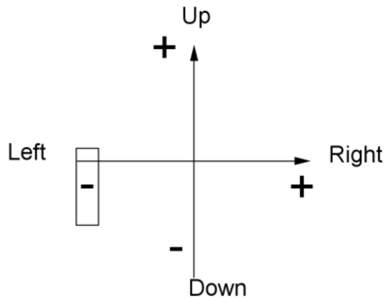


We called unbalanced force "**net force**" or resultant force also. As you see from the picture:

- if the forces acting on an object are in the same direction they are added.
- if they are opposite direction we take one of them in negative direction and make calculations considering their signs and find resultant force vector.

4.21 Convention

1. Always choose right hand side as positive and left hand side as negative.
2. Take going up as positive and moving down as negative.



4.30 LAWS OF MOTION

4.31 Newton's First Law of Motion

According to Newton's first law...

"An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force".

This means that there is a natural tendency of objects to keep on doing what they're doing. All objects resist changes in their state of motion. In the absence of an unbalanced force, an object in motion will maintain this state of motion.

Example

When a bus suddenly starts, the passengers sitting or standing in the bus tend to fall backward. This is due to inertia of rest and can be explained as follows: when the bus suddenly starts, the lower part of the body of the passenger which is in contact with the bus moves along with the bus while the upper part of the body tends to retain its state of rest due to inertia. As a result, the passenger falls backward.

4.32 Newton's Second Law of Motion

"Acceleration is produced when a force acts on a mass. The greater the mass, the greater the amount of force needed to accelerate the object."

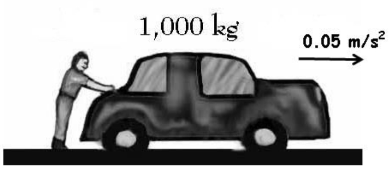
Heavier objects require more force to move the same distance as lighter objects.

The Second Law gives us an exact relationship between force, mass, and acceleration. It can be expressed as a mathematical equation:

$$F = ma$$

where F is the Force
m is the mass
a is the acceleration

Example 1



Praneel's car, with mass of 1,000 kg, is out of gas. Praneel is trying to push the car to a gas station, and he makes the car accelerate at 0.05 m/s^2. Using Newton's Second Law, you can compute how much force Praneel is applying to the car.

Solution: $F = ma$

$= 1000 \text{ kg} \times 0.05 \text{ m/s}^2$

Answer = <u>50 N</u>

Example 2

A 20 grams sparrow flying toward a bird feeder mistakes the pane of glass in a window for an opening and slams into it with a force of 2.0 N. What is the bird's acceleration?

Solution: Don't forget to convert grams into kilograms before any substitution.

20 g = 0.02 kg

Given: m = 0.02 kg *Unknown: a* =?
F = 2.0 N *Original equation: F = ma*

$$a = \frac{F}{m} = \frac{2.0\ N}{0.02\ kg}$$

$$= 100 \text{ m/s}^2$$

4.33 Newton’s Third Law of Motion

Newton states that “For every action, there is an equal and opposite reaction.”

According to Newton, whenever objects A and B interact with each other, they exert forces upon each other. When you sit on a chair, your body exerts a downward force on the chair and the chair exerts an upward force on your body. There are two forces resulting from this interaction - a force on the chair and a force on your body. These two forces are called action and reaction forces and are the subject of Newton's third law of motion.

Example

A bird flies by using its wings. The wings of a bird push air downwards. Since forces result from mutual interactions, the air must also be pushing the bird upwards. The size of the force on the air equals the size of the force on the bird; the direction of the force on the air (downwards) is opposite the direction of the force on the bird (upwards). For every action, there is an equal (in size) and opposite (in direction) reaction. Action-reaction force pairs make it possible for birds to fly.

4.40 MASS AND WEIGHT

Mass

The amount of matter an object has is defined as mass. This is an essential property of an object. The mass of the body remains same at any given place.

Weight

The weight of an object is defined as the force of gravity on the object and may be calculated as the mass times the acceleration of gravity. Since the weight is a force, its unit is the Newton.

$$F_w = mg$$

4.43 Difference between Mass and Weight

Mass	Weight
It is the quantity of matter in a body.	It is the force with which a body is attracted towards the centre of the earth.
It is a scalar quantity.	It is a vector quantity.
The mass of an object is constant on Earth and even in space.	The weight of an object can vary from place to place and becomes zero at the centre of the earth. It is also zero in places that are far away from earth.
$m = F/a$ is the mass of a moving body.	$W = mg$, is the weight of a body.
An ordinary weighing balance can help you weigh mass.	Spring balance helps measure the weight of an object.
The unit of mass in the SI system is Kilogram (kg).	The unit of weight is Newton (N)

Example

Peter, a dancer, has a mass of 45.0 kg.

a) What will be Peter's weight on Earth?

Solution: Peter's weight on Earth depends upon the gravitational pull of the earth on Peter's mass.

Given: m = 45.0 kg Unknown: w = ?

g = 10 m/s^2 Original equation: $w = mg$

Solve: $w = mg$ = (45.0 kg) (10 m/s^2)

= 450 N

b) What is Peter's mass on Jupiter, where the acceleration due to gravity is 25.0 m/s^2?

Solution: The mass of an object remains the same whether the object is on Earth, in space, or on another planet. Therefore, on Jupiter, Peter's mass is still 45.0 kg.

c) What is Peter's weight on Jupiter?

Solution: The acceleration due to gravity on Jupiter is 25 m/s^2.

Given: m = 45 kg *Unknown: w* = ?

g = 25 m/s^2 *Original equation: w = mg*

Solve: $w = mg$ = (45 kg) (25 m/s^2)

= 1130 N

4.50 TYPES OF FORCES

4.51 Gravitational Force

Gravitational force is the force of attraction between all masses in the universe; especially the attraction of the earth's mass for bodies near its surface; "the greater the distance between the two bodies the less the gravitational force"; "the gravitation between two bodies is proportional to the product of their masses and inversely proportional to the square of the distance between them."

4.52 Magnetic Force

Magnetic force is the force of attraction or repulsion that arises between electrically charged particles that is in motion. While only electric forces exist among stationary electric charges, both electric and magnetic forces exist among moving electric charges. Magnetic force is responsible for the action of electric motors and the attraction between magnets and iron.

4.53 Nuclear Force

The nuclear force is the force between two or more nucleons. It is responsible for binding protons and neutrons into atomic nuclei. The energy released by such binding causes the masses of nuclei to be less than the total mass of the protons and neutrons which form them.

4.54 Friction

Friction is a force that resists the relative motion of objects that are in contact with each other. Frictional forces exist between surfaces of two objects being in contact. Their direction is always parallel to that surface and opposite to the direction of the *intended motion* of an object. It is important to emphasize the word intended as frictional forces exist even if there is no motion.

If you run down the sidewalk and stop quickly, you can stop because of the friction between your shoes and the cement.

Friction not only happens with solid objects, but you do get **resistance** to motion in both liquids and gases.

The friction force is always parallel to the surface in contact.

Examples of Friction

1. When we rub our hands together, the heat produced is due to friction.
2. Falling meteorites enter into the earth's atmosphere and burn due to friction.
3. Lighting a matchstick is possible only because of friction between the stick and the box.

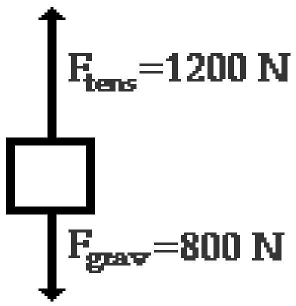
4.60 DETERMINING UNBALANCE FORCE

According to Newton's First Law, "An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force."

In Newton's first law, the unbalanced force refers to that force that does not become completely balanced (or cancelled) by the other individual forces. If either all the vertical forces (up and down) do not cancel each other and/or all horizontal forces do not cancel each other, then an unbalanced force exists.

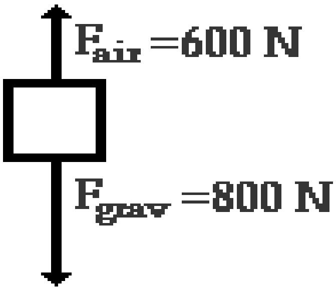
The existence of an unbalanced force for a given situation can be quickly realized by looking at the free-body diagram for that situation. Free-body diagrams for three situations are shown below. Note that the actual magnitudes of the individual forces are indicated on the diagram.

Examples



Unbalance Force = 1200 N – 800 N

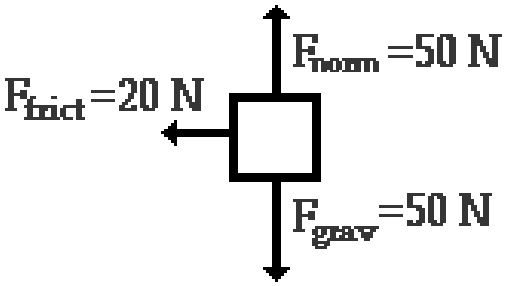
= <u>400 N Upward</u>



Unbalance Force = 600 N – 800 N

= - 200 N

= <u>200 N Downward</u>



Unbalance Force = 20 N left + (50 N –50 N)

= 20 N left + 0 N

= <u>20 N to the left</u>

4.70 EXERCISES

1. Which unit is equivalent to a Newton?

   A. kgm/s^2 B. kgm/s C. kg m D. Wm

2. A 100 kg mass starts from rest and is accelerated by a force of 200 N. The acceleration of the mass is

   A. 0.25 m/s^2 B. 0.5 m/s^2 C. 2 m/s^2 D. 4 m/s^2

3. A solid ball is taken from earth to the moon. On the moon the ball will have a different:

   A. weight B. density C. mass D. volume

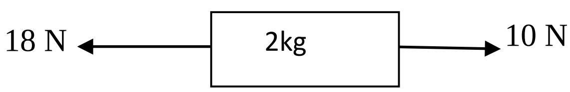
4. A 1.0 kg mass will have a weight of about

   A. 1 N B. 10 N C. 100 N D. 1000 N

5. A student pushes a 200 kg mass with a force of 10 N, but the mass does not move. What force does the mass exert on the student?

   A. 200 N B. 20 N C. 10 N D. 0 N

6. Find the net force acting on the object shown below and hence the acceleration if the mass is 2 kg?



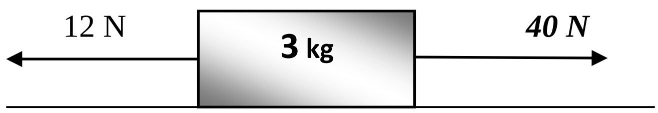
7. A rocket has a mass of 800 kg. It is launched into space towards the planet Mars in search for extra-terrestrial life.

(i) What is the weight of the rocket on earth?

(ii) At take off the rocket engine exerts an upward force of 15000 N on the rocket. Calculate the resultant force on the rocket.

(iii) Hence, determine the acceleration of the rocket.

8. A block of mass 3 kg is acted upon by a force of 40 N. A *frictional force* of 12 N also acts on the block.



What is the net force acting on the mass?

a. Calculate the acceleration of the mass.
b. What is the effect of friction on the mass above?

9. Singh a weightlifter can lift a 230.0 kg barbell on Earth. The acceleration due to gravity on the Jupiter is 274 m/s^2.

a) Would the barbells be heavier (by weight) on Jupiter or on Earth?
b) How much (in Newton) would the barbells weigh on Jupiter?

10. Samosa swings at a 0.15 kg baseball and accelerates it at a rate of 3.0×10^4 m/s^2. How much force does Samosa exert on the ball?

CHAPTER 5: MOMENTS (τ)

5.0 INTRODUCTION

Torque about a point is a concept that denotes the tendency of force to turn or rotate an object in motion. This tendency is measured in general about a point, and is termed as *moment of force*.

5.10 TURNING EFFECT OF A FORCE

The handle on a door is at the outside edge so that it opens and closes easily. A much larger force would be needed if the handle were near the hinge. Similarly it is easier to loosen a nut with a long spanner than with a short one.

The turning effect or moment of force depends on both the size of the force and how far it is from the pivot or fulcrum. It is measured by multiplying the force and the perpendicular distance of the line of action of the force from the fulcrum.

$$\tau = F \text{ x } d$$

where τ is the moment of Force

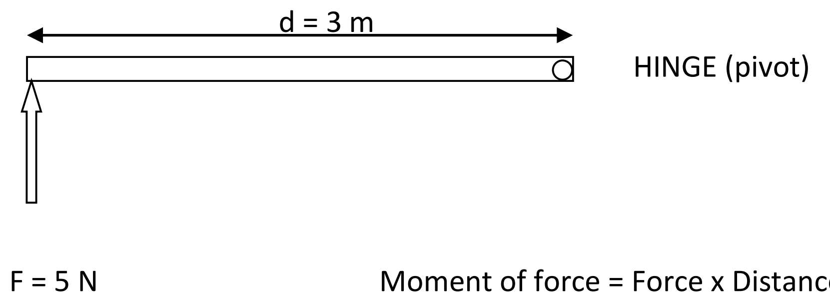
F is the force applied

d is the perpendicular distance to from the pivot point.

The SI unit of moment of force is Newton meter (Nm).

Example:

For the diagram given below, find the moment on the door using the hinge as the pivot.



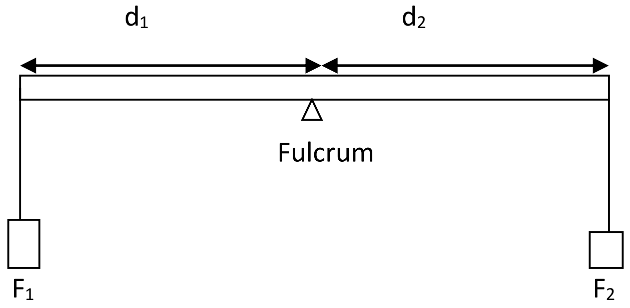
Moment of force = Force x Distance

= 5 N x 3 m

= 15 Nm

5.20 PRINCIPLE OF MOMENTS

Principle of moment stated that "when a body is in equilibrium, the sum of the clockwise moment about any point equals the sum of the anticlockwise moments about the same point."

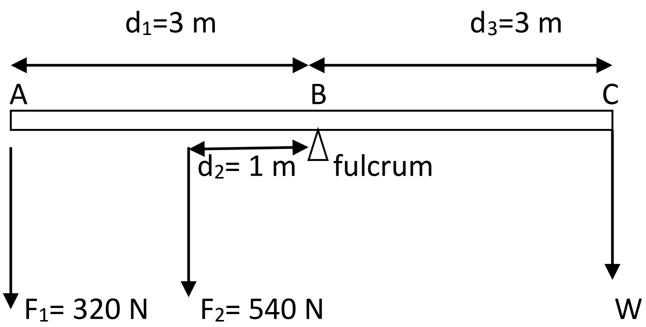


Sum of Anticlockwise Moment = Sum of Clockwise Moment

$F_1 \times d_1 = F_2 \times d_2$

If the mass is given then we need to calculate the weight force (*F = mg*) before determining the moment.

Example: The see-saw balance when Sue of weight 320 N is at A, Tom of weight 540 N is at B and Harry of weight W is at C. Find W a weight that will balance the see - saw.



Taking moments about the fulcrum:

Sum of anticlockwise moment = Sum of clockwise moment

$(F_1 \times d_1) + (F_2 \text{ X } d_2) = (F_3 \times d_3)$

(320 N x 3 m)+ (540 N x 1 m) = (W x 3 m)

960 + 540 = 3W

1500 = 3W

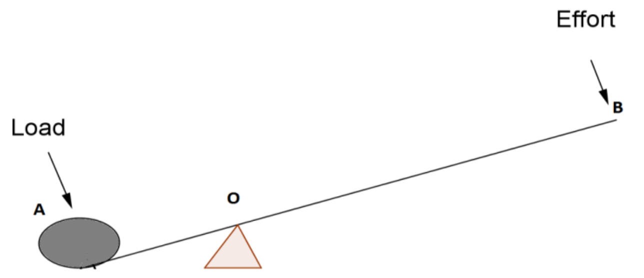
W = 1500/3

W = 500 N

5.30 LEVERS

A lever is any device which can turn about a pivot. In a working lever a force called the effort is used to overcome a resisting force called the load. The pivotal point is called the fulcrum. When we use a crowbar to move a heavy boulder, our hands apply the effort at one end of the bar and the load is the force exerted by the boulder on the other end.

If distance from the fulcrum O are as shown and the load is 1000 N (i.e. the part of the weight of the boulder supported by the crowbar), the effort can be calculated from the law of moments. OA = 10 cm, OB = 200 cm.



Sum of anticlockwise moment = Sum of clockwise moment

1000 N x 0.1 m = effort x 2 m

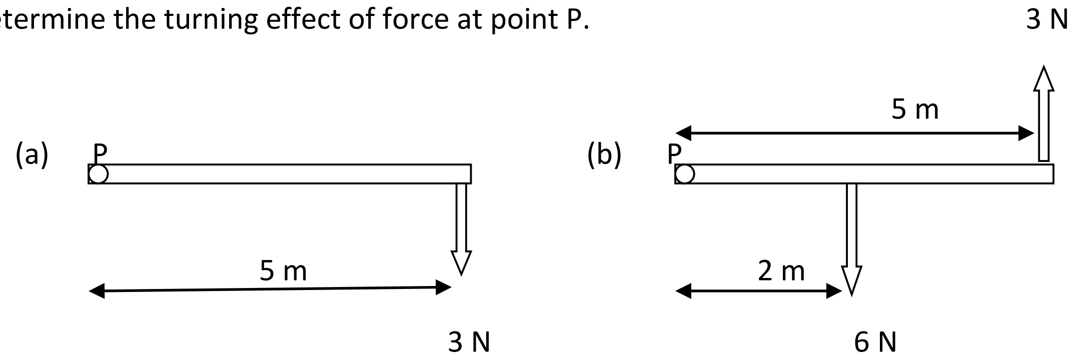
100 Nm = effort x 2 m

Effort = $\frac{100\ \text{N}}{2\ m}$

= 50 N

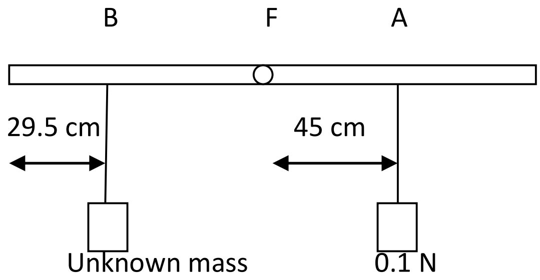
5.40 EXERCISES

1. Determine the turning effect of force at point P.



2. A meter ruler (of negligible weight) with a small hole in its centre is used in conjunction with a single known weight of 0.1 N to find the mass of unknown object. Other vital information is provided in the diagram below.

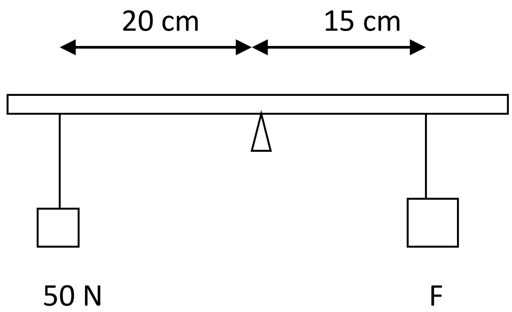
Note: F is the pivot of the ruler.



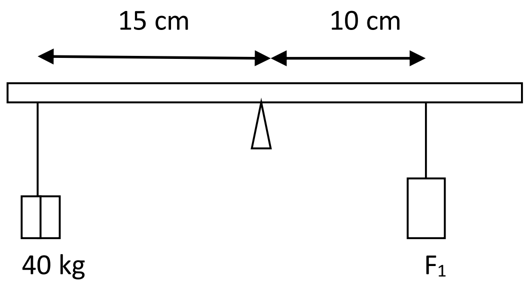
(i) What is the sum of clockwise moment about F?

(ii) What is the value of unknown mass?

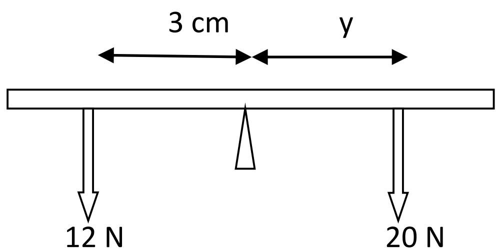
3. Find the value of force in the system below so that the beam is horizontally balanced.



4. Find the value of F_1 in the system shown below to have the beam balanced.



5. The meter ruler is supported at the center. If the ruler is balanced, determine the value of y in the diagram.



CHAPTER 6: KINEMATICS

6.0 INTRODUCTION

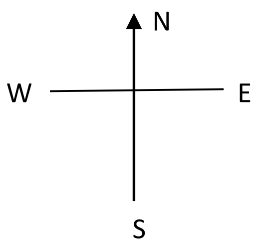
Kinematics will help us with understanding and describing the motion of objects. It allows us to represent the position, velocity, and acceleration of moving objects, and to express how these quantities are related to each other in time.

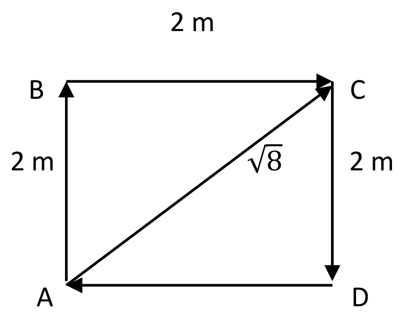
6.10 TERMS IN KINEMATICS

6.11 Distance and Displacement

The symbol used for both distance and displacement is (d). Distance and displacement both involve a change in position. Distance is a scalar quantity while displacement is a vector.

Example: A model train travels around the track from A to B then to C and to D and back to A as shown below.





Starting Point is A

The table shows the distance moved by the train and the displacement at various stages of the journey around the track.

	Distance travelled	**Displacement From Start**
At B	2 m	2 m north
At C	4 m	$\sqrt{8}$ m northeast
At D	6 m	2 m east
Back at the Start, A	8 m	0 m

6.12 Speed and Velocity

Speed is defined as distance travelled per unit time.

$$\textbf{Speed} = \frac{\textbf{Total distance covered (m)}}{\textbf{total time taken (s)}}$$

The SI unit of speed is m/s and is a scalar quantity for example 2 m/s.

Velocity can be defined as speed in a given direction.

$$\textbf{Velocity} = \frac{\textbf{distance travelled in given direction}}{\textbf{time taken}}$$

$$= \frac{\text{displacement(m)}}{\text{time(s)}}$$

The SI unit of velocity is the same as that of speed i.e. m/s and it is a vector quantity.

6.13 Average Speed and Instantaneous Speed

The average speed is the total distance travelled divided by the time taken.

$$\textbf{Average Speed} = \frac{\textbf{Total distance gone (m)}}{\textbf{Time taken(s)}}$$

Instantaneous Speed shows your speed at a particular instant in time. The speedometer of a car reveals information about the instantaneous speed of your car.

Average velocity and average speed are not necessarily the same unless it is a straight line motion in one direction.

Example:

On a trip, a family start out at 9.00 am and travels 100 km south. They stop for lunch and then travel a further 250 km south. After a short rest they travelled another 50 km north to reach their hotel at 5.00 pm.

Determine the average speed and average velocity of the journey.

Total time taken for the journey= 8.0 hours

Total displacement for the journey = 100 km (south) + 250 km (south) + 50 km (north)

= 100 + 250 - 50

= 300 km south

Average Velocity = $\frac{300 \text{ km}}{8 \text{ hr}}$

= 37.5 km/h south.

Total distance covered during the journey= 100 km + 250 km + 50 km

= 400 km

Average Speed = $\frac{400 \text{ km}}{8 \text{ hr}}$

= 50 km/h.

6.14 Acceleration

Acceleration is when an object changes velocity (i.e. speed increases, slows down or changes direction). It is calculated by dividing the change in velocity by the time taken for the change in velocity to occur. The unit of acceleration is meter per second per second (m/s^2).

$$\textbf{Acceleration} = \frac{\textbf{Change in velocity}}{\textbf{Change in time}}$$

$$a = \frac{\Delta v}{\Delta t}$$

Acceleration is used both as scalar and a vector quantity. When used in scalar, acceleration is calculated from

$$\textbf{Acceleration} = \frac{\textbf{Change in speed}}{\textbf{Change in time}}$$

Example

A car travelling at 5 m/s change its speed to 30 m/s in the time of 10 seconds. The change in speed is 30 m/s – 5 m/s = 25 m/s, and time taken equal 10 seconds.

$$\textbf{Acceleration} = \frac{\Delta v}{\Delta t}$$

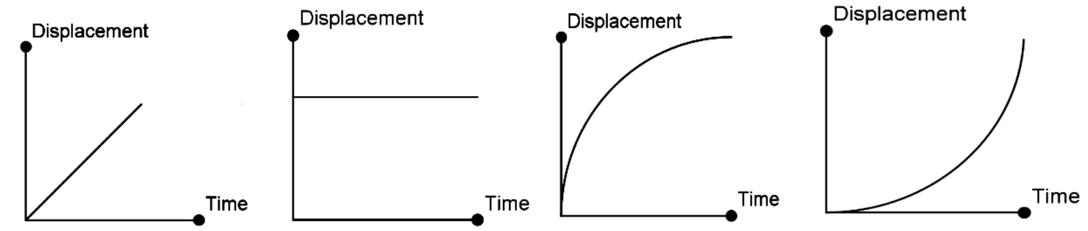
$$a = \frac{25 \text{ m/s}}{10 \text{ s}}$$

$$a = 2.5 \text{ m/s}^2$$

6.20 DISPLACEMENT/ TIME GRAPH AND VELOCITY/ TIME GRAPH

6.21 Displacement – Time Graph

These show the motion of an object very clearly and allow you to find position and velocity at any time. Any graph that you see will be a combination of these sections.



Constant velocity Stationary Acceleration Deceleration

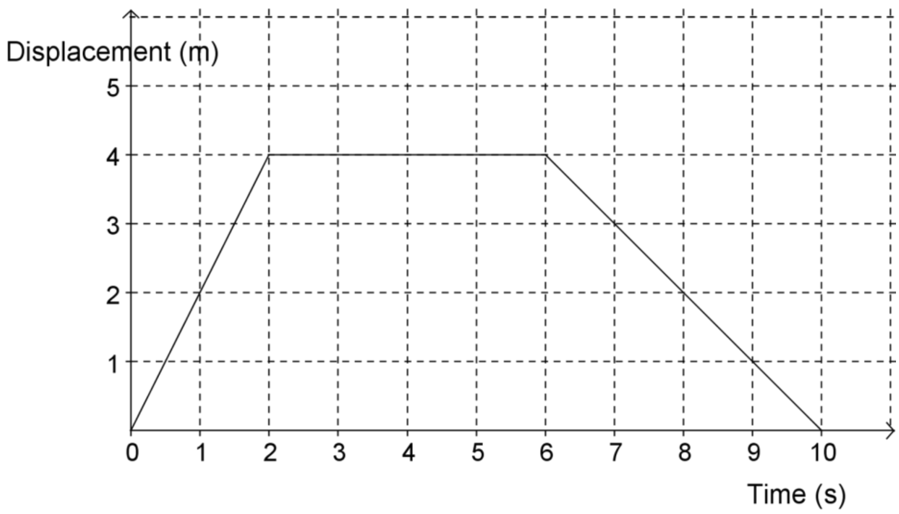
Note: The slope of displacement- time graphs give velocity.

Example:

A toy truck is moving towards east at 2 m/s for 2 seconds. For the next 4 seconds, the toy truck is not moving at all. Finally the truck moves towards west at 1 m/s for 4 seconds.

Displacement in meters	2	4	4	4	4	4	3	2	1	0
Time in seconds	1	2	3	4	5	6	7	8	9	10

Displacement against Time Graph



1. Find the slope of the graph between 0 seconds to 2 seconds and explain what the slope represents.

   Slope = velocity = $\frac{\Delta y}{\Delta x} = \frac{4-0}{2-0} = \frac{4}{2}$

   $= 2$ m/s

   For the first two seconds, the velocity of the toy truck is 2 m/s.

2. Find the slope of the graph between 2 seconds and 6 seconds

   Slope = gradient = velocity = $\frac{\Delta y}{\Delta x} = \frac{0}{4}$

   $= 0$ m/s

   Slope is a horizontal line so it's equal to 0 m/s, this indicate that it's not moving.

3. Find the slope of the graph between 6 seconds and 10 seconds.

   Slope = gradient = velocity = $\frac{y_{2-y1}}{x_{2-x1}} = \frac{0-4}{10-6} = \frac{-4}{4}$

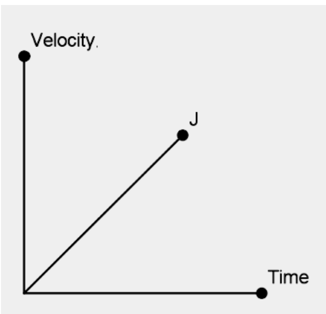
   $= -1$m/s

   which indicate the toy truck is moving in the opposite direction.

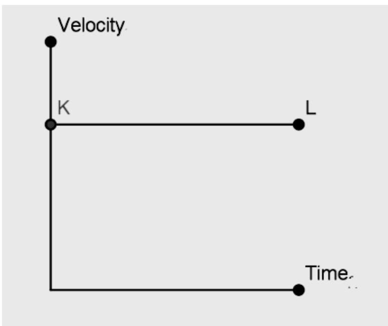
4. At time 10 seconds, object has return to its starting point.

6.22 Velocity – Time Graph

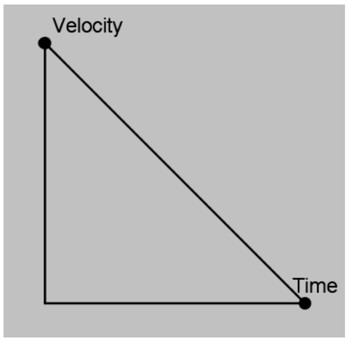
These are similar to displacement – time graph but velocity is on the y – axis instead of the displacement.



Constant acceleration



Constant velocity



Constant deceleration

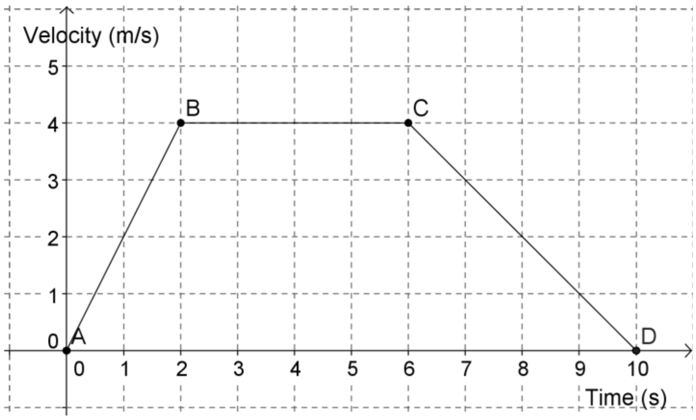
Note

- Velocity-time graph indicate the rate at which the object is moving.
- Slope of velocity-time graph gives acceleration. If slope is zero, the acceleration will be zero.
- Area below the graph of velocity-time graph gives displacement or distance.

Example

A car starts from rest and accelerates for 2 seconds. From time 2 seconds to time 6 seconds, it travels with a constant velocity. From time 6 seconds to time 10 seconds it travels in the opposite direction.

Velocity against Time Graph



1. Find the slope AB.

   Slope = gradient = acceleration = $\frac{\Delta y}{\Delta x}$ = $\frac{4-0}{2-0}$ = $\frac{4}{2}$ = 2 m/s^2
   It means the object is changing velocity at the rate of 2 m/s^2 .

2. Find the slope of the line BC.

   Slope = gradient = acceleration = $\frac{\Delta y}{\Delta x}$ = $\frac{0}{4}$ = 0 m/s.

   It means the object is moving with a constant velocity.

3. Find the displacement of the object in the first 2 seconds.

   Displacement = Area under the graph

   = $\frac{1}{2}$ x base x height **(area under the graph is a right angle triangle)**

   = $\frac{1}{2}$ x 2 x 4
   = 4 m

4. Find the slope of the line CD.

$$\text{Slope = gradient = acceleration} = \frac{\Delta y}{\Delta x} = \frac{0-4}{10-6} = \frac{-4}{4}$$
$$= -1\ m/s^2$$

Negative acceleration indicates the object is decelerating or slowing down.

5. Determine the distance covered in the entire journey.

Distance = ½ (2) (4) + 4(4) + 2(4)   area under the graph
= 4 + 16 + 8
= 28 m

6.30 EQUATIONS OF MOTION

Problems on bodies moving with uniform acceleration can often be solved quickly using the equations of motion.

Note that (**v_i**) stands for initial velocity and (**v_f**) for final velocity, it refers to the start and finish of the timing and do not necessarily mean the start and finish of the motion.

For uniform acceleration in straight line motion:

1st equation: $v_f = v_i + at$

2nd equation: $d = v_i t + 1/2at^2$

3rd equation: $v_f^2 = v_i^2 + 2ad$

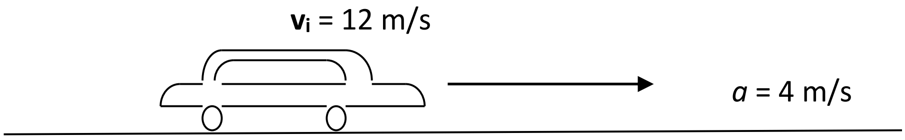
Where v_f **= final velocity**
v_i **= initial velocity**
a **= acceleration**
t **= time**
d **= distance**

Note: In deciding which equation to use
(a) To determine the time: must use the 1st or 2nd equation
(b) To determine the distance: must use the 2nd or 3rd equation
(c) To determine the velocity: must use the 1st or 3rd equation

It is important to list down what is given in the question. If an object starts from rest, it means initial velocity (***v_i***) equals zero.

Example

A car moves with an initial velocity of 12 m/s and accelerates at 4 m/s^2.



(a) Calculate distance travelled after 7 seconds.
v_i = 12 m/s, a = 4 m/s, t = 7 s
(Used the 2nd equation of motion)

$d = v_i t + ½at^2$
d = 12(7) + ½ (4) (7^2)
d = 84 + 98
d = 182 m

(b) Calculate the velocity of the car after it has travelled 30 meters.
v_i = 12 m/s, a = 4 m/s^2, d = 30 m
(Used the 3rd equation of motion)

$v_f^2 = v_i^2 + 2ad$
$v_f^2 = 12^2 + 2(4)(30)$
$v_f^2 = 144 + 240$
$v_f^2 = 384$
$v_f = \sqrt{384}$
v_f = 19.6 m/s

6.40 EXERCISES

1. During a competition, a competitor begins by travelling 5.0 km west. She then travels 2.0 km north and finally travels 5.0 km east.
   (a) What distances did she travelled?
   (b) What is her displacement from the start?

2. A car is driven 3.0 km east for 5 minutes, then 4.0 km south for 8 minutes and finally 3.0 km west for 2.0 minutes.
   (a) Calculate the cars average speed in km/h for the whole trip.
   (b) Find the cars average velocity in km/h for the whole trip.

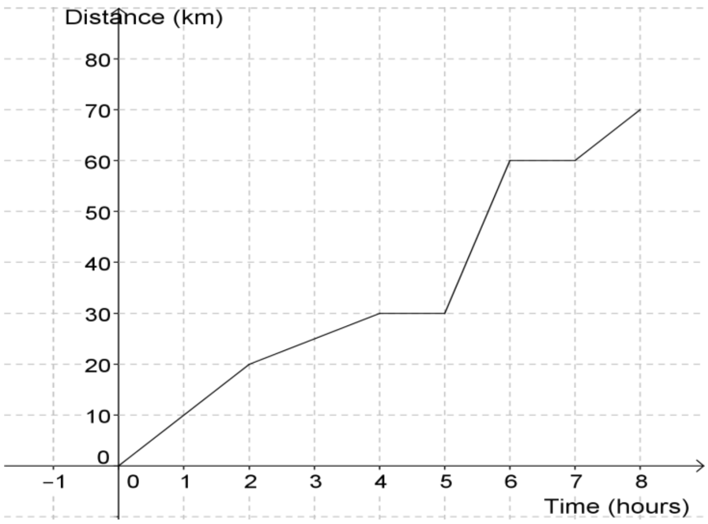
3. An airplane undergoes a change in velocity. What must have happened in terms of the plane's speed and direction of flight?

4. How much time does it take to travel from the position of -25 m to a position of 100 m, at an average speed of 15 m/s?

5. How much time does it take an object to change velocity from -3.0 m/s to5.0 m/s when the objects acceleration is 16 m/s.

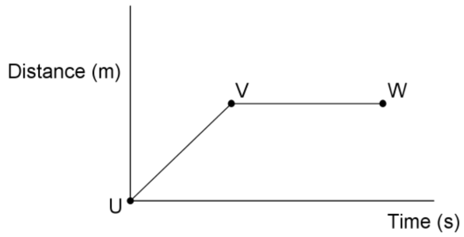
6. A ball is accelerated uniformly from rest along a straight line to a speed of 8.0 m/s in 2.0 s. Determine the ball's acceleration.

7 The distance – time graph for a girl on a cycle ride is shown below.



(i) How far did she travel?
(ii) How long did she travel?
(iii) What was her average speed in km/h?
(iv) How many stops did she make?
(v) What was her average speed excluding stop?

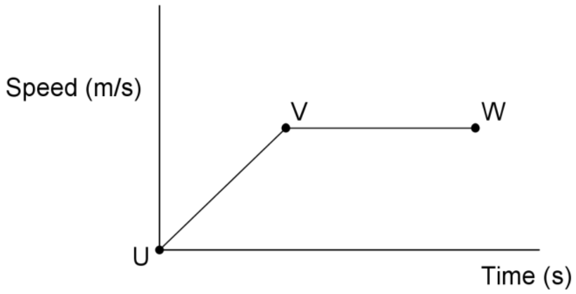
8 Describe the motion if any, of the objects in the region.
(a) UV
(b) VW



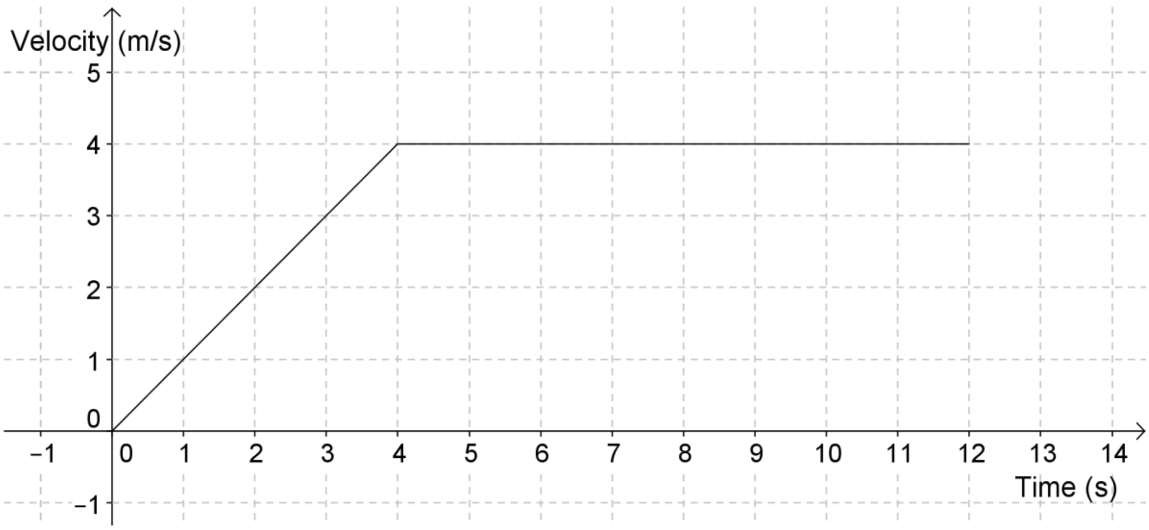
9 Describe the motion if any, of the object in the region.

(a) UV

(b) VW



10 Shown below is an incomplete velocity – time graph for a boy running a distance of 100 m.



(a) What is the acceleration during the first 4 seconds?

(b) How far does the boy travel during

(i) the first 4 seconds

(ii) the first 9 seconds

11 A body starts from rest and reaches a speed of 5 m/s after travelling with uniform acceleration in a straight line for 2 seconds. Calculate the acceleration of the body.

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

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

13 A car accelerates from 4 m/s to 20 m/s in 8 seconds. How far does it travel in this time?

14 A motor cyclist travelling at 12 m/s decelerate at 3 m/s^2.

(a) How long does he take to come to rest?
(b) How far does he travel while coming to rest?

15 Calculate the uniform acceleration of a sports car which:

(a) Starts from rest and reaches a speed of 15 m/s in 10 seconds?
(b) Changes its speed from 20 m/s to 30 m/s in 4 seconds?
(c) Starts from rest and goes a distance of 98 m in 7 seconds?

16 A ball rolls from rest down an incline with a uniform acceleration of 4 m/s^2.

(a) What is its speed after 8 seconds?
(b) How long will it take to reach a speed of 36 m/s?
(c) How long does it take to travel a distance of 200 m and what is its speed after travelling this distance?

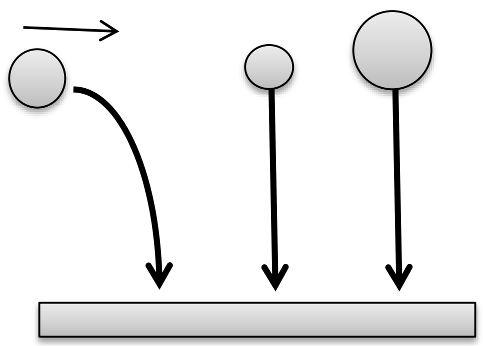
CHAPTER 7: PROJECTILE MOTION

7.0 INTRODUCTION

Aristotle believed that if two objects of different mass were dropped at the same time, the heavier one would hit the ground first. Galileo did not believe this. He reasoned that if two bricks of the same size and mass were dropped at the same time, they would hit the ground at the same time. He also reasoned that it would not make any difference in the speed the bricks fell if the two bricks were glued together. Thus, the two glued bricks would fall at the same rate as a third brick which had the same size and mass as the first two. If this were true, then it did not make any difference how heavy two objects were, they would both fall at the same rate if they were not acted upon by air resistance. Some scientists disagreed until Galileo's theory was proven when the air pump was invented in 1650. A coin and a feather were both dropped at the same time in an evacuated tube and they hit the other end at the same time.

7.10 THE LAW OF FALLING BODIES

The law of falling bodies assumes that no air is present to act on the objects being dropped. It says that, under the influence of gravity alone, all bodies fall with equal acceleration, regardless of size, mass, density, or horizontal velocity. This is illustrated in the image below.



Three balls falling to the ground at the same time even though the one on the left has horizontal motion and the one on the right has more mass.

Why do two objects of different mass and dropped from the same height, hit the ground at the same time?

The reason is that, when an object is in free fall, it is "weightless". Since both of these objects are experiencing the same force, then they both will fall at the same velocity and they will both hit the ground at the exact same time. The only factor that would change this result is air resistance.

Example

If one were to take a feather and a bowling ball and drop both at the same time, the bowling ball would hit the ground first while the feather remains floating. This is because the feather is experiencing "air resistance" while the bowling ball is barely affected. If one were to take this experiment to the moon, the bowling ball and feather would hit the surface at the exact same time. This is because there is no "air resistance" on the moon.
So mass of an object makes no difference when it is in free fall, because it is basically weightless.

7.20 FREE FALL

Free fall is the movement of an object in response to a gravitational attraction.

When an object is released, it falls toward the earth due to the gravitational attraction the earth provides. As the object falls, it will accelerate at a constant rate of approximately 10 m/s^2 regardless of its mass.

There are many different ways to solve free fall exercises. The sign convention used may be chosen by you or your teacher.

Like any moving object, the motion of an object in free fall can be described by the three kinematic equations. The kinematic equations that describe any object's motion are:

7.30 THE KINEMATIC EQUATIONS

1. $V_f = V_i + gt$
2. $d = V_i t + \frac{1}{2} g t^2$
3. $V_f^2 = V_i^2 + 2gd$

where, V_i = initial velocity (m/s)
V_f = final velocity (m/s)
d = displacement (m)
t = time (s)
g = gravitational acceleration (10 m/s^2)

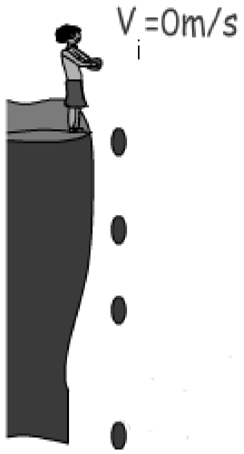
Note that "g" is always downwards hence $g = -10$m/s^2

There are a few points to note when using the equations to analyze free fall motion.:

1. If an object is merely dropped (as opposed to being thrown) from an elevated height, then the initial velocity (***V_i***) of the object is 0 m/s.

2. If an object is projected upwards in a perfectly vertical direction, then it will slow down as it rises upward. The instant at which it reaches the peak of its trajectory, its velocity is 0 m/s. This value can be used as one of the motion parameters in the kinematic equations; for example, the final velocity (***V_f***) after traveling to the peak would be assigned a value of 0 m/s.

7.31 Objects Dropped From A Height



Since V_i = 0 m/s

Formulas

$V_f = 0 + gt$	**$V_f = gt$**
$d = 0 + ½gt^2$	**$d = ½gt^2$**
$V_f^2 = 0 + 2gd$	**$V_f^2 = 2gd$**

Example 1

A girl drops a ball from a roof of the house and it takes 3 seconds for the ball to hit the ground.

(a) Calculate the velocity just before the ball touches the ground. (g = 10 m/s²)

Velocity, Vf = *gt*

= (10 m/s)(3 s)

= <u>30 m/s</u>

(b) Calculate the distance travelled by the ball before it hits the ground.

Distance travelled. ***$d = ½gt^2$***

= ½(10 m/s)(3 s)^2

= <u>45 m</u>

Example 2

An object does free fall motion. It hits the ground after 4 seconds.

Calculate

(a) the velocity of the object after 3 seconds
(b) the velocity of the object just before it hits the ground.
(c) What can be the height it is thrown?

Solution

a) Velocity after 3 seconds: $V_f = gt$

$= (10\ m/s^2)(3\ s)$

$= \underline{30\ m/s}$

b) Velocity after 4 seconds: $V_f = gt$

$= (10\ m/s^2)(4\ s)$

$= \underline{40\ m/s}$

c) Height : $d = ½gt^2$

$= ½\ (10\ m/s^2)(4\ s)^2$

$= \underline{80\ m}$

7.32 Object Projected Vertically Upwards

In this case, there is also *g* (gravitational acceleration) but the mass's direction is upward. Thus, our velocity decreases in 10 m/s in each second until the velocity becomes zero. At the top, because of the zero velocity, the mass changes its direction and starts to free fall.

Example 1

A ball is thrown upwards with an initial speed of 20 m/s.

(a) How far does the ball rise in 1 second?

Solution

$\boldsymbol{d = V_i t + ½gt^2}$ $\quad d = (20\ m/s)\ (1\ s) + ½(-10\ m/s^2)\ (1\ s)^2$

$d = 20 - 5$

$d = 15\ m$

The ball reaches a height of 15 meters after 1 second of its motion

(b) How long does it take to reach the highest point in its motion?

Solution

At highest point, $V_f = 0$ $\quad V_f = V_i + gt$

$$0 = 20 + (-10\ m/s^2)\ t$$

$$10t = 20$$

$$t = 20/10$$

$$t = 2.0 \text{ seconds}$$

(c) How high above the ground is the highest point in its motion?

Solution

Maximum height reached:

$\boldsymbol{d = V_i t + \frac{1}{2} g t^2}$ $\quad d = (20\ m/s)(2\ s) + \frac{1}{2}(-10\ m/s^2)(2\ s)^2$

$$d = 40 - 20$$

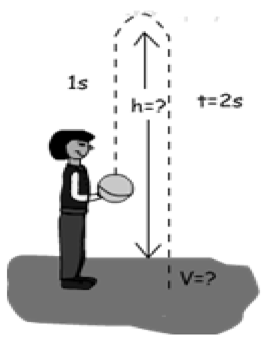
$$d = 20\ m$$

Maximum height reached by the ball is 20 meters.

Example 2

John throws the ball straight upward and after 1 second, it reaches its maximum height then it does free fall motion which takes 2 seconds. Calculate

(a) the balls initial velocity
(b) the maximum height(h) traveled by the ball before it hits the ground
(c) the velocity of the ball before it crashes the ground. (g = 10m/s²)



Solution

$V_f = 0$, g = -10 m/s^2, t = 1 s, V_i =???

(a) Initial Velocity, V_i : $V_f = V_i + gt$

$0 = V_i$ + (-10 m/s^2) (1 s)

V_i = <u>10 m/s</u>

Downward direction: V_i = 0, t = 2 s, g = 10 m/s^2, d =? V_f =??

(b) Maximum height: $d = V_i t + ½gt^2$

d = 0 + ½(10 m/s^2) (2 s)^2

d = <u>20 m</u>

(c) Velocity, V_f: $V_f = V_i + at$

V_f = 0 + (10 m/s^2) (2 s)

V_f = <u>20 m/s</u>

7.40 EXERCISES

1 A small object is dropped from rest from a tall building. After what time will the object have a velocity of 40 m/s?

A. 1 s B. 2 s C. 3 s D. 4 s

2. A stone is dropped from a cliff:

(a) How far will it have fallen in 4 s?
(b) What will its velocity be at that point?
(c) What is the average velocity during the 4 s?

3. A stone falls from rest from the top of a high tower. Ignoring air resistance and taking g = 10 m/s^2,

(a) What is the velocity after (i) 2 s, (ii) 5 s
(b) How far has it fallen after (i) 2 s, (ii) 5 s

4. A stone is thrown upward with a velocity of 12 m/s

(a) How far will it have risen in 1 second?
(b) What will its velocity be at that paint?
(c) What is the maximum height that it will reach before coming down again?

5. A sandbag is released from a balloon that is ascending vertically at 8 m/s. The sandbag hits the ground 15 s later.

(a) What is the velocity of the sandbag at the moment of release?
(b) Describe the motion of the sandbag after release
(c) Calculate the height of the balloon above the ground at the moment of release

6. A tennis ball is thrown straight up at a speed of 40 m/s and caught at the same level. Calculate:

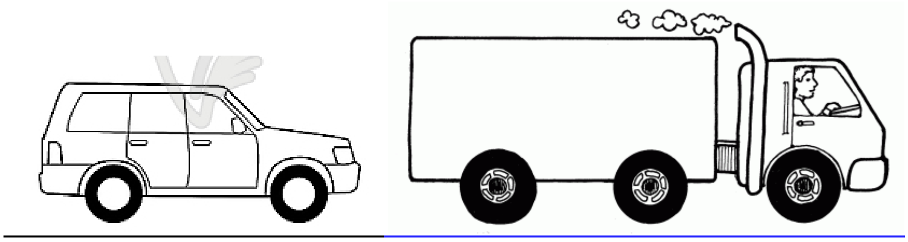
(a) the maximum height reached by the ball.
(b) The time of flight of ball.

7. A stone is tossed up from the new Melrose Bridge at 15 m /s. The bridge is 25 m high. Calculate:

(a) the maximum height to which the stone will rise above the bridge
(b) the time taken to reach this maximum height
(c) the time it will take the stone to hit the water.

CHAPTER 8: MOMENTUM

8.0 INTRODUCTION



Look at the given picture. If both the car and the truck have same speed, which one will come to a stop first when brakes are applied at the same time? Of course, it is hard to stop the truck compared to the car. Well, what is the reason making car stop easier? They have same speed but different masses. Can mass effect the stopping time or distance? The answer is again YES! It is hard to stop heavier objects. What we are talking about so far is momentum.

8.20 MOMENTUM

Momentum is a physical concept that is defined as “moving body”. In other words when we talk about momentum we must have moving object, it must have both mass and velocity.

Momentum = Mass x Velocity

We show momentum in physics with “*p*”, mass with “m” and velocity with “V”. Then equation becomes;

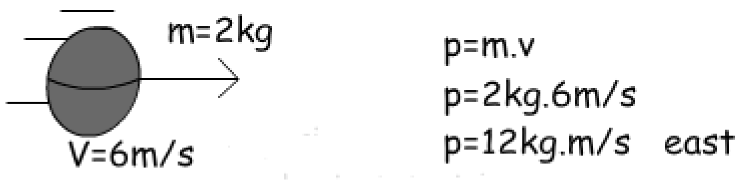
$$p = mV$$

Since velocity is a vector quantity and multiplied with mass (scalar quantity) momentum becomes a vector quantity. Direction of momentum is the same as velocity. From the definition and given equation we can change momentum by changing its mass or changing its velocity.

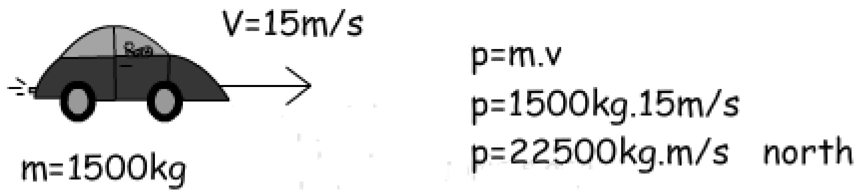
The unit of momentum is kgm/s.

Examples

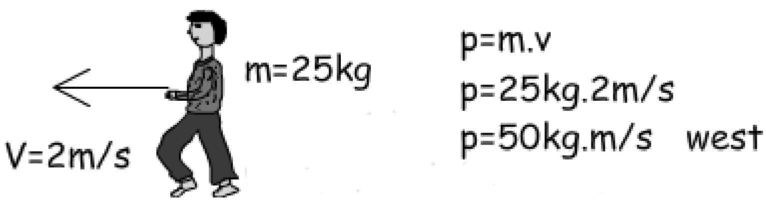
1. A ball of mass 2 kg moves with velocity of 6 m/s to the east.



2. A car having 15 m/s velocity and 1500 kg mass moves to the north.



3. A child having mass 25 kg and velocity 2 m/s moves to the west.



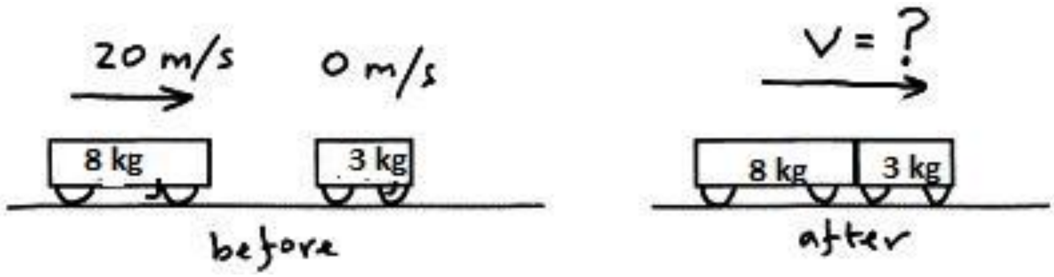
8.30 THE LAW OF CONSERVATION OF MOMENTUM

"When two objects interact the total momentum remains the same provided no external forces are acting (a closed system)."

The momentum before collision = the momentum after collision.

Example 1

A toy car of mass 8 kg is travelling at 20 m/s. It collides with a car of mass 3 kg which is stationary. The two cars join together and move of as one object, what is the velocity of the two cars as they move off together?



Momentum before = momentum after

$(m_1 \times V_1) + (m_2 \times V_2) = m_{comb} \times V_{comb}$

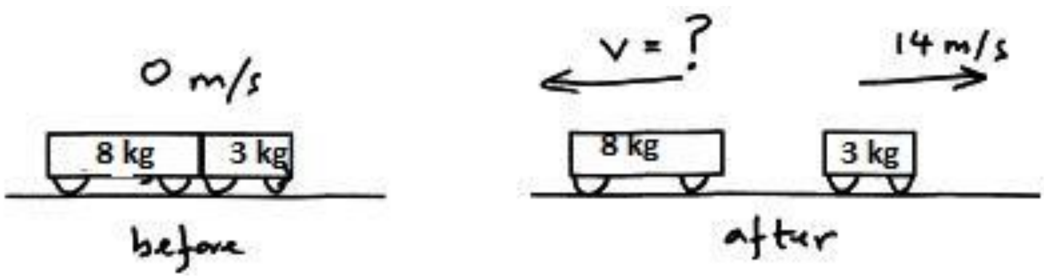
$(8 \times 20) + (3 \times 0) = (8 + 3) \times V_{comb}$

$160 + 0 = 11 \times V_{comb}$

$V_{comb} = \underline{14.5 \text{ m/s}} \longrightarrow$

Example 2

Two objects are in stationary and in contact with each other. They are pushed apart by an explosion. The 3 kg toy car moves right with a velocity of 14 m/s and the 8 kg car moves left. What is the velocity of the 8 kg toy car as it moves left?



Momentum before = momentum after

$(m1 + m_2) \times V_1 = (m_1 \times V_2) + (m_2 \times V_3)$

$11 \times 0 = (8 \times V_2) + (3 \times 14)$

$0 = (8 \times V_2) + 42$

$0 - 42 = 8 \times V_2$

$V_2 = \frac{-42}{8} = -5.25 \text{ m/s or } 5.25 \text{ m/s} \longleftarrow$

8.40 EXERCISES

1. What is the momentum in kgm/s of a 10 kg truck travelling at

a) 6m/s, b) 30 cm/s c) 26 km/hr.

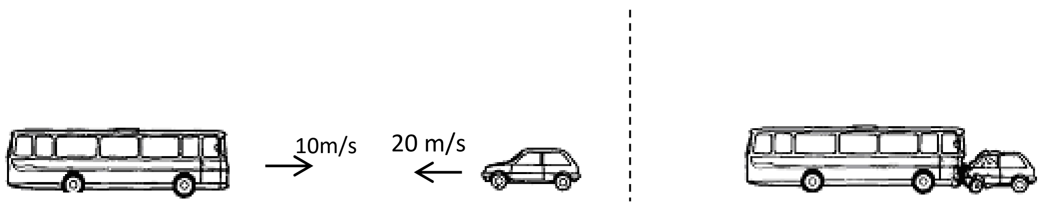
2. A delivery tank carrying water travel along a straight level stretch of highway at a constant speed throughout the journey. Unknown to the driver an appreciable amount of water has meanwhile leaked out of the tank. What effects will the leaking water have on the speed and momentum of the truck?

	Speed	Momentum
A.	Increase	Increase
B.	Constant	Constant
C.	Constant	Decrease
D.	Increase	Constant

3. A boy of mass 50 kg running at 5 m/s jumps on to a 20 kg trolley travelling in the same direction at 1.5 m/s. What is their common velocity?

4. A truck of mass 600 kg moving at 3 m/s collides with another truck of mass 1500 kg moving in the same direction at 2 m/s. What is their common velocity just after the collision if they move off together?

5. A 700 kg bus traveling towards the right at 10 m/s collides with a 300 kg BMW car traveling to the left at 20 m/s. After collision they stick together.



Before Collision **After Collision**

(i) Calculate the total initial momentum.

(ii) Determine the total momentum after collision.

(iii) Calculate the final speed of the two vehicles after collision.

6. A truck of mass 60 kg travelling to the right at 20 m/s collides head on with an oncoming car of mass 40 kg travelling at 10 m/s.

i)Sketch a diagram before the collision.

After the collision, both the car and truck couple together and move off.

ii) Calculate the final momentum.

iii) Calculate the velocity after the collision. (Show direction).

CHAPTER 9: ENERGY

9.0 INTRODUCTION

Energy is one of the most fundamental parts of our universe. We use energy every day. Energy lights our homes and powers our vehicles and planes. It warms our homes, cooks our food, plays our music, and gives us pictures on television.

Energy stored in plants is eaten by animals, giving them energy. And predator animals eat their prey, which gives the predator animal energy.

Everything we do is associated to energy in one form or another.

9.10 WORK DONE BY A CONSTANT FORCE

In Physics, the word "work" takes on a different meaning from the one commonly used. Work is defined as a force applied through a distance. Work done on an object by a constant force is the product of the object's displacement and the force acting parallel to the displacement.

$$W = F \times d$$

The SI unit for work is the **joule** (J). One joule is the product of one Newton and one meter, or a Joule is a one-Newton force applied through one meter, 1 J = 1 Nm.

Example 1

If a girl pushes a box with a 5.0 N force, and the box travels 2.0 m in the direction of her push, the amount of work done will be

$$W = F \times d$$

$$= 5.0 \text{ N} \times 2.0 \text{ m}$$

$$= 10 \text{ J}$$

Example 2

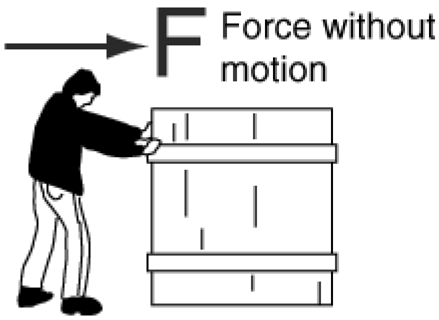
A 10 kg object experiences a horizontal force which causes it to accelerate at 5 m/s^2 , moving it a distance of 20 m, horizontally. How much work is done by the force?

The magnitude of the force is given by $F = ma$ = (10)(5) = 50 N. It acts over a distance of 20 m, in the same direction as the displacement of the object, implying that the total work done by the force is given by

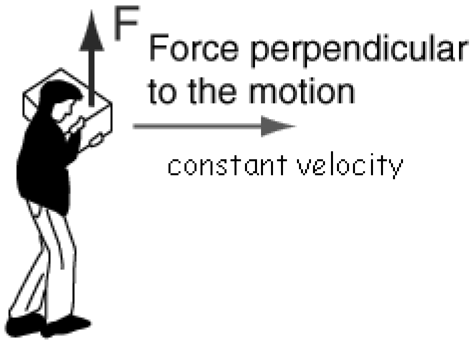
$$W = F \times d = (50)\,(20) = \underline{1000 \text{ J}}.$$

9.20 WHEN A FORCE DOES NO WORK

A force with no motion or a force perpendicular to the direction of motion does no work.



In the diagram above, no matter how hard or how long you have pushed, if the crate does not move, then you have done no work on the crate.



In the above diagram if the box is being carried at constant velocity, then no net force is necessary to keep it in motion. The force exerted by the person is an upward force equal to the weight of the box, and that force is perpendicular to the motion. When there is no motion in the direction of the force, then no work is done by that force.

Energy can be defined as the capacity for doing work. The simplest case of mechanical work is when an object is standing still and we force it to move. The energy of a moving object is called kinetic energy.

Note:

1. Energy is the ability to produce or create work. Work, on the other hand, is the ability to provide force and a change in distance to an object.

2. There are many types of energy such as solar energy, etc., but there is only one type of work.

3. Both work and energy are scalar units.

4. Both work and energy are measured in joules.

9.30 POWER

Power is the rate of work done in a unit of time. Power just shows us the time that the work requires. For example, same work is done by two different people with different time. Say one of them does the work in 5 seconds and the other does in 8 seconds. Thus, the man doing the same work in 5 seconds is more power full. The shorter the time the more power it has.

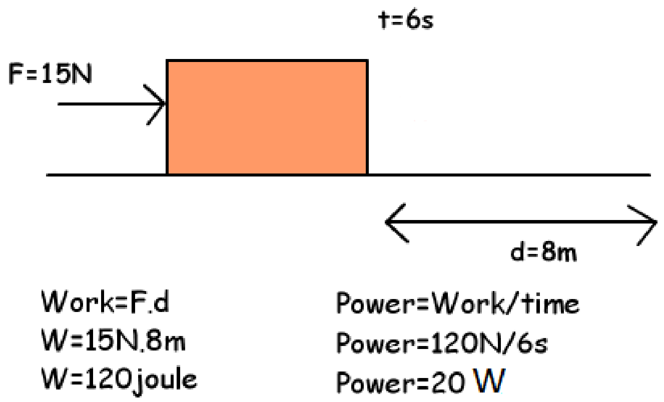
$$\text{Power} = \frac{\text{Workdone}}{\text{Time taken}}$$

The unit of power is, J/s, however, we generally use watts (W).

1 J/s = 1 W

Example

Find the power of the man who pushes a box 8 m with a force of 15 N in 6 seconds.



The power of the man is 20 W. In other words he does 20 Joule of work in 6 seconds.

Note: Amount of power does not show the amount of work done. It just gives the time that work requires.

9.40 FORMS OF ENERGY

There are many forms of energy: like solar, wind, wave and thermal to name a few, but we will look at 5 only.

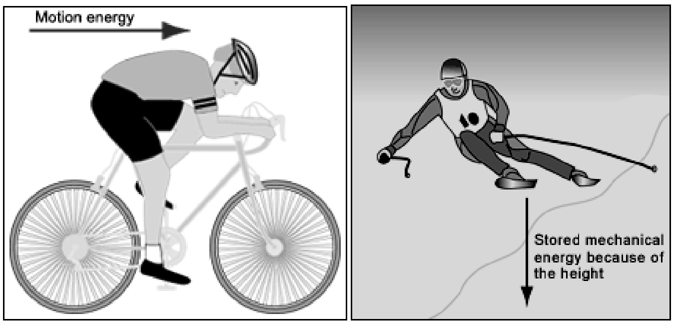
1. *Mechanical energy:*

Mechanical energy is the sum of potential energy and kinetic energy present in the components of a mechanical system. It is the energy associated with the motion or position of an object. For instance, if a man is pushing a car, he transfers chemical energy from him to the car and the car therefore attains mechanical energy. There are two types; energy of motion (kinetic energy) or stored energy of position (potential energy).

- Motion energy: This is the energy something has because it is moving (eg a speeding cricket ball). You can feel the effect of this energy if the cricket ball hits you. Motion energy is also called kinetic energy.

- Stored mechanical energy: This is energy something has stored in it because of its height above the ground or because it is stretched or bent or squeezed (eg in a stretched rubber band). You can feel it when the band is released.

Stored mechanical energy is also called potential energy.



Source: http://www1.curriculum.edu.au/sciencepd/energy/mech_activity.htm

We will look at this in more detail later.

2. *Nuclear energy*

Nuclear power stations work in pretty much the same way as fossil fuel-burning stations, except that a "chain reaction" inside a nuclear reactor makes the heat instead.

The reactor uses Uranium rods as fuel, and the heat is generated by nuclear fission: neutrons smash into the nucleus of the uranium atoms, which split roughly in half and release energy in the form of heat.

Carbon dioxide gas or water is pumped through the reactor to take the heat away, this then heats water to make steam. The steam drives turbines which drive generators and produces electricity.

3. *Radiant energy*

Radiant energy is the energy of electromagnetic waves. Radiant energy is sometimes used to refer to the electromagnetic waves themselves, rather than their energy (a property of the waves), Because electromagnetic (EM) radiation can be considered to be a stream of photons, radiant energy can be viewed as the energy carried by these photons. The sun provides radiant energy.

4. *Electrical energy*

Electrical energy is energy stored in a charged particle within an electric field. Electric fields are areas surrounding a charged particle that exert a force on another charged particle within the field. Electrical energy is a type of potential energy, or energy stored in an object due to the position of the object. In the case of electrical energy, the object is the charged particle, and the position is within the electric field.

Another way of looking at electrical energy is electrical potential, which is measured in volts. Electrical energy is used to move charges through wires to create current, or electricity. Electricity is used to do work in our homes.

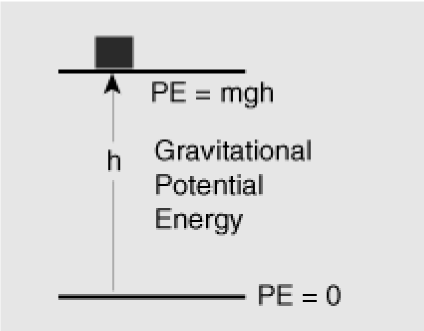
Lightning involves the transformation of electrical energy into thermal energy and light energy.

5. *Chemical energy*

Chemical energy is energy that has been stored in chemical form, such as in fuels or sugars or as energy stored in car batteries. Gasoline is a chemical that combines with oxygen and a little heat to release the great amount of thermal energy stored in the chemical structure of the gasoline. Other such chemicals include sucrose, methane, ethanol, and methanol.

9.50 POTENTIAL AND KINETIC ENERGY

9.51 Potential Energy



Gravitational potential energy is the energy stored in an object as the result of its vertical position or height. The energy is stored as the result of the gravitational attraction of the Earth for the object. The gravitational potential energy dependent on two variables. They are the mass of the object and the height to which it is raised. There is a direct relation between gravitational potential energy and the mass of an object. More massive objects have greater gravitational potential energy. There is also a direct relation between gravitational potential energy and the height of the object. The higher the object is elevated, the greater the gravitational potential energy it have. These relationships are expressed by the following equation:

PE_{grav} = mass x pull of gravity (*g*) x height

(gravitational field *g* = 10 N/kg on the Earth).

Examples

1. What is the potential energy of a 6 kg mass 4 m above the ground?
Potential energy = 6 x 10 x 4 = 240 J

2. A 45 kg girl jumps from a 0.4 m high stool onto the ground. How much potential energy does she lose?
Potential energy lost = 45 x 10 x 0.4 = 180 J

3. A man slides a 25 kg box up a ramp onto the back of a lorry. If the ramp is 2 m long and the back of the lorry is 0.8 m above the ground how much potential energy does the box gain?
All that matters is the VERTICAL height moved and not the length of the ramp. So:
Potential energy gained = 25 x 10 x 0.8 = 200 J

9.52 Kinetic Energy

Kinetic energy is energy of motion or because it is moving. The kinetic energy of a mass *m* is given by

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

where E_k is the kinetic energy

m = mass of object

v = speed of object

Kinetic energy is a scalar quantity; it does not have a direction. Unlike velocity, acceleration, force, and momentum, the kinetic energy of an object is completely described by magnitude alone. Like work and potential energy, the standard metric unit of measurement for kinetic energy is the Joule. As might be implied by the above equation, 1 Joule is equivalent to 1 kgm^2/s^2.

Examples

1. What is the kinetic energy of a 500 kg horse running at 15 m/s?
Kinetic energy = ½ x 500 x 15^2 = 56 250 J

2. What is the kinetic energy of a one milligram raindrop falling at 0.5 mm/s.
Kinetic energy = ½ x 0.000001 x 0.0005^2 = 0.000 000 000 000 125 J = 1.25 x 10^{-13} J
Notice here that the mass must be in kg and the velocity in m/s.

9.60 HOOKE'S LAW

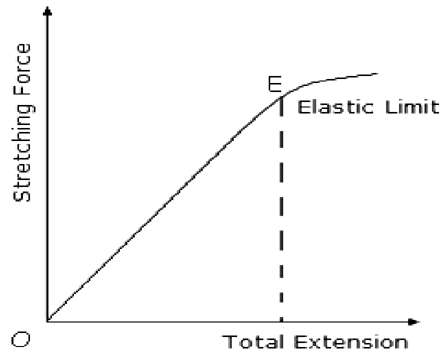
Elasticity is the ability of a material to return to its original shape/length when the stretching force or the compressing force is no longer acting on it. Hooke's law states that the force applied is proportional to the extension of spring provided the elastic limit is not exceeded.

This means that doubling the force doubles the extension, trebling the force trebles the extension and so on. Using the sign for proportionality we can write **Hooke's Law** as

$$F = -kx$$

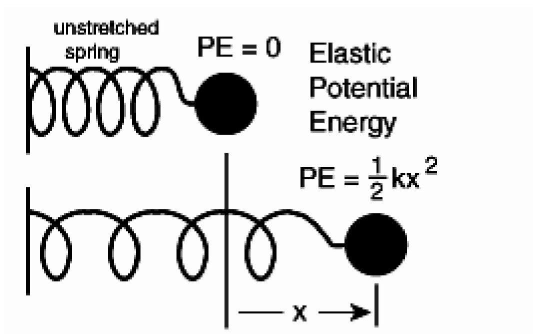
where F = Force applied on spring (N)
x = Extension on the spring (m)
k = spring constant (N/m)

The graph of the figure on the right is for a spring stretched beyond its elastic limit. OE is the straight line passing through the origin O and its graphical proof that Hooke's Law holds over this range.



Elastic Potential energy is given as the area under the graph in the extension *x*.

E_p (elastic) = $½kx^2$



Examples

Question 1: A spring is stretched by 50 cm and has force constant of 2 N/m. Calculate the Force applied?

Solution: Given: Force constant k = 2 N/m

Extension x = 0.5 m.

The force applied is given by $F = - kx$

$= - 2 N/m \times 0.5 m$

$= - 1 N.$

Question 2: A force of 100 N is stretching a spring by 0.2 m. Calculate the force constant?

Solution: Given: Force F = 100 N,

Extension x = 0.2 m.

The force constant is given by $k = - F/x$

$= - 100/0.2 m$

$= - 500 N/m.$

9.70 SOURCES OF ENERGY

Energy can be generally classified as non-renewable and renewable. Most of the energy used in the world is from non-renewable supplies. Most countries are dependent on ***non-renewable*** energy sources such as fossil fuels (coal and oil) and nuclear power. These sources are called non-renewable because they cannot be renewed or regenerated quickly enough to keep pace with their use. Some sources of energy are renewable or potentially renewable. Examples of renewable energy sources are: solar, geothermal, hydroelectric, biomass, and wind.

9.71 Non- Renewable Sources of Energy

1. Fossil Fuels

1. Coal

Coal is the most abundant fossil fuel in the world. Coal formed slowly over millions of years from the buried remains of ancient swamp plants. During the formation of coal, carbonaceous matter was first compressed into a spongy material called "peat," which is about 90% water. As the peat became more deeply buried, the increased pressure and temperature turned it into coal.

2. Oil

Crude oil or liquid petroleum is a fossil fuel that is refined into many different energy products (e.g., gasoline, diesel fuel, jet fuel, heating oil). Oil forms underground in rock such as *shale*, which is rich in organic materials. After the oil forms, it migrates upward into porous reservoir rock such as sandstone or limestone, where it can become trapped by an overlying impermeable cap rock. Wells are drilled into these oil reservoirs

to remove the gas and oil. Over 70 percent of oil fields are found near tectonic plate boundaries, because the conditions there are conducive to oil formation.

Despite its limited supply, oil is a relatively inexpensive fuel source for most developed countries. It is a preferred fuel source over coal. An equivalent amount of oil produces more kilowatts of energy than coal. It also burns cleaner, producing about 50 percent less sulfur dioxide. However, for Fiji oil is a very expensive fuel.

3. Gas

Natural gas production is often a by-product of oil recovery, as the two commonly share underground reservoirs. Natural gas is a mixture of gases, the most common being *methane* (CH_4). It also contains some *ethane* (C_2H_5), *propane* (C_3H_8), and *butane* (C_4H_{10}). Natural gas is usually not contaminated with sulfur and is therefore the cleanest burning fossil fuel. After recovery, propane and butane are removed from the natural gas and made into *liquefied petroleum gas* (*LPG*).

2. Nuclear Power

Nuclear energy originates from the splitting of uranium atoms in a process called fission. At the power plant, the fission process is used to generate heat for producing steam, which is used by a turbine to generate electricity.

9.72 Renewable Sources of Energy

1. Solar Energy

The solar cells also called photovoltaic (PV) cells, which as the name implies (photo meaning "light" and voltaic meaning "electricity"), convert sunlight directly into electricity. A module is a group of cells connected electrically and packaged into a frame (more commonly known as a solar panel), which can then be grouped into larger solar arrays.

Photovoltaic cells are made of special materials called semiconductors such as silicon, which is currently used most commonly. Basically, when light strikes the cell, a certain portion of it is absorbed within the semiconductor material. This means that the energy of the absorbed light is transferred to the semiconductor. The energy knocks electrons loose, allowing them to flow freely.

PV cells also all have one or more electric field that acts to force electrons freed by light absorption to flow in a certain direction. This flow of electrons is a current, and by placing metal contacts on the top and bottom of the PV cell, we can draw that current off for external use. This current, together with the cell's

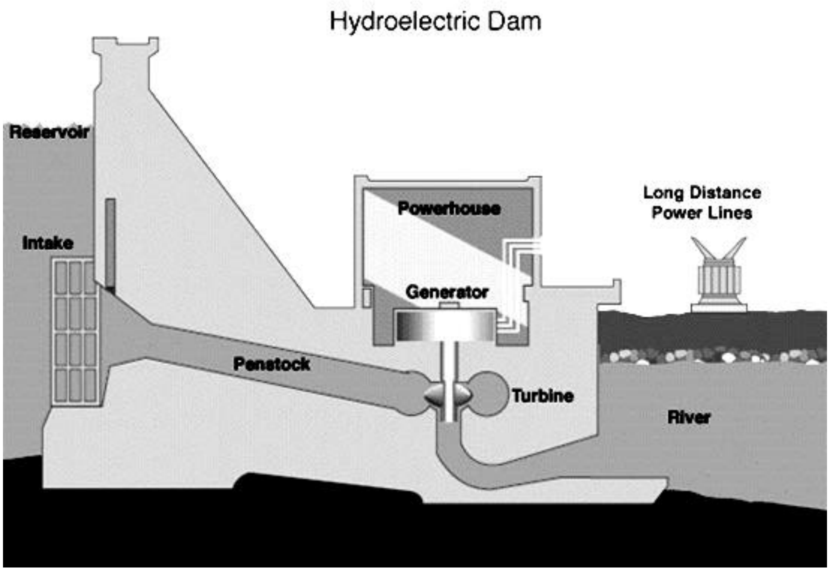
voltage (which is a result of its built-in electric field or fields), defines the power (or wattage) that the solar cell can produce.

Energy Transformation: Sunlight hits the PV panel and the panel transforms the light energy into electrical energy. The electrical energy (electricity) passes through the wire circuit to light up the bulb.

2. Hydropower

The dam stores lots of water behind it in the reservoir. Near the bottom of the dam wall there is the water intake. Gravity causes it to fall through the penstock inside the dam. At the end of the penstock there is a turbine propeller, which is turned by the moving water. The shaft from the turbine goes up into the generator, which produces the power. Power lines are connected to the generator that carries electricity to your home and mine. The water continues past the propeller through the tailrace into the river past the dam.

Energy Transformation: The potential energy in the head of water is converted into kinetic energy in the turbine which converts the kinetic energy into electrical energy.



Source: http://www.alternative-energy-news.info/technology/hydro/

3. Wind Energy

Wind power is produced by using wind generators to harness the kinetic energy of wind. Wind turbines operate on a simple principle. The energy in the wind turns two or three propeller-like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity.

Wind turbines are mounted on a tower to capture the most energy. At 30 meters or more above ground, they can take advantage of faster and less turbulent wind.

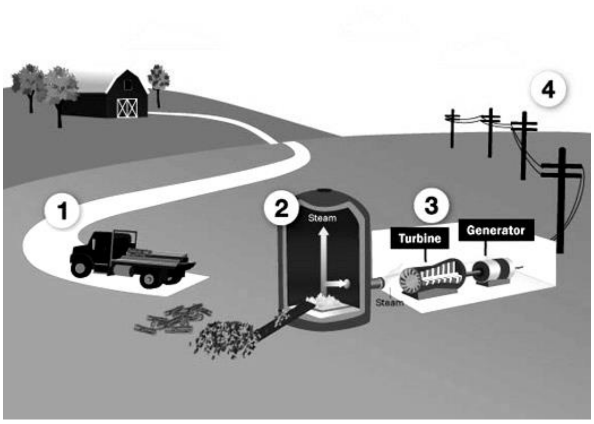
Wind turbines can be used to produce electricity for a single home or building, or they can be connected to an electricity grid for more widespread electricity distribution.

Energy Transformation: Windmills convert the kinetic energy of wind movement into mechanical power that moves the parts of a windmill, for example, to pump water, a generator is part of the machine that converts mechanical energy into electrical energy.

Source: http://www.alternative-energy-news.info/south-korea-off-shore-wind-farm/

4. Biomass

Biomass is any organic matter like trees, plants, or animal waste that can be used as an energy source. Energy comes from the sun through a process called photosynthesis, and is released when biomass is burned or decomposes.



Source: http://www.greenmountain.com/resources/enviro-kids/renewable-energy-101/biomass-energy

Leftover wood and crop waste from factories and farms can be burned to produce electricity.

1 Wood scraps, sawdust and crop waste are collected from farms or manufacturing plants
2 The waste is burned to heat water and create steam
3 Steam is sent to a turbine, which spins to power a generator
4 Generator creates electricity and sends to transmission lines

5. Ocean Power

One way to harness the kinetic energy of all that moving ocean water involves building a dam, known as a barrage, on a smaller arm of the bay. Sluice gates along the barrage open when the tides produce an adequate difference in the level of the water on opposite sides of the dam. This allows water to flow across turbines that look just like those used in a traditional hydroelectric power plant. The turbines turn a generator, which produces electricity.

Another way to take advantage of ocean tides is to tap into tidal currents, which run close to the shore at water depths of about 20 to 30 meters. To do this, power companies use turbines resembling those seen on terrestrial wind farms, except they are oriented so that the rotors are underwater. The rotors, each about 20 meters in diameter, are also spaced more closely than those on wind farms. As tidal currents surge past the turbines, the rotors spin, turning a generator.

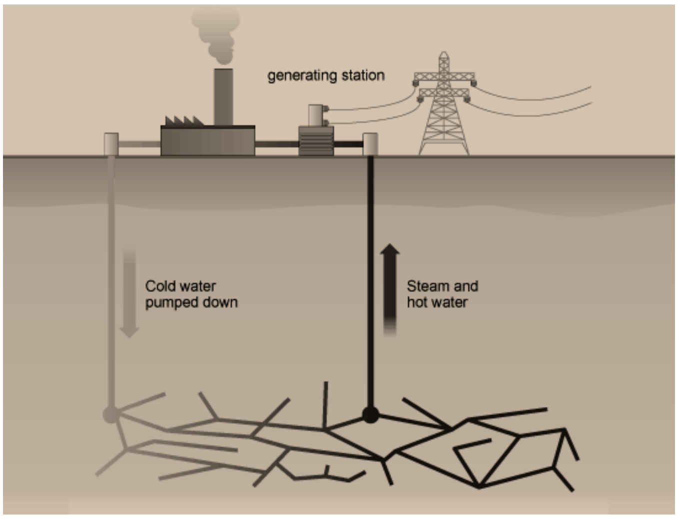
Source:http://energyinformative.org/wave-energy/

This device looks like a sea snake in the water. It consists of a series of joints that generate power as the waves move them up and down through hydraulic rams and a generator. An underwater cable moves the electricity to the shore.

6. Geothermal

Deep inside the Earth lies hot water and steam that can be used to heat our homes and businesses and generate electricity cleanly and efficiently.

The heat inside the Earth is intense enough to melt rocks. Those molten rocks are known as magma. Because magma is less dense than the rocks surrounding it, it rises to the surface. Sometimes magma escapes through cracks in the Earth's crust, erupting out of volcanoes as part of lava. But most of the time magma stays beneath the surface, heating surrounding rocks and the water that has become trapped within those rocks. Sometimes that water escapes through cracks in the Earth to form pools of hot water (hot springs) or bursts of hot water and steam (geysers). The rest of the heated water remains in pools under the Earth's surface, called geothermal reservoirs.



Source: http://www.electrical-res.com/geothermal-energy-electricity/

9.80 EXERCISES

1. The work done in moving a block across a rough surface and the heat energy gained by the block can both be measured in

   A. Watts B. Newtons

   C. degrees D. Joules

2. Which of the following has the greatest gravitational energy with respect to the floor?

   A. 6 kg mass placed 5 m above the floor.

   B. 10 kg mass placed 2 m above the floor.

   C. 2 kg mass placed 10 m above the floor.

   D. 1000 kg mass resting on the floor

3. A man lifts a 10 kg parcel to a height of 80cm above the ground at a constant speed of 1 m/s.

   (a) The work he does on the parcel is

   A. 800 J B. 80 J C. 8000 J D. 0 J

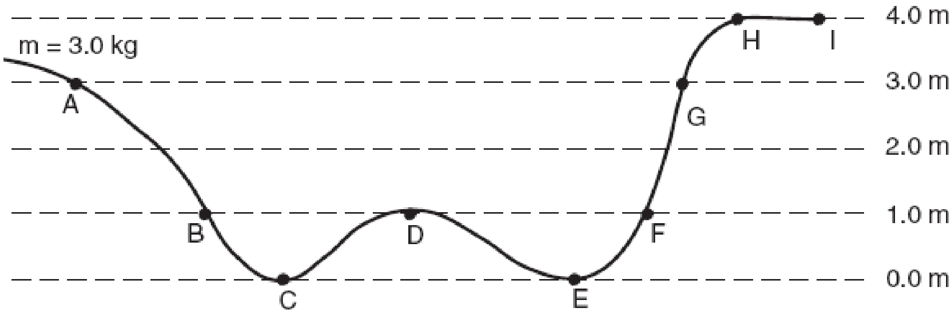
   (b) The man now holds the parcel at the same height above the ground. The work he does now on the parcel is

   A. 800 J B 80 J C. 8000 J D. 0 J

4. A ball has a mass of 2 kg. It is dropped from a cliff and strikes the ground below at 10 m/s.

   i. What is the kinetic energy as it is about to strike the ground?
   ii. What was its potential energy before it was dropped?
   iii. Determine the height from which it was dropped.

5. A 3.0 kg object is placed on a frictionless track at point *A* and released from rest.



   i. Calculate the gravitational potential energy of the object at point *A*.
   ii. Calculate the kinetic energy of the object at point *B*.
   iii. Which letter represents the farthest point on the track that the object will reach?

6. A spring which has a natural length of 20 cm. When a 6 N weight is hung on it, the spring stretches to 32 cm.

   (a) The spring constant is:

   A. 0.5 N/m B. 5 N/m C. 50 N/m D. 250 N/m

   (b) If the 6 N weight is replaced by a 5 N weight, what is the new length?

   A. 10 cm B. 24 cm C. 28 cm D. 30 cm

7. A spring of length 10cm stretches to 22 cm when a force of 4 N is applied to it. If it obeys Hooke's law, its total length when a force of 6 N is applied is

   A. 28 cm B. 42 cm C. 50 cm D. 56 cm

9. A spring is compressed a distance of 14 cm if a force of 35 N acts on it. Calculate:
   i) the spring constant in (N/m).
   ii) the energy stored in the spring if it is compressed to 14cm.

CHAPTER 10: FLUID STATICS

9.0 INTRODUCTION

Fluid statics is the science and technology of fluids at rest and their effects on boundaries such as solid surfaces or interfaces with other fluids.

9.10 DENSITY (ρ)

Density is the mass of a unit volume of a substance. It is a scalar quantity and its S.I units is kilogram per cubic meter (kg/m^3). Can also be written as grams per cubic centimeter (g/cm^3).

$$\text{Density} = \frac{\text{Mass (kg)}}{\text{Volume (m}^3)}$$

Example 1: If a piece of glass has a mass of 50 g and a volume of 20 cm^3, what is its density?

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$= \frac{50\ \text{g}}{20\ \text{cm}^3}$$

$$= 2.5\ \text{gcm}^{-3}$$

Example 2: Density of copper is 8.9 g/cm^3.Find the mass of copper that has a volume equal to 10 cm^3.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$8.9\ \text{g/cm}^3 = \frac{\text{mass}}{10\text{cm}^3}$$

$$\text{Mass} = 8.9\ \text{g/cm}^3 \times 10\ \text{cm}^3$$

$$\text{Mass} = 89\ \text{g}$$

9.20 RELATIVE DENSITY

Relative density has no units; it is just a number which is defined as a ratio of density or ratio of masses.

$$\text{Relative density} = \frac{\text{density of the substance}}{\text{density of water}}$$

or

$$\text{Relative density} = \frac{\text{mass of a certain volume of substance}}{\text{mass of a equal volume of water}}$$

It means density of substance compared to density of water. Density of water is 1.0 g/cm^3 or 1000 kg/m^3.

Example

If the relative density of copper is 8.9, its density in

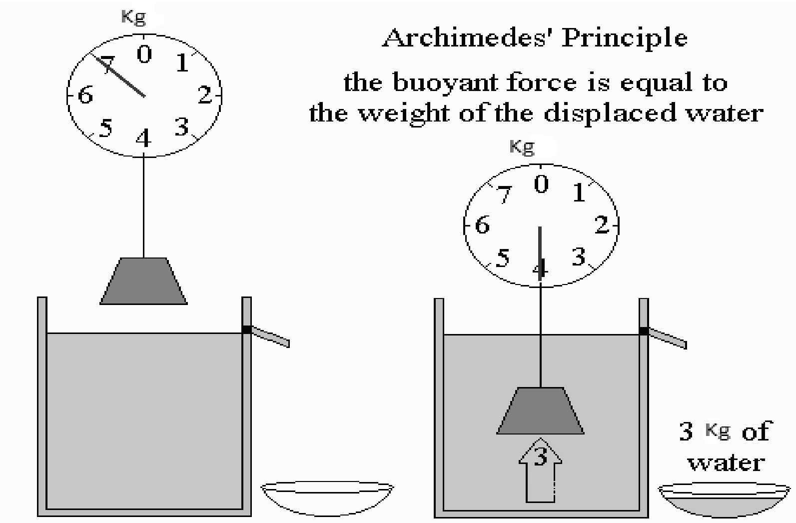
(i) g/cm^3 is 8.9 g/cm^3

(ii) kg/m^3 is 8.9 x 1000

= 8900 kg/m^3

9.30 ARCHIMEDES'S PRINCIPLE

"When an object is partially or completely immersed in a fluid, the upthrust on the object is equal to the weight of the fluid displaced."



Upthrust = weight of fluid displaced = Apparent loss of weight of object

Example

An object weighs 30 N in air and 20 N when immersed in water. The density of water is 1000 kg/m^3. Find:

(i) the upthrust applied by water.
(ii) the weight of water displaced.
(iii) the mass of water displaced.
(iv) the volume of water displaced.

Solution

(i) Upthrust = 30 - 20 = 10 N

(ii) Weight of water displaced = upthrust = 10 N

(iii) $W = mg$

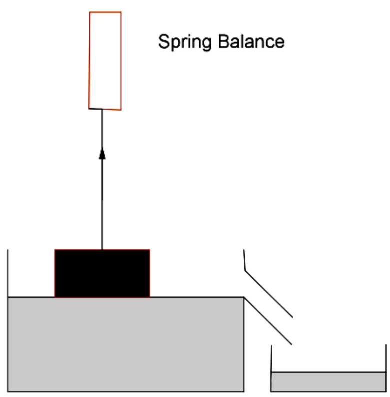
$$m = \frac{W}{g} = \frac{10}{10} = 1\text{kg}$$

(iv) $\rho = \frac{m}{V}$

$$V = \frac{m}{\rho} = \frac{1}{1000} = 0.001\ \text{m}^3$$

9.31 Principle Of Floatation

"A floating body displaces its own weight of the fluid in which it floats".



For an object to float, the net vertical force acting on the object must be zero.

$$\therefore \quad \text{upthrust} = \text{weight of the object}$$

From Archimedes Principle, it follows that the weight of fluid displaced is equal to the upthrust. This means that the displaced liquid must be equal to the weight of the object.

Upthrust	=	weight of object	=	weight of fluid displaced

Example

An object which weighs 30 N in air floats in water.
Calculate:

(i) the upthrust acting on the object.
(ii) the weight of water displaced.
(iii) the volume of water displaced.

Solution

(i) Upthrust = 30 N

(ii) Weight of water displaced = upthrust = 30 N

(iii) Mass of water displaced = $\frac{30}{10}$ = 3 kg

$$\rho = \frac{m}{V}$$

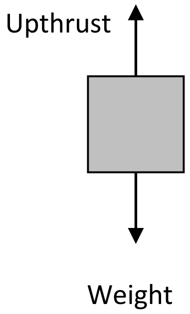
$$V = \frac{m}{\rho} = \frac{3}{1000} = 0.003 \text{ m}^3$$

9.40 FLOATING AND SINKING

Fluids provide partial support to any object placed in it. Any object when placed in a fluid would seem to weigh less. According to Archimedes there is an upwards force on the object that comes from the liquid itself and makes the object appear to lose weight.

This upwards force is called Upthrust. It is caused by the pressure difference between two depths in a liquid.

There are two forces acting on an object when placed in a fluid:

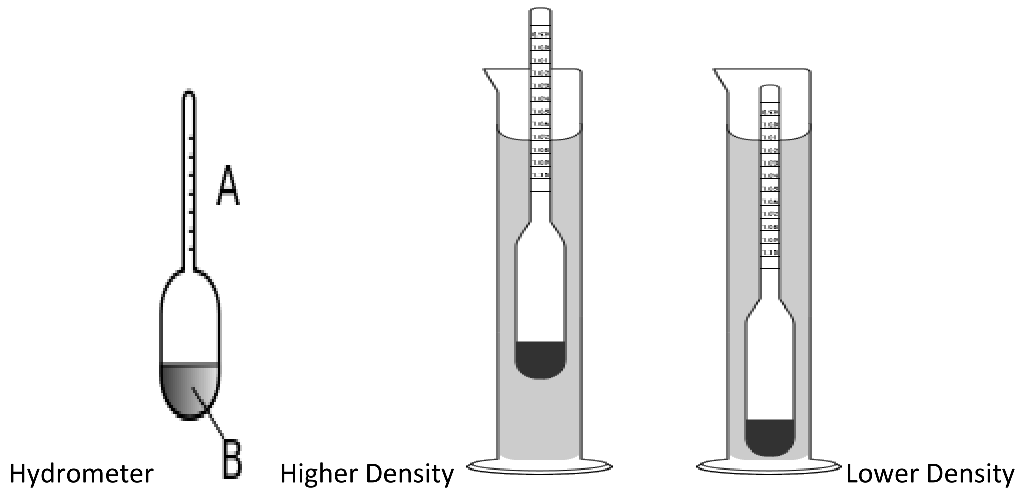


The movement of the object in a fluid depends on the net force arising from these two forces.

Three Cases

1. Upthrust > weight $\Rightarrow$ Object will rise upwards.
2. Upthrust < weight $\Rightarrow$ Object will sink.
3. Upthrust = weight $\Rightarrow$ Object will float.

9.50 HYDROMETER



A **hydrometer** is an instrument used to measure the relative density of liquids; that is, the ratio of the density of the liquid to the density of water.

A hydrometer is usually made of glass and consists of a cylindrical stem and a bulb weighted with mercury or lead shot to make it float upright. The liquid to be tested is poured into a tall container, often a graduated cylinder, and the hydrometer is gently lowered into the liquid until it floats freely. The point at which the surface of the liquid touches the stem of the hydrometer is noted. Hydrometers usually contain a scale inside the stem, so that the specific gravity can be read directly.

Operation of the hydrometer is based on Archimedes' principle that a solid suspended in a fluid will be buoyed up by a force equal to the weight of the fluid displaced by the submerged part of the suspended solid. Thus, the lower the density of the substance, the farther the hydrometer will sink.

9.60 PRESSURE

Pressure is the force acting on unit area. The S.I unit for pressure is Newton per square meter (N/m^2 or N/m^2). Special name given for these units is Pascal (Pa).

$$1 \text{ Pa} = 1 \text{ Nm}^{-2}$$

Therefore, 1 Pascal is the pressure acting when a force of 1 N is spread over an area of 1 m^2 .

$$\textbf{Pressure} = \frac{\textbf{Force(N)}}{\textbf{Area}(\textbf{m}^2)}$$

Example1:

If a force of 30 N acts over an area of 0.5 m^2, what is the pressure on this area?

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

$$= \frac{30\text{N}}{0.5\text{m}^2}$$

$$= 60 \text{ Nm}^{-2} \text{ or } 60 \text{ Pa.}$$

Example 2:

If a pressure of 100 kPa acts on an area of 2 m^2, what is the total force on this area?

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

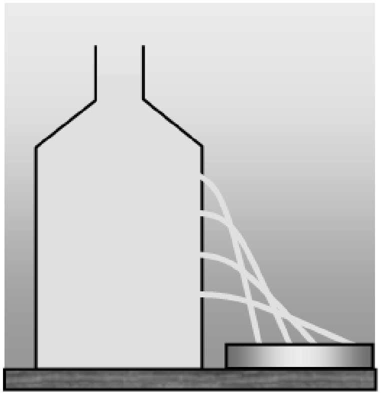
$$100 \times 10^3 \text{ Pa} = \frac{\text{F}}{2 \text{ m}^2}$$

$$\text{Force} = (100 \times 10^3 \text{ Pa}) \times (2 \text{ m}^2)$$

$$\text{Force} = 200{,}000 \text{ N}$$

9.61 Pressure in Liquid

1. *The Pressure In A Liquids Increases With Depth*
Get a can or a large plastic bottle with a series of holes drilled in the side one above the other. Cover the holes with your fingers or a piece of sticky tape and then fill the container with water.
Now remove the tape. The water gushes out but comes out faster from the holes nearer the bottom where the water is deeper and so the pressure of the water is greater.
Just imagine doing the experiment with a high-density liquid. The pressure would be much greater.



Magnitude of pressure in liquid can be determine by the product of density of the liquid, pull of gravity (10 m/s^2) and depth. Pressure in liquid is the same horizontally.

$$P = \rho gh$$

where P is the pressure

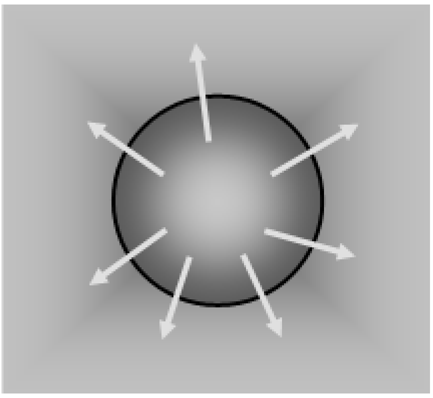
ρ is the density of the liquid

g is the acceleration of gravity

h is the depth of liquid

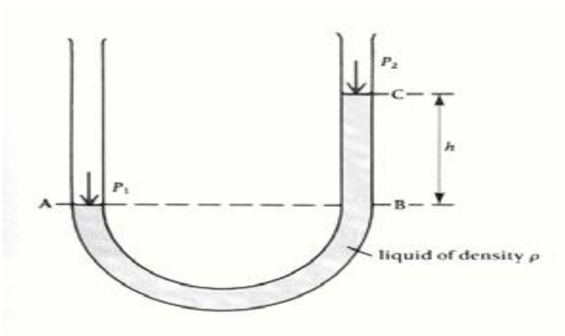
Pressure in liquid increased with depth because the further down you go the greater the weight of liquid above.

2. *The Pressure In Liquids Acts Equally In All Directions*
Take a plastic bag and fill it with water. Make some holes in the bag and then squeeze it quickly. The water squirts out equally fast from all the holes, even the ones near the top of the bag.

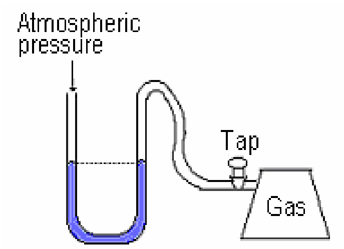


9.62 U – Tube Manometer

A manometer is a device that measures pressure. It's typically called by a more descriptive name, such as a barometer, depending on the particular device. The term "manometer" typically refers to an instrument that measures pressure with a column of liquid. A simple manometer consists of a U-shaped tube that contains a liquid. If the pressure on one surface of the liquid differs from the pressure on the other surface of the liquid, the liquid will move away from the source of greater pressure. Pressure can be calculated by using P = ρ g h, where h is measured from the distance between the levels of the water in the manometer.

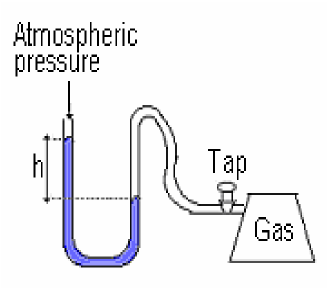


Measuring gas pressure by using manometer



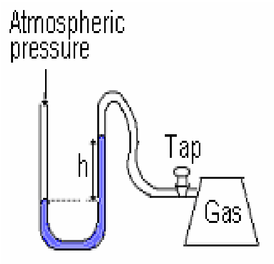
In this case the pressure of the Gas is equal Atmospheric pressure

$$P_{Gas} = P_{atm}$$



The diagram indicate that pressure of Gas is more than Atmospheric pressure

$$P_{Gas} = P_{atm} + h$$

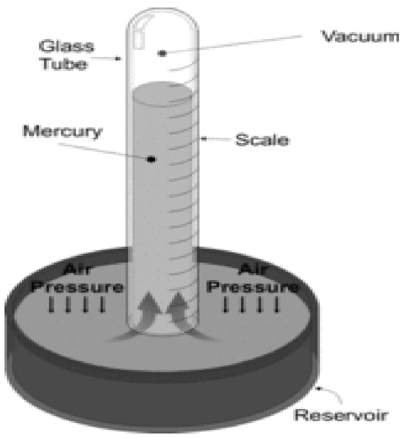


In this third case the pressure of Gas is less than the Atmospheric pressure

$$P_{Gas} = P_{atm} – h$$

9.63 The Mercury Barometer

The classic mercury barometer is typically a glass tube about 1 meter high with one end open and the other end sealed. The tube is filled with mercury. This glass tube sits upside down in a container, called the reservoir, which also contains mercury. The mercury level in the glass tube falls, creating a vacuum at the top.



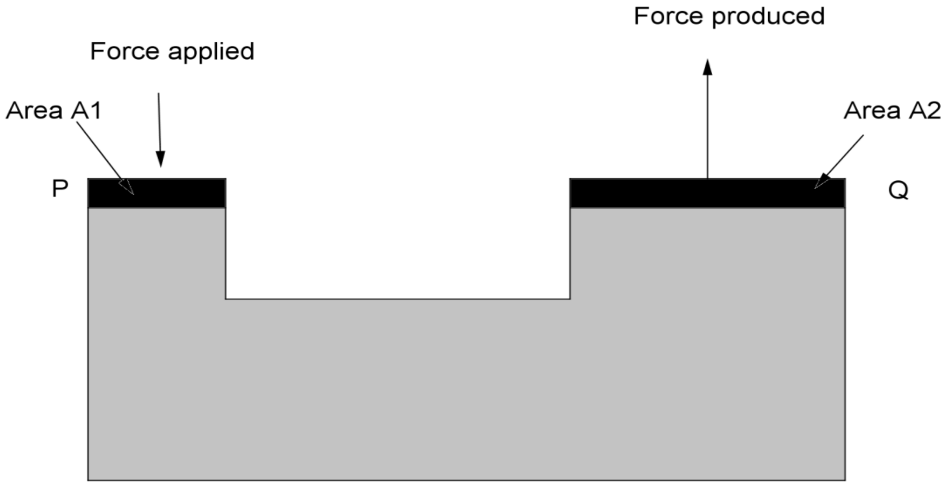
Source: http://weather.about.com/od/weatherinstruments/a/barometers.htm

The barometer works by balancing the weight of mercury in the glass tube against the atmospheric pressure just like a set of scales. If the weight of mercury is less than the atmospheric pressure, the mercury level in the glass tube rises. If the weight of mercury is more than the atmospheric pressure, the mercury level falls.

Atmospheric pressure is basically the weight of air in the atmosphere above the reservoir, so the level of mercury continues to change until the weight of mercury in the glass tube is exactly equal to the weight of air above the reservoir.

9.70 HYDRAULIC LIFT PRINCIPLE

The simplest form of a Hydraulic lift consists of a piston and a cylinder which is filled with a liquid such as oil or water.



When force is applied at P, the pressure produced is:

$$P = \frac{F}{A} = \frac{F_1}{A_1}$$

From Pascal's Principle, it follows that this pressure is transmitted through the liquid and to the piston at Q. Pressure at Q is given by:

$$P = \frac{F}{A} = \frac{F_2}{A_2}$$

Therefore, the force produced at Q is:

$$F_2 = P A_2$$

The area of piston Q, A_2 is much larger than the area of piston P, A_1. This means that a much larger force must be produced at Q. A small force applied at P results in a much larger force being produced at Q.

Pressure at P = Pressure at Q

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

where: F_1 = applied force (N)

A_1 = area of smaller cylinder.

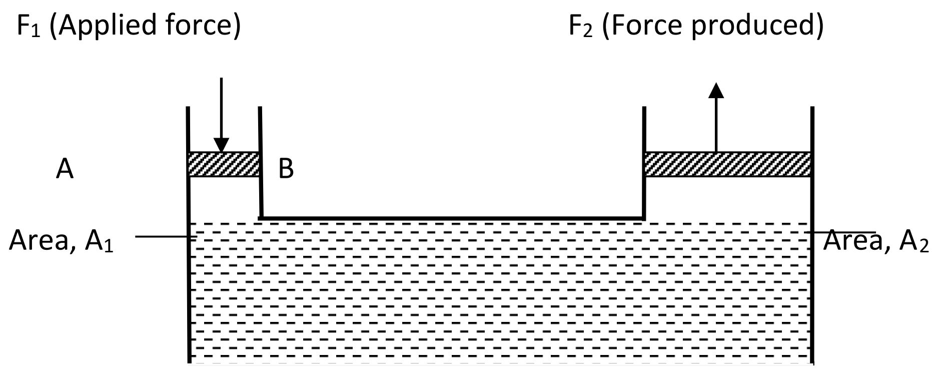
F_2 = force produced (N)

A_2 = area of larger cylinder.

Example

The figure below shows two cylinders connected by a pipe. On each cylinder there is a weightless piston and the space below each piston is full of oil.

The area of piston A is 4 cm^2 and the area of piston B is 1800 cm^2. A 6 kg mass is placed on A:



(i) What is the downward force on A?
(ii) Calculate the pressure on the oil under A.
(iii) Calculate the upward force on B.

Solution

(i) $F = mg$

$= 6 \times 10$

$= 60$ N

(ii) $P = \frac{F}{A}$

$= \frac{60}{0.0004}$

= 150000N

(iii) *F = P x A*

= 150000 x 0.18

` =27000 N

9.80 EXERCISES

1. The density of mercury is 13600 kg/m^3. What is this value in $\mathrm{g/cm^3}$?

2. Find the mass of water which will fit in a large tank measuring 2 m x 1 m x 20 cm. Density of water is 1000 kg/m^3 or 1.0 $\mathrm{g/cm^3}$.

3. Find the volume of a lump of softwood whose mass is 120 g. Density of softwood is 0.6 $\mathrm{gcm^{-3}}$ or 600 $\mathrm{kgm^{-3}}$.

4. What are the relative densities of:

   (a) Cork whose density is 2.5 $\mathrm{gcm^{-3}}$.
   (b) Petrol with density of 700 $\mathrm{kgm^{-3}}$.

5. A block of density 2400 kg/m^3 has a volume of 0.20 m^3. What is
   (a) Its mass
   (b) Its weight
   (c) Its apparent weight when completely immerse in a liquid of density 800 kg/m^3.

6. Find the upward force in Newton when each of these is under water (density of 1 $\mathrm{g/cm^3}$).
   (a) A lump of iron of volume 2000 cm^3
   (b) A glass stopper of volume 50 cm^3

7. What is the pressure on a surface when a force of 50N acts on area of
   (i) 4.0 m^2
   (ii) 80 m^2
   (iii) 0.06 m^2

8. A block of concrete weighs 900 N and its base is a square of side 3.0 m. What pressure does the block exert on the ground?

9. In a hydraulic press a force of 20 N is applied to a piston of area 0.20 m^2. The area of other piston is 3.0 m^2. What is
   (a) the pressure transmitted through the liquid.
   (b) the force on the other piston.

10. Why must a liquid and not a gas be used as the fluid in the hydraulic machine and what other properties of a liquid do hydraulic machine depend on?

11. What is the pressure 100 m below the surface of sea water of density 1150 kg/m^3?

CHAPTER 11: HEAT ENERGY

11.0 INTRODUCTION

What makes the water hot or cold?

Heat energy content in a body makes it hotter or colder. Greater the heat energy content, hotter will be the body. Heat is a form of energy. This form of energy is very essential for the survival of life in any form. It plays a prominent role in our daily life. For example, we need heat energy for cooking, heating water, ironing, etc.

Weather conditions are totally decided by the heat energy changes. For example, occurrence of seasons, rain, wind, etc. is the result of heat energy changes in nature.

11.10 HEAT AND TEMPERATURE

In everyday speech, heat and temperature go hand in hand: the hotter something is the greater its temperature.

11.11 Heat

Heat energy is a measure of the sum of kinetic and potential energy in all the molecules or atoms in an object. The kinetic energy is from the random motion of the particles, and the potential energy originates from the repulsive electromagnetic force between the electrons of atoms that are close to each other.

11.12 Temperature

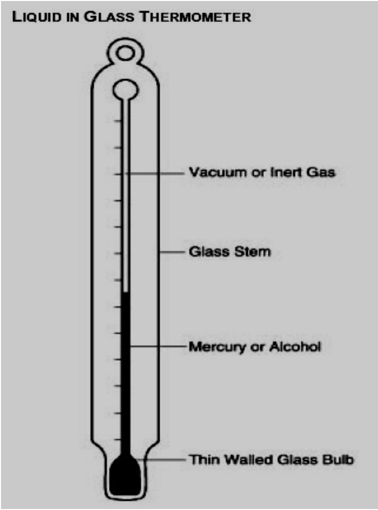
Temperature is a physical quantity which measures the degree of hotness of an object. It is a measure of the average kinetic energy which each molecule of an object possesses.

11.14 Differences between Heat Energy and Temperature

Heat Energy	Temperature
A form of Energy	Degree of hotness of an object.
Unit: Joule (J)	Unit: Kelvin (K)/ Degree Celsius (C)
Sum of the kinetic energy and potential energy of the particles.	Average kinetic energy of the particles.
Derived quantity	Base quantity

11.15 Thermometer

A thermometer is a device that measures temperature. It is placed in contact with an object and allowed to come to thermal equilibrium with that object. The operation of a thermometer depends on some property, such as volume, those changes with temperature. Many house-hold thermometers contain colored alcohol that expands when heated and rises in a narrow tube. The hotter the thermometer, the more the alcohol expands and the higher it rises. Mercury is another liquid commonly used in thermometers.



A thermometer has two important elements: the temperature sensor (e.g. the bulb on a mercury-in-glass thermometer) in which some physical change occurs with temperature, plus some means of converting this physical change into a numerical value (e.g. the visible scale that is marked on a mercury-in-glass thermometer).

11.16 Liquid in Glass Thermometer

Liquid in glass thermometer works on the principle that liquid expands as the temperature increases and contracts as the temperature decreases. The most commonly used liquids in such thermometers are Mercury and Alcohol.

Temperature dependant property	Type of thermometer	Temperature range (Typical)
1. Volume expansion/ contraction of a liquid	Mercury in glass Alcohol in glass (Clinical)	-10 ºC – 110 ºC -60 ºC – 60 ºC 35 ºC – 42 ºC
2. Volume variation at constant pressure	Constant pressure gas thermometer.	Approximately 15K to 1300K
3. Pressure variation at constant volume..	Constant volume gas thermometer	Approximately 15K to 1300K
4. Thermoelectric effect	Thermocouple Thermopile	100 ºC – 700 ºC
5. Resistance variation	Platinum thermometer	-200 ºC –1200 ºC

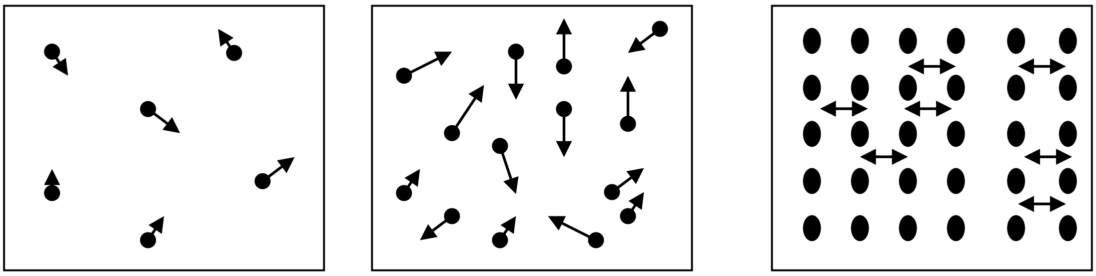
11.20 THE KINETIC THEORY OF MATTER

The basic assumptions of kinetic theory:

- Matters are made up of particle and these particles are in constant motion.
- In solid state the motion is mainly that of vibration about fixed point.
- Liquid state: motion is mainly that of rotation and translation.

- Gaseous state: motion is mainly that of translation and some rotation. Motion increases as temperature increases.
- Diameters of the particles are negligible compared to inter-particle distances. Implies that matter has lots of empty spaces.

GASEOUS STATE LIQUID STATE SOLID STATE



- Particles in liquid and gaseous state are in constant random motion and collide with each other very frequently. Fast moving particles also collide with the walls of the container they occupy. This accounts for the presence of pressure which is constantly exerted by the liquid or gas.
- Inter particle collision are elastic. There will be no loss in energy and momentum during collision. Both kinetic energy and momentum are conserved.

11.21 The Effect of Heat on Matter.

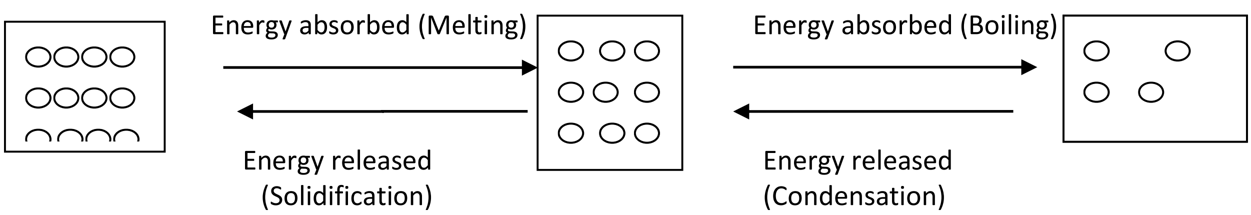
When heat is added to a body, various things can result. It can expand in volume, increase in temperature and also change its state.

Expansion: When heat is added to a solid, the particles gain energy and vibrate more vigorously about their fixed positions, forcing each other further apart. As a result expansion takes place. Similarly, the particles in a liquid or gas gain energy and are forced further apart. The degree of expansion depends on the substance.

Increase in Temperature: For a given rise in temperature a liquid will expand more than a solid. Gases expand enormously on heating, causing a possible explosion if the gas is in a confined space.

Changes in State

Solid Liquid Gas



When a substance is heated the speed of the particles increase as do their kinetic energy and the temperature rises. When a substance is cooled the speed of the particles decrease and so do their kinetic energies and the temperature drops. If the substance is cooled further the motion of the particles continues to slow down and their vibrations become less and less. Eventually a temperature can be reached at which point the atoms and molecules in the substance are at their lowest energy state and their movement virtually ceases. This is reached at a temperature of -273 °C and is called **absolute zero**. This is the lowest possible temperature because the atoms and molecules are at their lowest energy state and therefore there is no energy for transfer.

11.30 FORMS OF HEAT TRANSFER

Heat energy can be transferred in three ways:

11.31 Conduction

Conduction is the transfer of energy from one atom to another atom. The atoms in a substance are always vibrating. When heat is applied to a substance the heat energy is given to the atoms and they vibrate and move faster and so their kinetic energy increases. The vibrating atoms bump into neighbouring atoms and pass on their kinetic energy. These atoms then pass on their kinetic energy to atoms close to them and so on. In this way the heat energy moves through the substance.

Conduction takes place in solids, liquids and gases, but works best in solids as their atoms are located closer together. Metals are the best solids for conducting heat.

- *Bimetallic Strip*

The fact that different substances can expand by different amounts is used in some heat detectors in fire alarm circuits, or as a switch in an electrical heating device. A bimetallic strip is used which is made of two metals fixed together. When the metals expand on heating, one expands more than the other causing the bar to curve. The curved bar touches on electric contact and sets off the alarm. This can also be used to break and make electrical contact as the temperature rises and falls in ovens, heater etc.

11.32 Convection

Convection is the movement of heat in liquids and gases. The particles in liquids and gases are not tightly packed together and so free to move around. When the particles in a liquid or gas with a lot of heat energy move to take the place of the particles with less heat energy convection is said to take place and the heat energy is transferred from the hot areas to the cold areas.
When liquids and gases are heated their atoms gain kinetic energy and move faster. As a result the particles move further apart and so take up more volume. As more volume is taken up the

density (mass per unit volume) decreases i.e. it becomes lighter in weight. Thus the area of hotter less dense liquid or gas will rise into the area of colder denser liquid or gas. The denser colder liquid or gas will then sink into the warm areas till it is warm enough to rise and so convection currents are set up and heat is transferred.

11.33 Radiation

Radiation is the transfer of heat energy by electromagnetic radiation and specifically by infra red radiation. All objects whether hot or cold radiate heat energy (infra red radiations). The hotter the object the more heat energy it radiates. All objects also receive radiation and the exchange of radiant energy is a continuous process. Therefore a body at constant temperature is receiving and radiating energy at the same rate.

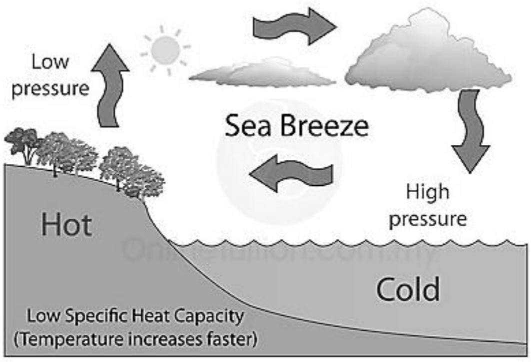
Infra red radiation is an electromagnetic radiation and so can travel through a vacuum, thus radiation unlike conduction and convection does not require particles for its propagation. It is for this reason we can receive heat energy from the sun.

11.40 LAND AND SEA BREEZE

Land and sea breezes are basically caused by differential heating of the land and sea during the day and night, creating differences in local air pressure, thus inducing winds to blow in different directions.

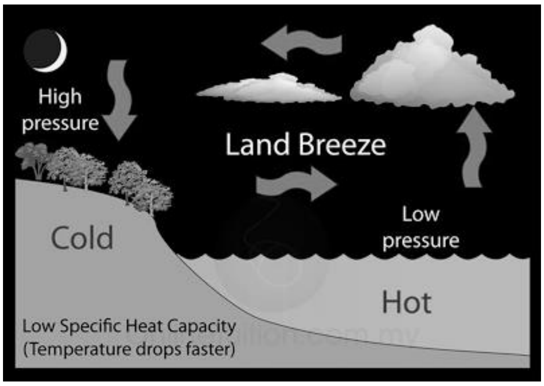
11.41 Sea Breeze

During the day when the sun heats up the earth's surface, the land heats up much faster than the sea. Warm air above the land expands and rises. This creates a region of local low pressure. A sea breeze on the other hand remains comparatively cool and is a region of high pressure. A sea breeze thus blows in from the sea to the land. This is gentle breeze, best experienced along coastal districts in the tropics.



11.42 Land Breeze

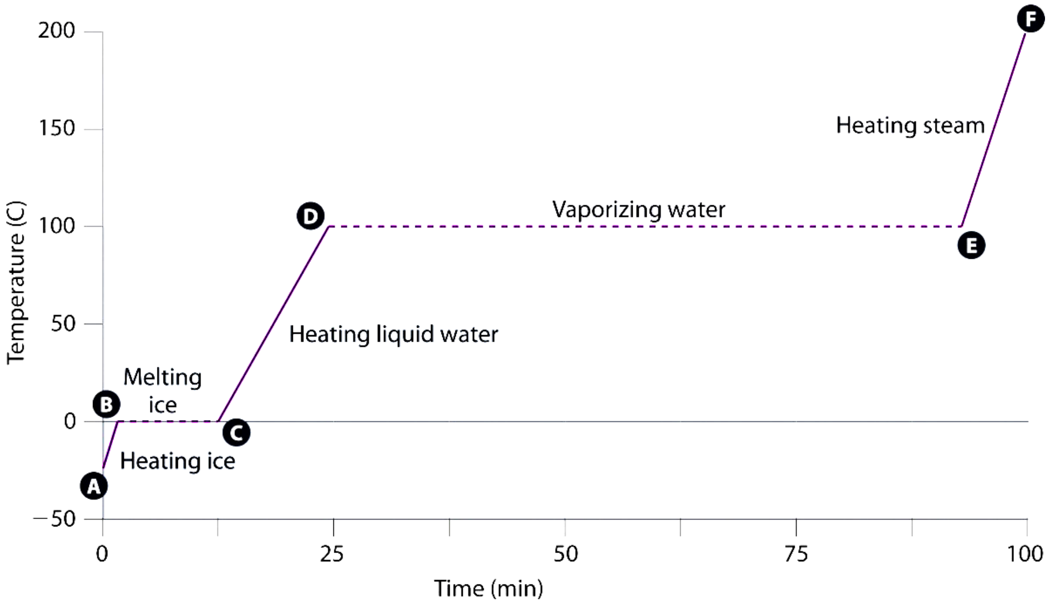
At night the reverse takes place as the land cools down much faster than the sea the cooler and denser air on the land creates a region of local high pressure. The sea on the other hand, conserves its heat and is relatively warmer than the land. The air over the sea expands and rises creating a region of local low pressure. A land breeze thus blows out from the land to the sea. Land has lower heat capacity than sea water. Therefore, in day time, the



temperature of the land increases faster than the sea. Hot air (lower density) above the land rises. Cooler air from the sea flows towards land and hence produces sea breeze.

11.50 HEATING CURVES

"A Heating Curve for Water" shows a heating curve, a plot of temperature versus heating time, for a sample of water. The slope of the line depends on both the mass of the ice and the specific heat (c) of ice, which is the number of joules required to raise the temperature of 1 kg of ice by 1 °C.



http://2012books.lardbucket.org/books/principles-of-general-chemistry-v1.0/s15-05-changes-of-state.html

- *A–B: heating solid ice;* As the temperature of the ice increases, the water molecules in the ice crystal absorb more and more energy and vibrate more vigorously. At the melting point, they have enough kinetic energy to overcome attractive forces and move with respect to one another.
- *B–C: melting ice;* As more heat is added, the temperature of the system does *not* increase further but remains constant at 0 °C until all the ice has melted.
- *C–D: heating liquid water;* Once all the ice has been converted to liquid water, the temperature of the water again begins to increase. Now, however, the temperature increases more slowly than before because the specific heat capacity of water is *greater* than that of ice. When the temperature of the water reaches 100°C, the water begins to boil.
- *D–E: vaporizing water;* Here, the temperature remains constant at 100 °C until all the water has been converted to steam.

- *E–F: heating steam*; At this point, the temperature again begins to rise, but at a *faster* rate than seen in the other phases because the heat capacity of steam is *less* than that of ice or water.

Note

Thus *the temperature of a system does not change during a phase change*.

11.60 SPECIFIC HEAT CAPACITY

The amount of heat that must be supplied to increase the temperature by 1 °C for a mass of 1 kg of the substance

Specific heat capacity, c SI unit: = J/ kg°c^{1}

$C = \frac{Q}{m\Delta T}$ or $Q = mc\Delta T$

Where Q = heat absorbed / released, unit J

m = mass of the substance, unit kg

ΔT = temperature difference, unit °C

Note: negative sign means heat lost and positive sign means heat energy gained

Example

What does specific heat of aluminium 900 J /kg°C mean?
It means 900 J of heat needs to be supplied to 1 kg of aluminium to produce a 1 °C temperature increase.

What does specific heat of water 4 200 J /kg°C^{1} mean?
4 200 J of heat needs to be supplied to 1 kg of water to produce a 1 °C temperature increase.

11.61 The Physical Meaning Of Specific Heat Capacity

When two objects of equal mass are heated at equal rates, the object with the smaller specific heat capacity will have a faster temperature increase. When two objects of equal mass are left to cool down, the temperature of the object with smaller heat capacity will drop faster.
A substance with a small value of specific heat capacity heats up and cools at a faster rate.
For example, metal like iron, steel, copper and aluminium is used as pots and pans because they can be quickly heated up when there is only small heat absorption.

A substance with a high value of specific heat capacity heats up and cools at slower rate. It requires more heat to raise its temperature by a specific amount. For example, water acts a heat reservoir as it can absorb a great amount of heat before it boils. Water is used as a cooling agent in a car radiator.

11.70 SPECIFIC LATENT HEAT Unit: J kg^{-1}

The amount of heat required to change the phase of 1 kg of the substance at a constant temperature.

$$Q = mL$$

where Q = heat absorbed or released by the substance

m = mass of the substance

11.71 Specific latent heat of fusion (L_f)

The amount of heat required to change 1 kg of the substance from solid to liquid phase without a change in temperature.

11.72 Specific latent heat of vaporization (L_v)

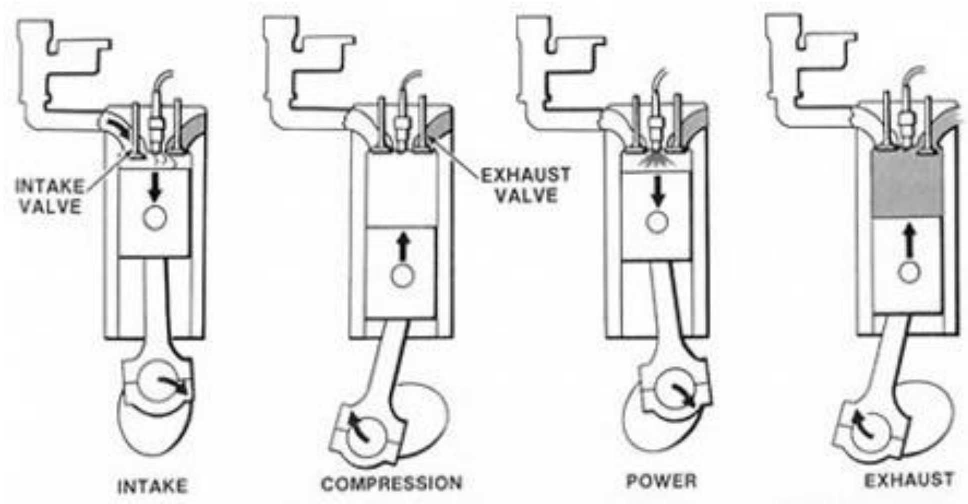
The amount of heat required to change 1 kg of the substance from the liquid to gaseous phase without a change in temperature.

Specific latent heat of fusion of ice is 336 000 Jkg^{-1} meaning 336 000 J of latent heat is needed for 1 kg ice to melt to become water at 0 °C.

Specific latent heat of vaporization of water is 2.26×10^6 Jkg^{-1} meaning 2.26×10^6 J of latent heat is needed for 1 kg water to boil to become vapour at 100 °C.

11.80 HEAT ENGINES

Heat engines are devices that use heat to do work. A basic heat engine consists of a gas confined by a piston in a cylinder. If the gas is heated, it expands, moving the piston. This wouldn't be a particularly practical engine, though, because once the gas reaches equilibrium the motion would stop. A practical engine goes through cycles; the piston has to move back and forth. Once the gas is heated, moving the piston up, it can be cooled and the piston will move back down. A cycle of heating and cooling will move the piston up and down. This cycle starts with piston at the top of the cylinder.



Source: http://www.woodsbrosracing.com/amsoil/article.htm

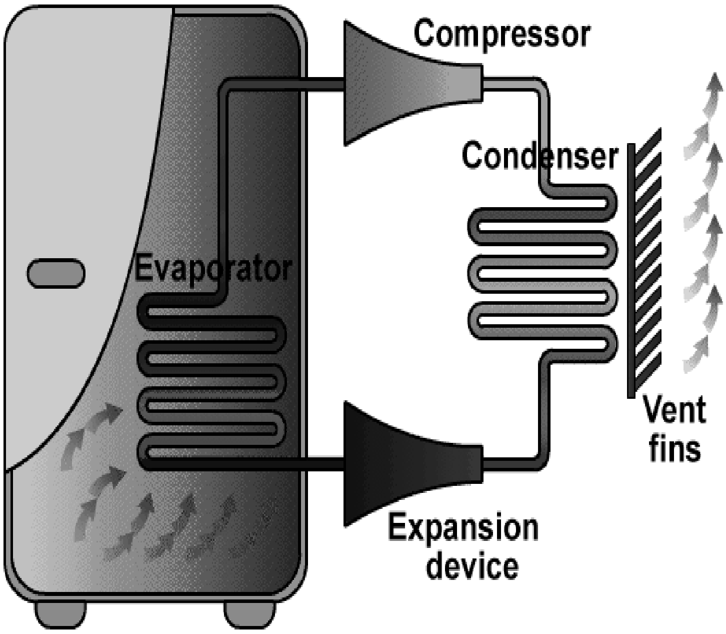
Intake stroke	Intake valve opens and the piston moves down allowing the fuel-air mix to enter the open space.
Compression stroke	The piston moves upwards. This compresses the fuel-air mix by forcing it into a smaller space. Compression makes the fuel-air mix explode with greater force.
Power cycle	Spark from a spark plug ignites the fuel-air mix. The explosion forces the piston down the cylinder.
Exhaust cycle	The exhaust valve opens and the piston moves back to the top of the cylinder which forces the exhaust fumes out.

The bottom of each piston is attached to the crankshaft.

As the pistons are forced up and down they rotate the crankshaft, which after sending the power through the transmission will then turn wheels.

11.81 Refrigerators

A device such as a refrigerator or air conditioner, designed to remove heat from a cold region and transfer it to a hot region, is essentially a heat engine operating in reverse.



Elements	Functions
Evaporator	The cold liquid absorbs heat from the air in the fridge, chilling the inside of the fridge. The liquid vapourises.
Compressor	The vapour is compressed, bringing it to a higher temperature.
Condenser	Allows the gas to cool and liquify, and to release this heat through ventilation fins on the back of the fridge. As the heat is removed the gas condenses to a liquid.
Expansion device	The flow of the liquid is controlled and pressure is lowered so that some of the liquid turns into a vapour. This evaporation cools the remaining liquid.
Ventilation fins	Heat from the condenser is released through the ventilation fins on the back of the fridge.

11.90 EXERCISES

1. State the advantageous and disadvantageous of using mercury as the liquid in a liquid in glass thermometer.

2. State the advantageous and disadvantageous of using alcohol as the liquid in a liquid in glass thermometer.

3. State the characteristics of the liquid used in a liquid in glass thermometer.

4. State and explain how the sensitivity of a liquid in glass thermometer can be increased.

5. Calculate the total heat that is absorbed by a copper block of mass 500 g and which has been heated from 31 °C to 80 °C. (specific heat capacity of copper = 390 J Kg^{-1} $°C^{-1}$)

6. When an electric heater is supplied with an electric power of 2 kW to heat 4 kg of water for 1 minute, calculate the increase in temperature of the water. [Specific heat capacity of water = 4 200 JKg^{-1} $°C^{-1}$). Assume there is no heat loss to the surroundings.

7. A lead bullet moves horizontally with a velocity of 130 ms^{-1} and embedded into a cement wall after collision. If the specific heat capacity of lead = 130 JKg^{-1} $°C^{-1}$ and all heat produces is absorbed by the bullet, what is the increase in temperature of the bullet?

8. An aluminium block of mass 1 kg is heated by an electric heater for 3 minutes and a temperature rise of 15 °C is recorded. If the electric heater is connected to a voltmeter which gives a reading of 30 V and an ammeter which gives a reading of 2.5 A, calculate the specific heat capacity of the aluminium.

9. Water of mass 300 g of at temperature 40 °C is mixed with 900 g of water at temperature 80 °C. If there is no heat loss to the surroundings, what is the final temperature when thermal equilibrium is achieved by the mixture of water?

10. The specific latent heat of fusion of ice is 336 000 Jkg^{-1}. What is the quantity of heat required to melt 2.5 kg of ice at 0 °C?

11. An electric kettle contains 3 kg of water. Calculate the amount of heat required to boil away all the water after the boiling point has been reached.

12. What is the quantity of heat that is required to convert 4 g of ice into steam at 100 °C?
    Specific latent heat of fusion of ice is 336 000 Jkg^{-1}
    Specific latent heat of vaporization of water is 2.26×10^6 Jkg^{-1}
    Specific heat capacity of water = 4.2×10^3 J $kg^{-1}°C^{-1}$

CHAPTER 12: LIGHT

12.0 INTRODUCTION

Light is something that we are familiar with. We have learned to use light and have found many different ways to utilize it, some of which we now take for granted. For example, we have mirrors to reflect light. Another example of this would be people who use glasses or contact lenses to see better, telescopes to see farther and microscopes to see objects hundreds of times larger than they actually are. The light from lasers is used to perform a number of surgical techniques. Many telephone cables are now being replaced by fibre optics, which carry an enormous amount of information in a small space.

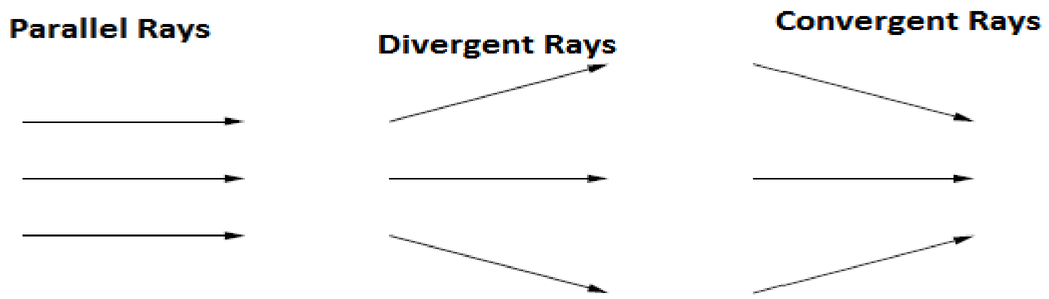
12.10 STRAIGHT PATH FOR LIGHT

In a dusty atmosphere it is sometimes possible to see light travelling and it does appear to be moving in a straight line.

Source: http://www.exo.net/~pauld/workshops/ScienceForMonks/shadows.html

Sunlight creates straight line shadows in the air.

Sunbeams streaming through the clouds suggest that light travels in straight lines. The direction of the path in which light is travelling is called a **ray** and is represented in diagrams by a straight line with an arrow on it. A **beam** is a stream of light and is shown by a number of rays; it may be parallel, diverging (spreading out) or converging (getting narrower).



All visible objects either emit light or reflect light. Some do both, most just reflect. The way that we "see" things is by responding to the light that is reflected off of them into our eyes.

When an object either emits light or reflects it, the light travels in all directions from the object. Only a tiny fraction of the light from the object gets into our eyes at one time .

Imagine a tree off in the distance. We may focus our eyes on the top branches of the tree but light from the trunk and the branches facing us is still traveling into our eyes. The rays have to travel through the tiny aperture in the iris - the pupil.

The same happens with a pinhole camera and the light source.

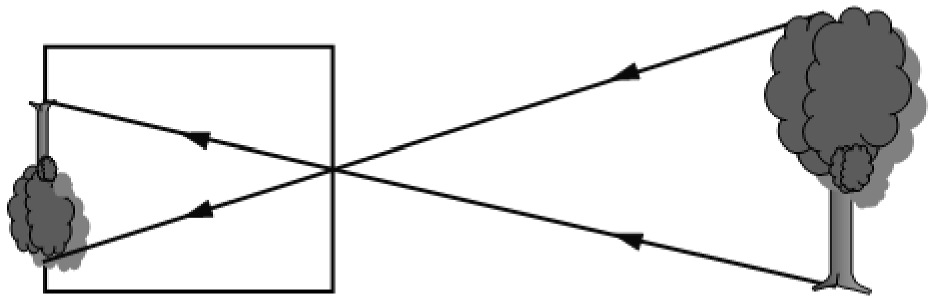
12.11 Pinhole Camera

Take a cardboard box (or an empty can - with the top taken off so that there are no sharp edges) and replace one side with a greaseproof paper screen.

Hold it so that you are pointing the pinhole end towards a brightly lit object (perhaps a sunlit tree through a window) and you will see the image formed on the screen.

The diagram shows why the image is upside down.

Since the pinhole is so small, only a tiny proportion of rays from top branch can pass through the hole. Their path is indicated by the line. These light rays haven't encountered any different media, so they travel in a straight path from the tree branch to the screen. The same is true for rays from the bottom of the tree.



Notice that the rays from the top branch and from the trunk have to cross at the pinhole in order to pass through. This is what causes the image of the tree (or light bulb, or any other object) to be upside down.

The retina cells at the top of your eye get image information from the lower part of an object you are looking at and the cells at the bottom from the top of the object.

12.12 Binocular Vision

In binocular vision, the visual axes of the eyes are arranged in such a manner that the images of the object viewed strike the identical portions of the retinas of both eyes. This produces a single stereoscopic image—a view of the world in relief. Binocular vision also makes it possible to determine visually the relative location of objects in space and to judge their distance from each other.

OPAQUE - An object that cannot be seen through and which does not allow light to enter. An example would be a brick wall.

TRANSLUCENT - An object that cannot be seen through, but allows light to enter. An example would be a stained-glass window.

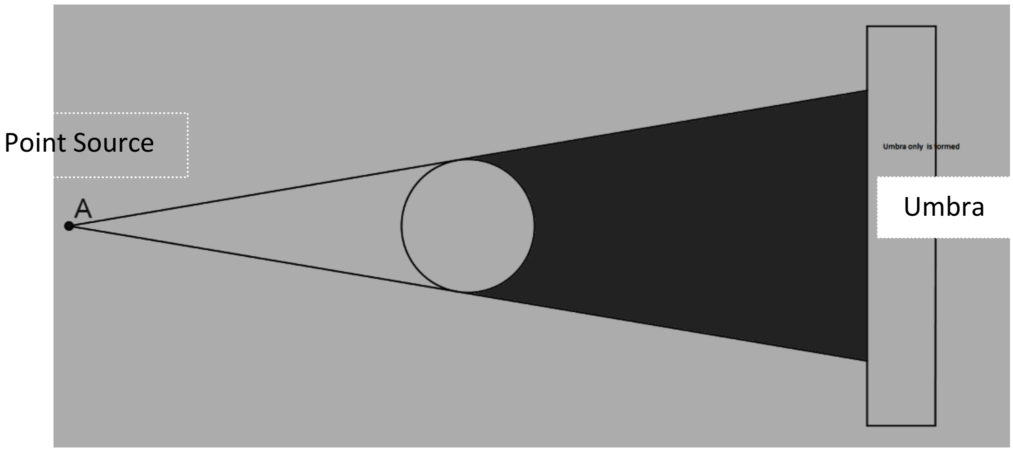
TRANSPARENT - An object that can be seen through. An example would be a normal window.

12.13 Shadows

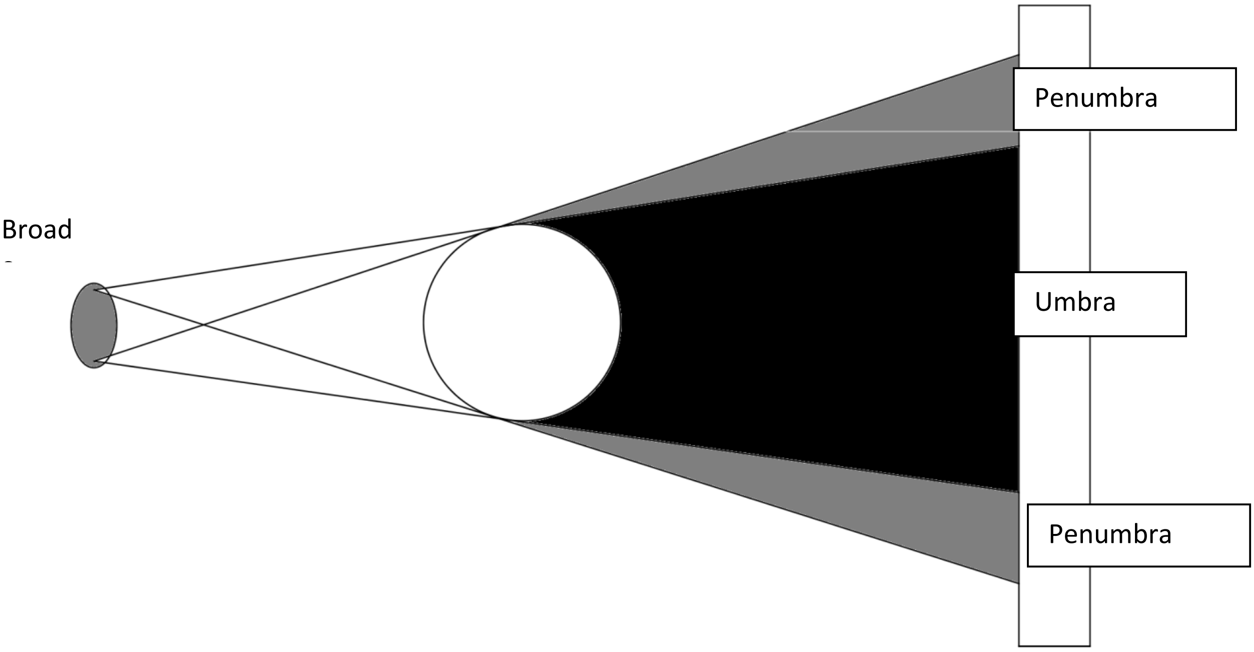
Where there is no light there is darkness, we call this a shadow. In fact at night we are in the shadow of the Earth.

A shadow is formed where light is 'missing'. A dark shadow (umbra) is formed where no light falls and a light shadow (penumbra) is formed where some light falls, but some is blocked.

If the light source is very tiny and concentrated in one place (a point source) only a sharp shadow is formed.



If the source is broader light from the top of the source causes a lower shadow than that from the top. You therefore get partial shadow or penumbra as well as umbra.



The region of deep, total shadow is called the **UMBRA** and the region of partial shadow is called the **PENUMBRA**. The umbra is a region where no light can get to while the penumbra is a region where some light can reach.

12.14 Eclipses

When the Sun, Moon and the Earth come into a straight line an **ECLIPSE** occurs. This does not happen very often because the Moon's orbit is inclined to that of the Earth. A **TOTAL** eclipse occurs when all the Moon or Sun is blotted out. A **PARTIAL** eclipse is when only part of the Sun or Moon is covered.

Lunar Eclipse

When the Earth comes between the Sun and the Moon we get a 'Lunar eclipse' or eclipse of the Moon.

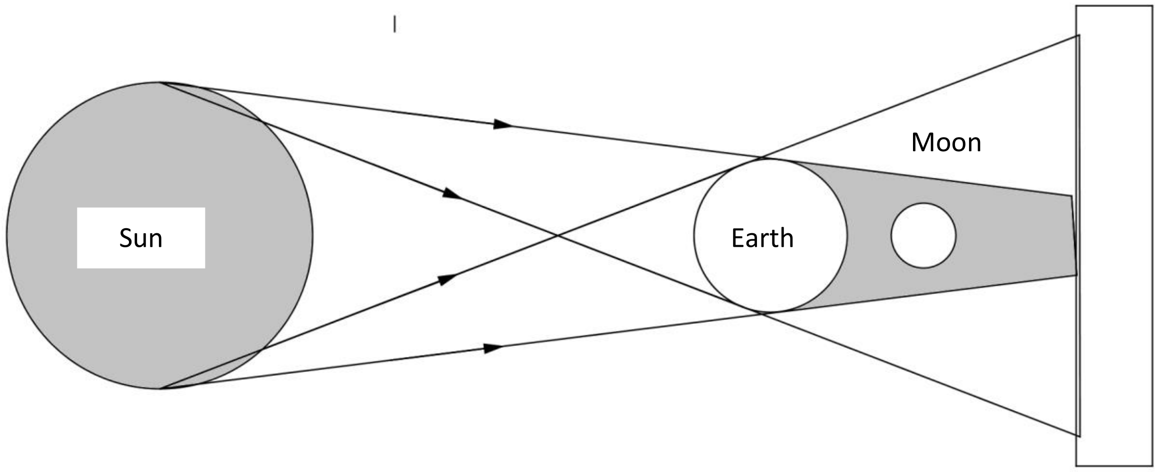


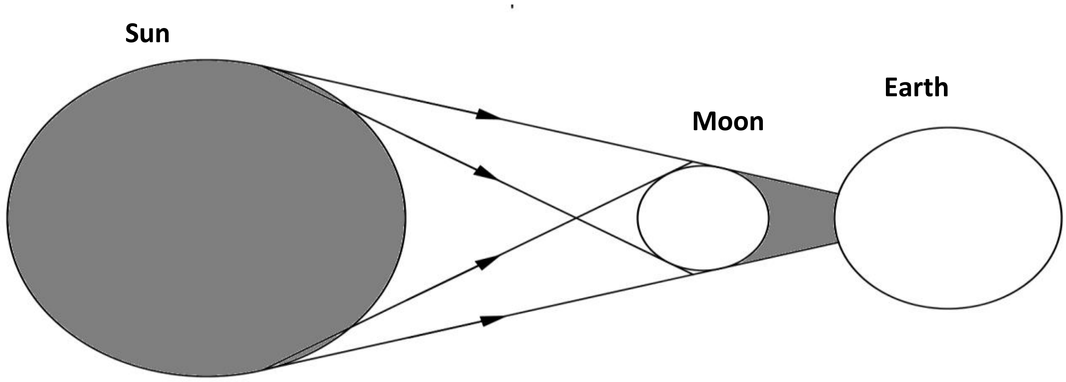
Figure 1

The Moon passes into the shadow of the Earth, it ever completely disappears because a small amount of the Sun's light is refracted by the Earth's atmosphere and falls on the Moon during the eclipse. This light gives the Moon a reddish appearance.

You can see form Figure 1 that at the distance of the Moon the Earth's shadow is much bigger than the Moon and so the Moon takes some time to pass through it.

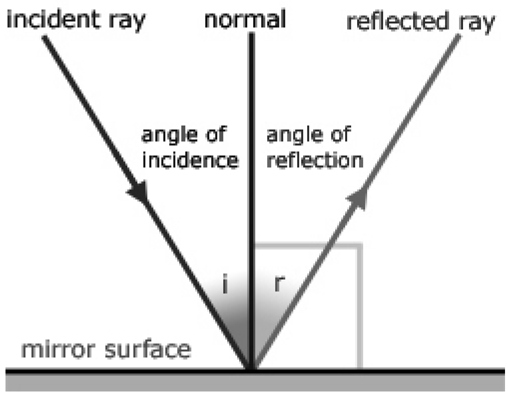
Solar Eclipse

It’s much more impressive when the Moon comes between the Sun and the Earth. The shadow of the Moon falls on part of the Earth and this is a Solar eclipse or eclipse of the Sun. When seen from the Earth the Moon and Sun look almost exactly the same size and so in a total eclipse the Moon just covers the Sun.



Eclipses do not occur as often as you might expect. This is due to the tilt of the Moon's orbit around then Earth compared with the plane of the Earth's orbit around the Sun. An eclipse, of the Sun or the Moon, will only occur if all three bodies – Sun, Earth and Moon are in a line.

12.20 REFLECTION



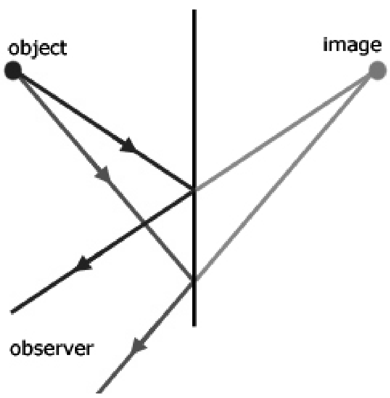
Source: http://www.a-levelphysicstutor.com/optics-plane-mirrs.php

The diagram shows a ray of light hitting a plane mirror.

- A line drawn at right angles to the mirror where the light hits it is called the NORMAL to the surface at that point.
- The **angle of incidence** is the angle between the normal and the incident ray.
- The **angle of reflection** is the angle between the normal and the reflected ray.
- The **Law of reflection** states that the angle of incidence equals the angle of reflection. The incident ray and the reflected ray and the normal are all in the same plane.

12.21 The Image in a Plane Mirror

The image in a plane mirror seems to be somewhere in space behind the mirror, this type of image is called a virtual image. It is actually the same distance from the mirror as the object is in front of the mirror.



Source: http://www.a-levelphysicstutor.com/optics-plane-mirrs.php

You can see the image but you can't actually touch it or focus it on a surface. The light rays from the object spread out, hit the mirror and then reflect – they seem to have come from a point behind the mirror. This is the image of the object.

The image in a plane mirror also looks as though it is reversed from left to right. This property is called **LATERAL INVERSION**.

12.22 Real and Virtual Images

A **real** image is one which can be produced on a screen (as in a pinhole camera) and is formed by rays that actually pass through it.

A **virtual** image cannot be formed on a screen and is produced by rays which seem to come from it but do not pass through it. The image in a plane mirror is virtual. Rays from a point on an object are reflected at the mirror and appear to come from the point behind the mirror where the eye imagines the rays intersect when produced backwards.

12.30 CURVED MIRRORS

When you look into the two sides of the bowl of a spoon you are actually using two simple curved mirrors. The side that curves inwards is called CONCAVE and the side that curves outwards is called **CONVEX**.

It is the same with mirrors, if the reflecting surface curves inwards you have a **CONCAVE** mirror and if the reflecting surface curves outwards you have a **CONVEX** mirror.

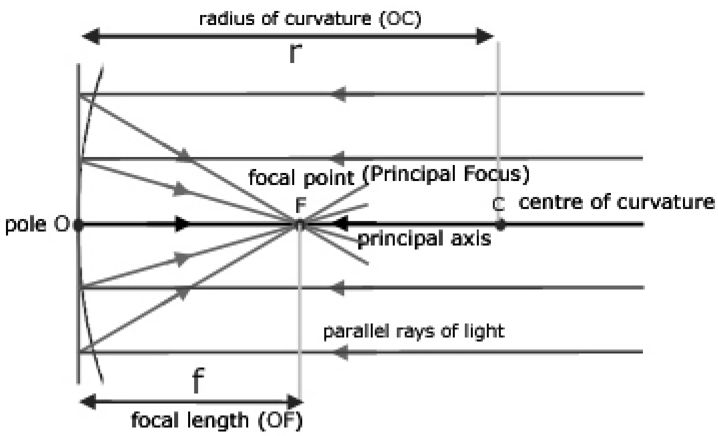
Curved mirrors are parts of a sphere and so are known as **SPHERICAL MIRRORS**. The center of this sphere is called the **CENTRE OF CURVATURE (C)** of the mirror and its radius the **RADIUS OF CURVATURE (R)** of the mirror.

The distance from the pole (P) to the principal focus (F) is called the **FOCAL LENGTH** of the mirror. The principal focus and focal length of a concave mirror are real but those of a convex mirror are virtual.

The effect of the two types of curved mirror on a parallel beam of light is shown by the two diagrams.

12.31 Concave Mirrors

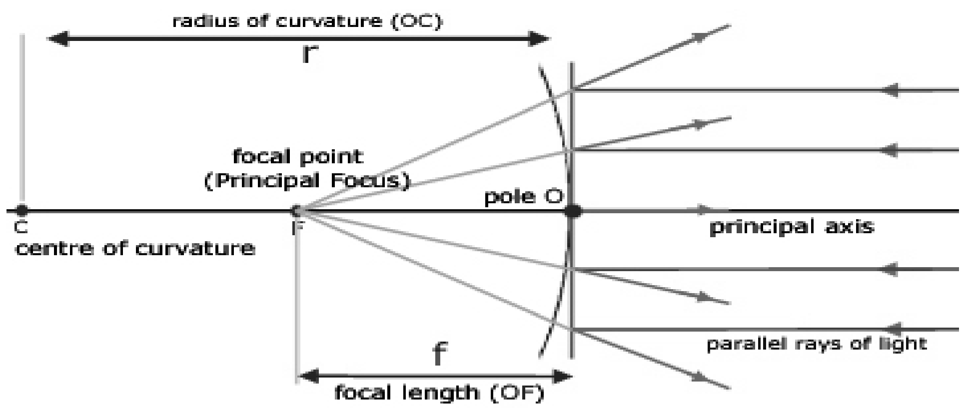
A concave mirror will converge a beam of light and it gives a real image. However, if the object is closer to the mirror than its focal length the image is virtual.
The focal length and radius of curvature of a concave mirror are real.
The image produced is up the right way, virtual and magnified if the object is closer to the mirror than its focal length but inverted and real if it is further away.



Source: http://www.a-levelphysicstutor.com/optics-concav-mirrs.php

12.32 Convex Mirror

A convex mirror will diverge a beam of light and it gives a virtual image. The focal length and radius of curvature of a convex mirror are virtual. The image produced is always up the right way and smaller than the object, the convex mirror gives a wide field of view because of this and thus used as rear view mirrors in cars and other motor vehicles.



Source: http://www.a-levelphysicstutor.com/optics-convex-mirrs.php

12.33 Ray Diagrams

Ray diagrams are scale drawings which can be used to find details of the images formed by curved mirrors or lenses. The usual details required from a ray diagram are the size, position and nature of the image. The nature of the image refers to whether the image is *inverted* (or *upright*), *virtual* (or *real*) or whether it is *enlarged* (or *diminished*).

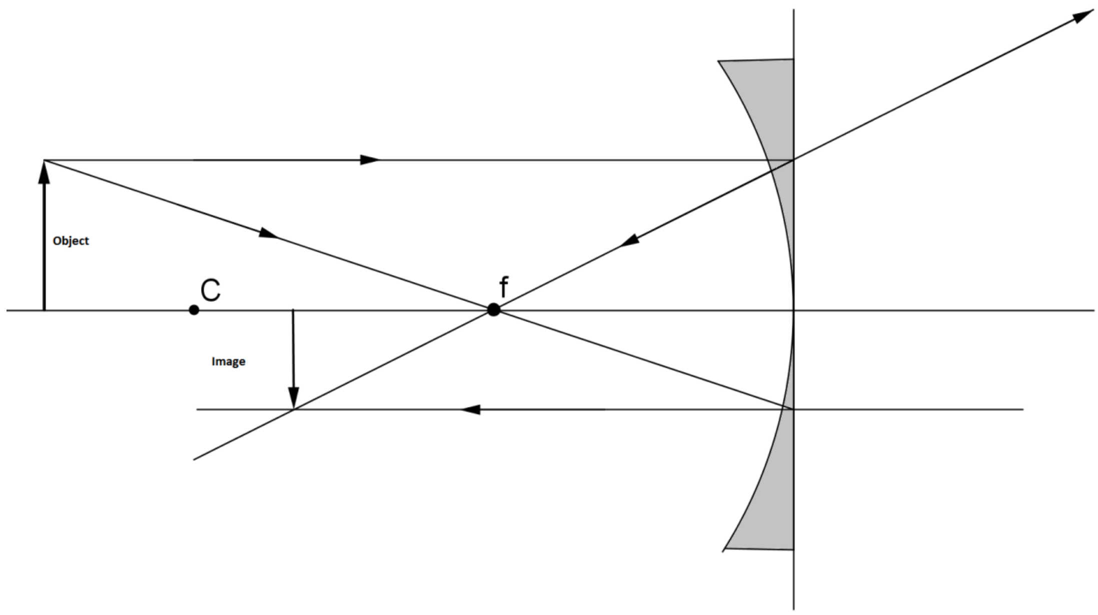
From the top of the object draw *two* of the following rays and where the reflected rays meets or appear to come from is the top of the image.

1. A ray parallel to the principal axis reflects through (or from in convex mirrors) the principal focus F.
2. A ray through the center of curvature C which hits the mirror normally, is reflected back along its own path (the radius of a sphere is perpendicular to the surface where it meets the surface)
3. A ray through the principal focus F is reflected parallel to the principal axis.

12.34 Images Formed By A Concave Mirror

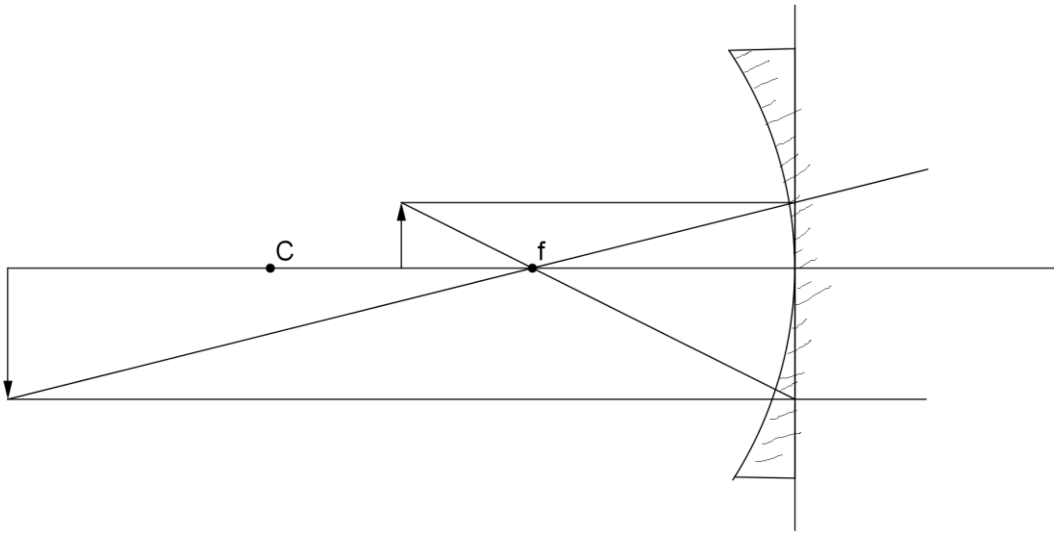
The ray diagrams in the Figure shown below show the images for four object positions. In each case rays are drawn from the top of an object and where they intersect after reflection gives the top of the image.

(a) Objects beyond C



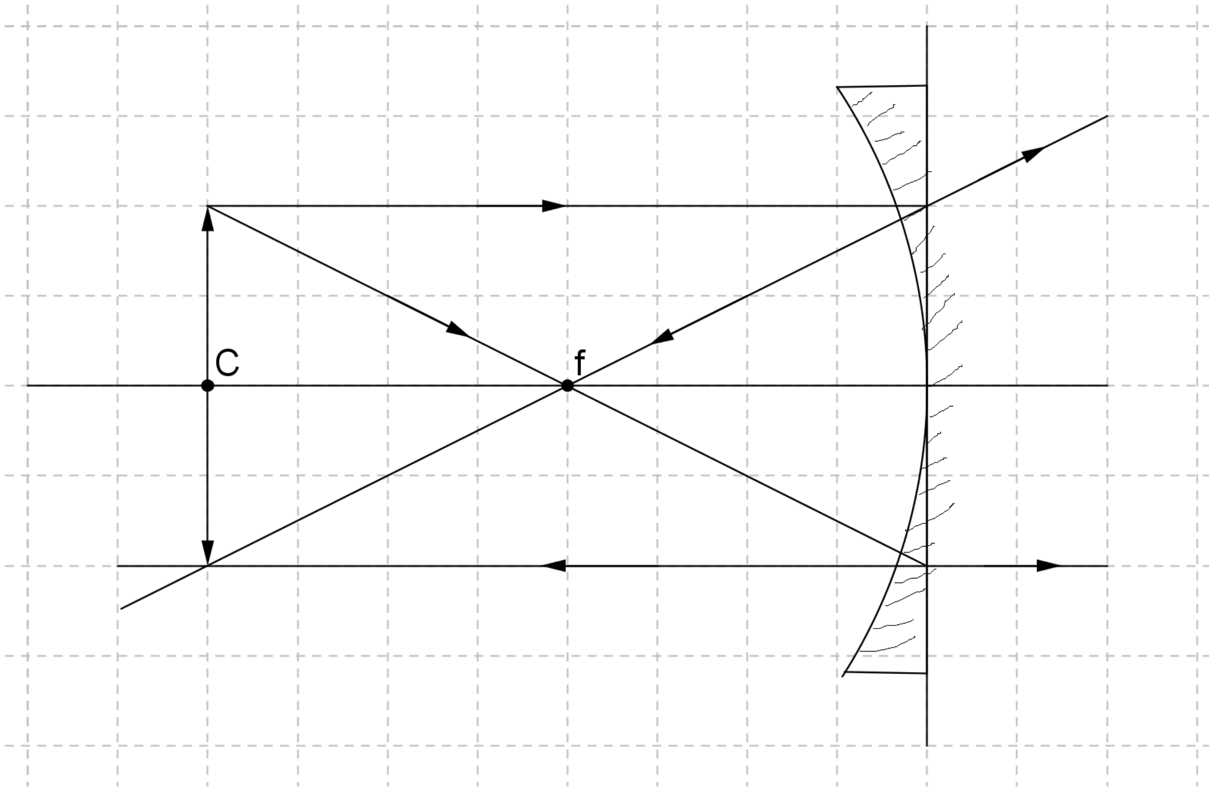
nature of the image : real, diminished and inverted.

(b) Objects between C and F



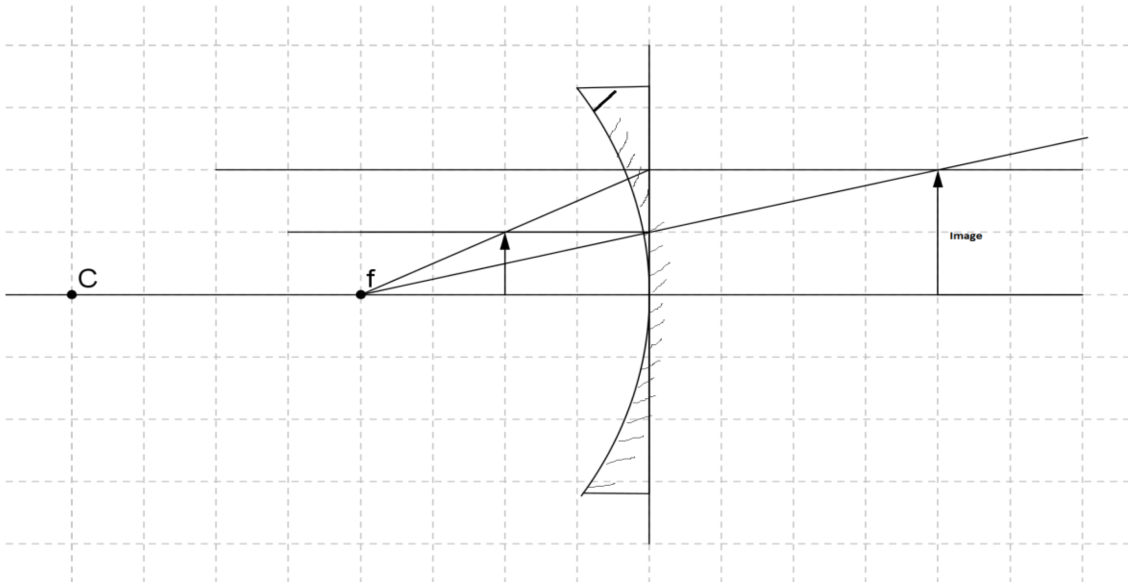
nature of the image : real, enlarged and inverted

(c) Objects at C



nature of the image : real, same size and inverted

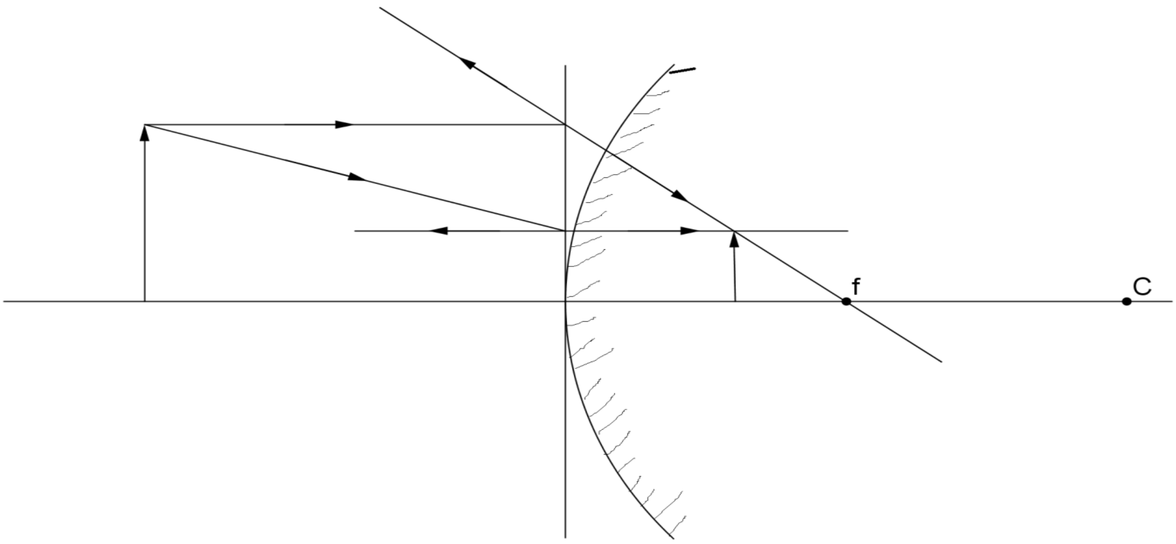
(d) Objects between F and P



nature of the image : virtual, enlarged and upright.

12.35 Images Formed By A Convex Mirror

A convex mirror produces only virtual images which are always upright and smaller than the object.



nature of the image : virtual, diminished and upright.

12.40 REFRACTION OF LIGHT

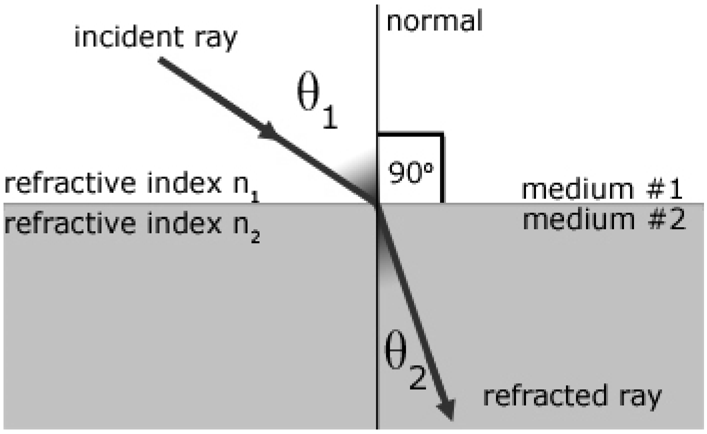
If you place a coin in an empty cup and move back until you just cannot see it, the result is surprising if someone gently pours water.

Although light travels in straight lines in one transparent material, e.g. air, if it passes into a different material, e.g. water to air, it changes direction at the boundary between the two, i.e. it is bent. The bending of light when it passes from one medium to another is called refraction.

12.41 The Laws of Refraction

Consider a single light ray travelling through a low density material and being refracted at the surface of a transparent material with higher density.

- The normal is a line drawn at right angles to the material's surface at the ray's point of entry.
- The angle of incidence is the angle the light ray makes with the normal.
- The angle of refraction is the angle the refracted light ray makes with the normal inside the material.



Source: http://www.a-levelphysicstutor.com/optics-refract.php

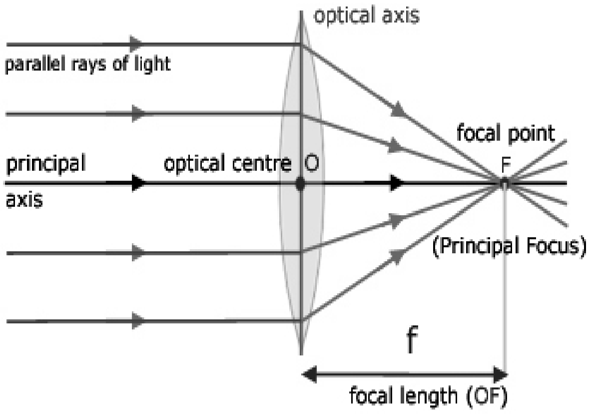
Note

1. A ray of light bent towards the normal when it enters a more denser medium.
2. A ray of light bent away from the normal when it enters a less dense medium

12.50 LENSES

Lenses are used in many optical instruments; they have spherical surfaces and there are two types.

A convex lens is thickest in the center and is also a converging lens because it bends light inwards. You may have used one as a magnifying glass.

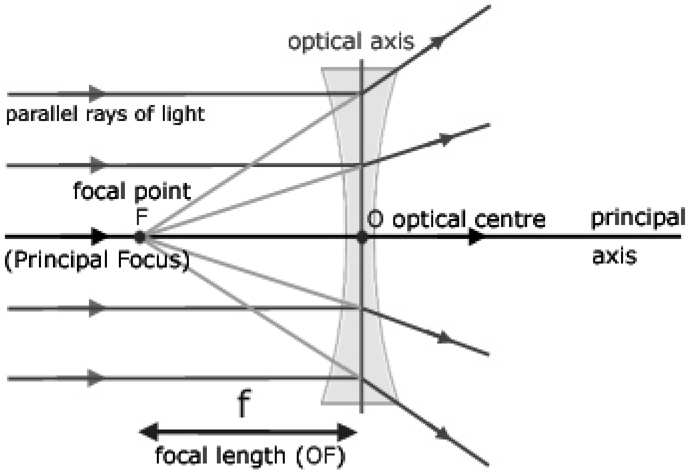


Source: http://www.a-levelphysicstutor.com/optics-convx-lnss.php

- The pole of the lens is the centre of the lens. Rays drawn passing through this point are not diverted, they continue in a straight line.
- The focal length of a lens is the distance between the pole of the lens and the focal point OR the perpendicular distance between the axis of the lens and the focal plane.
- The focal point or principal focus of a convex lens is point through which rays of light travelling near to and parallel to the principal axis pass after refraction by the lens. (The point all emerging rays pass through).

A concave or diverging lens is thinnest in the center and spreads light out. It always gives a diminished image.

The focal point or principal focus of a concave lens is point from which rays of light travelling near to and parallel to the principal axis seem to emerge from after refraction by the lens. (The point all emerging rays can be 'traced back' through).



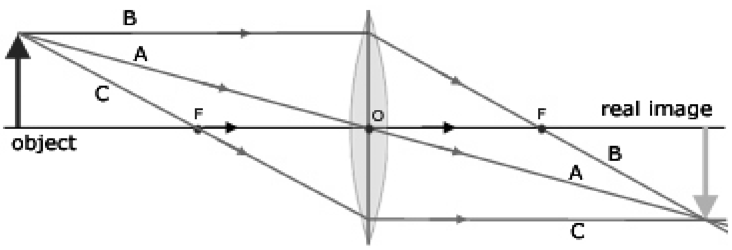
Source: http://www.a-levelphysicstutor.com/optics-concv-lnss.php

12.51 Ray Diagrams for a Convex Lens

Convex lenses converge light thus behaving similarly to a concave mirror.

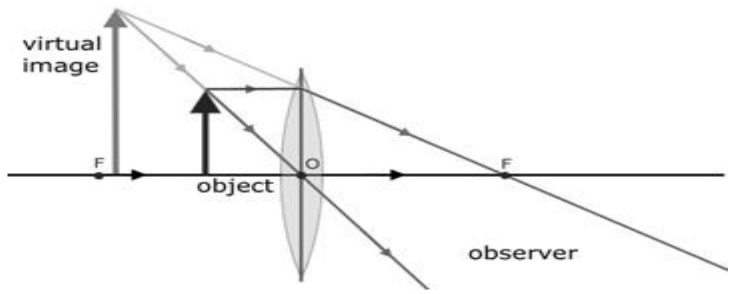
From the top of the object draw any *two* of the following rays:

1. A ray passing through the principal focus (on the same side as the object) and being refracted through the lens, emerging parallel to the principal axis.
2. A ray passing through the optical centre of the lens.
3. A ray parallel to the principal axis, which refracts through the lens, passing through the principal focus.



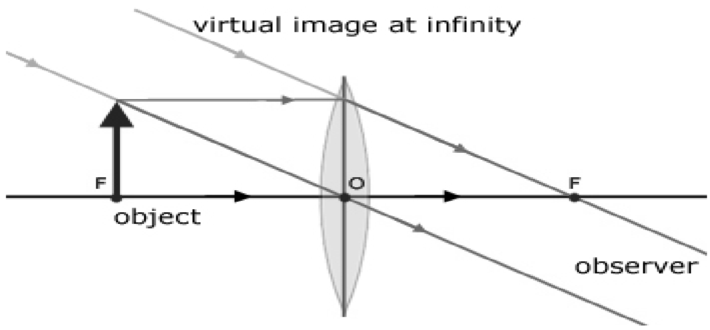
The drawings displayed below depict the various cases for convex (converging) lenses.

Object between *f* and the lens



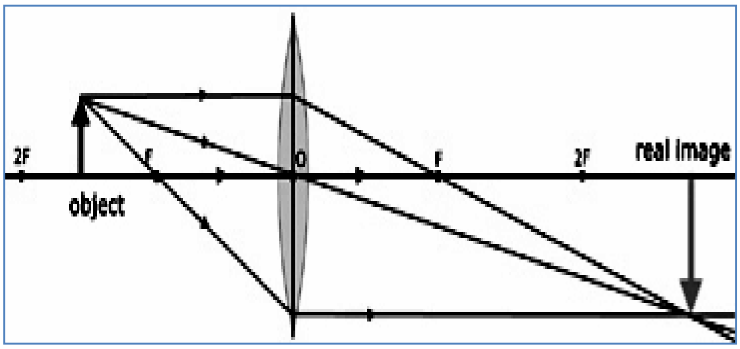
The image is the same side of the lens as the object and is upright, virtual and magnified.

Object at f



The image is formed at infinity from parallel rays that do not converge. Therefore no image is formed.

Objects between F and 2F

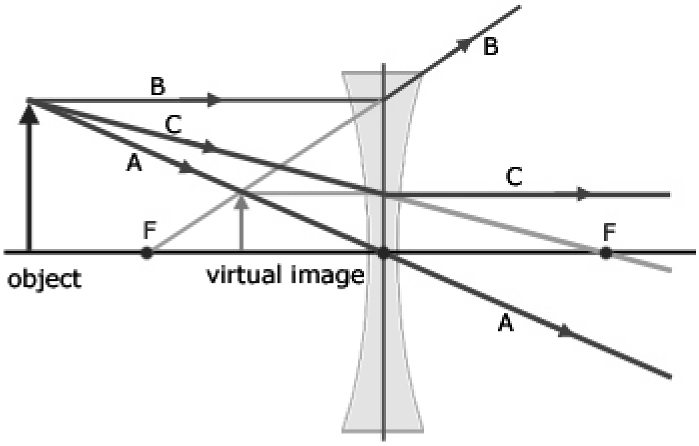


The image is on the opposite side of the lens than the object. It is real, inverted and magnified.

12.52 Ray Diagrams For A Concave Lens

From the top of the object draw any ***two*** of the following rays:

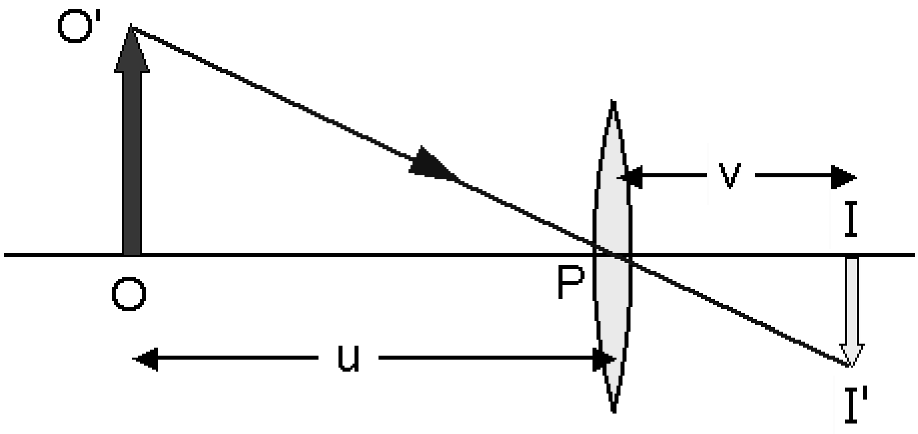
1. A ray through the principal focus (on the opposite side of the lens) and being refracted through the lens, emerging parallel to the principal axis.
2. A ray passing through the optical centre of the lens.
3. A ray parallel to the principal axis, which refracts through the lens and <u>appears</u> to have come from the principal focus.



The image produced is always virtual, upright, diminished and on the same side of the lens as the object.

12.53 Magnification of a Lens

Lenses give an image of the object. The size of the image compared with the object depends on the magnification of the lens.



Magnification = image height (II')/object height (OO')

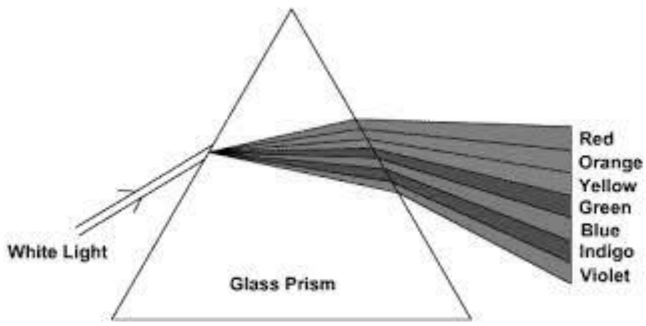
The magnification is also equal to image distance/object distance or v/u.
Magnifications don't always have to be bigger than one. For example in a camera and in your eyes the image is smaller than the object.

For a convex lens with an object distance of 15 cm and an image distance of 7.5 cm the magnification would be 7.5/15 or 0.5, the image is real and half the size of the object.

12.60 COLOURS

In 1665, during his investigation on optics, Isaac Newton discovered that by placing a triangular prism in the path of a beam of white light, he was able to split the beam into seven bands of colour, namely red, orange, yellow, green, blue, indigo, violet. The process of separating white light into its constituent coloured lights is known as the dispersion of white light.

The dispersion of white light depends on the wavelength of each colour of light. Since red light has the longest wavelength of 700 nm, it travels the fastest in glass and is refracted the least. On the other hand, violet light has the shortest wavelength of 400 nm. It travels the slowest in glass and is refracted the most.



12.70 NATURAL REFRACTION PHENOMENA

1. Mirages

We often see what appears like water on a dry road on sunny, hot days. However, when we get to the water-like area that produces the reflection, the road is perfectly dry. This is an optical effect called a mirage. It appears not only on roads and pavement, but also on deserts or any open area subject to heating by sunlight.

These mirages are caused not by any water on the surface, but by warm air immediately above the road. The sunlight beating on the road warms the road significantly above the ambient air temperature. The warm road in turn warms a layer of air immediately above it.
Because warm air is less dense than cool air, it has a lower refractive index. Consider light originating in the cold air above the boundary. When the light strikes the boundary to traverse into the region of less refractive index it bends. If light strikes the boundary at a shallow grazing angle, it is totally reflected by the boundary. This is called "Total Internal Reflection" which in this case gives rise to mirage.

2. Rainbow

Rainbows are caused by the splitting of white sunlight into it component colours by raindrops. Some of the light that falls on a water drop enters it. As it enters the drop, the colour components of the sunlight are refracted (bent) by different amounts depending upon their wavelength.

Then, the different colours reflect off the back of the inside of the drop, and when they pass through the front of the drop again, they are refracted once again.

A rainbow is always directly opposite the sun from the observer's perspective. This explains why rainbows are only seen when the sun is low in the sky, usually in the late afternoon.

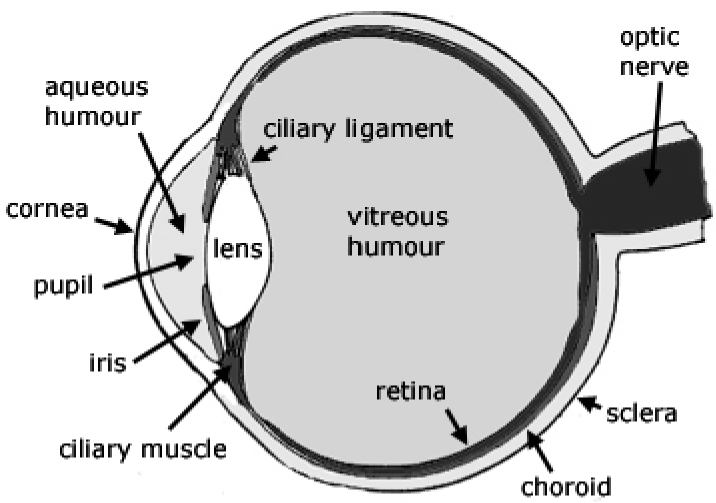
12.80 THE EYE

The human eye has been called the most complex organ in our body. It's amazing that something so small can have so many working parts. But when you consider how difficult the task of providing vision really is, perhaps it's no wonder after all.

In a number of ways, the human eye works much like a digital camera:

1. Light is focused primarily by the cornea — the clear front surface of the eye, which acts like a camera lens.
2. The iris of the eye functions like the diaphragm of a camera, controlling the amount of light reaching the back of the eye by automatically adjusting the size of the pupil (aperture).
3. The eye's crystalline lens is located directly behind the pupil and further focuses light. Through a process called accommodation, this lens helps the eye automatically focus on near and approaching objects, like an autofocus camera lens.
4. Light focused by the cornea and crystalline lens (and limited by the iris and pupil) then reaches the retina — the light-sensitive inner lining of the back of the eye. The retina acts like an electronic image sensor of a digital camera, converting optical images into electronic signals. The optic nerve then transmits these signals to the visual cortex — the part of the brain that controls our sense of sight.

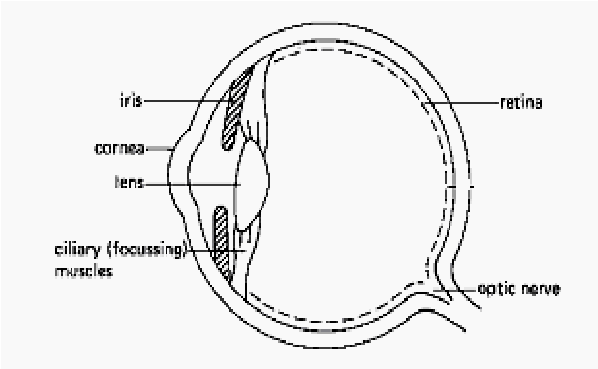
Parts of the Eye,



Source: http://www.a-levelphysicstutor.com/optics-eye.php

12.90 EXERCISES

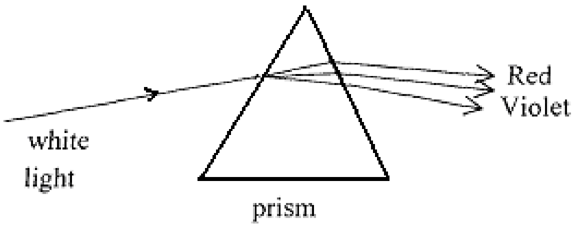
1. The diagram below shows parts of an eye.



2. Which part shown above controls the amount of light entering the eye?

A. iris B. retina C. cornea & lens D. ciliary muscles

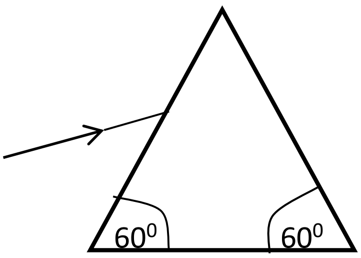
3. A beam of white light, incident on a glass prism is spread into a spectrum of colors.



This phenomenon is called:

A. reflection. B. dispersion. C. diffraction. D. interference.

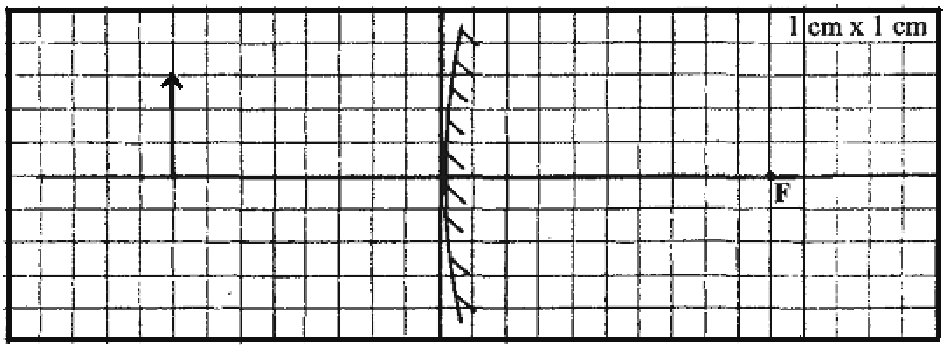
4. The diagram below shows a ray of red light incident on a glass prism.



(i) Complete the diagram to show the path of the light through and out of the prism.

(ii) If white light was used instead of red light, what difference, if any would you notice?

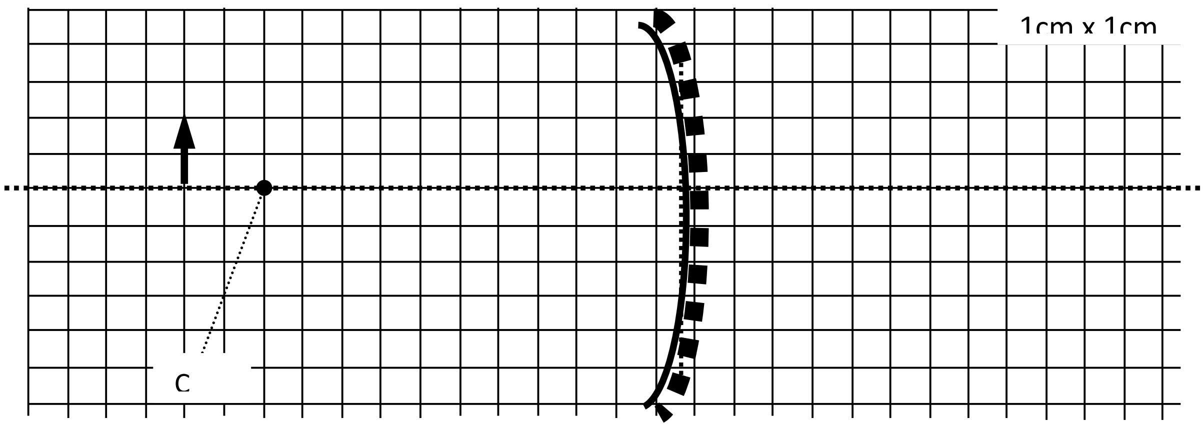
5. An object 3 cm tall is placed 8 cm in front of a convex mirror of focal length 10 cm.



(i) Dray ray diagrams to locate the image formed.

(ii) What is the magnification of the image formed?

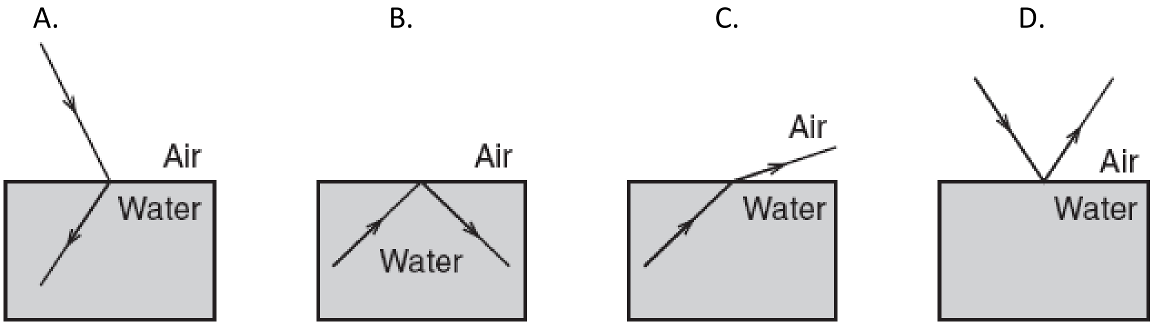
6. An object 2 cm high is placed perpendicular to the principle axis of a concave mirror. The radius of curvature of the mirror is 10 cm and the object is 12 cm from the pole of the mirror as shown in the diagram given below.



i) Draw suitable construction rays to find the position of the image.

ii) Determine the nature of the image.

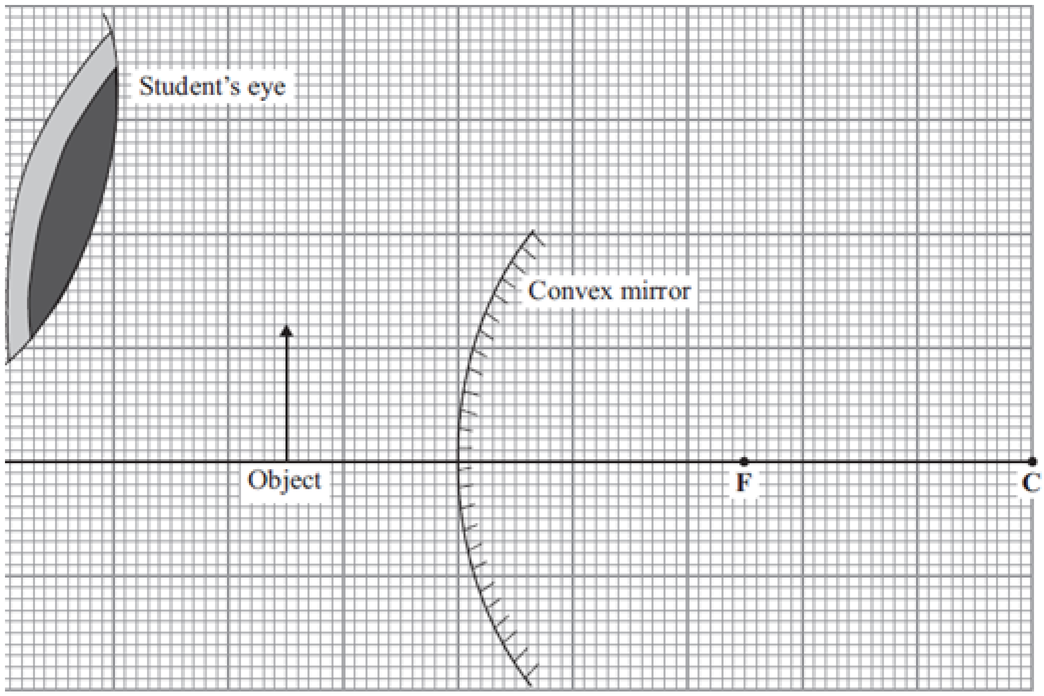
7. Which ray diagram best represents the phenomenon of refraction?



8. A student investigates the formation of images by a convex mirror. In the mirror, she can see the image of an object placed in front of the mirror. In the diagram, F is the principal focus of the mirror and C is the centre of curvature of the mirror.

(a) Use a ruler to draw two rays from the top of the object which show the position of the image and how the student sees the image.

Mark the direction of the rays at each stage.



(b) The image is a virtual image.

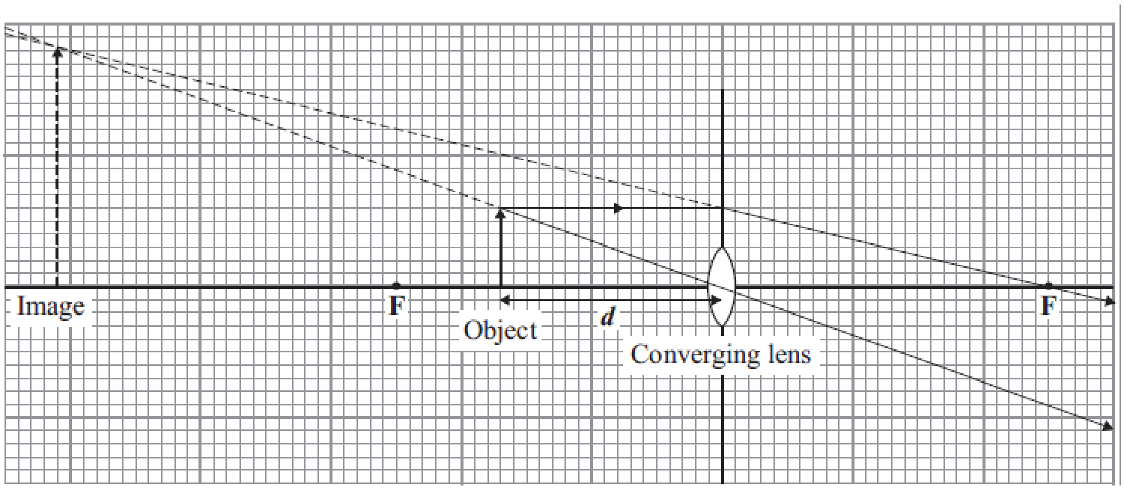
How can you tell from the rays you have drawn that the image is a virtual image?

9. A student investigates how the magnification of an object changes at different distances from a converging lens.

The diagram shows an object at distance *d* from a converging lens.

(i) The points F are at equal distances on either side of the centre of the lens. State the name of these points.

(ii) Explain how you can tell, from the diagram, that the image is virtual.



(iii) The height of the object and the height of its image are drawn to scale. Use the equation in the box to calculate the magnification produced by the lens shown in the diagram.

$$\text{magnification} = \frac{\text{image height}}{\text{object height}}$$

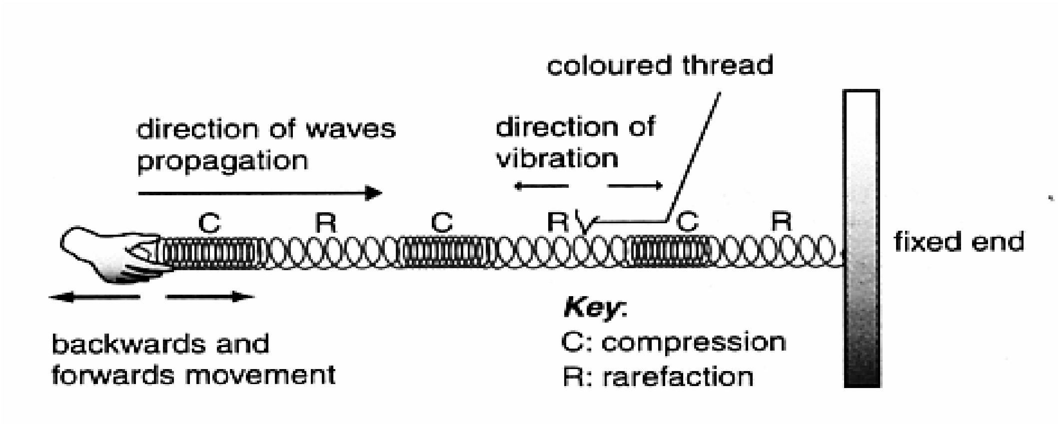
CHAPTER 13: WAVES

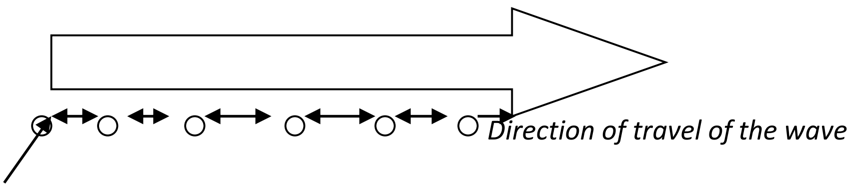
13.0 INTRODUCTION

A **wave** is a disturbance which can transfer energy without the particles of wave having to move from one place to another.

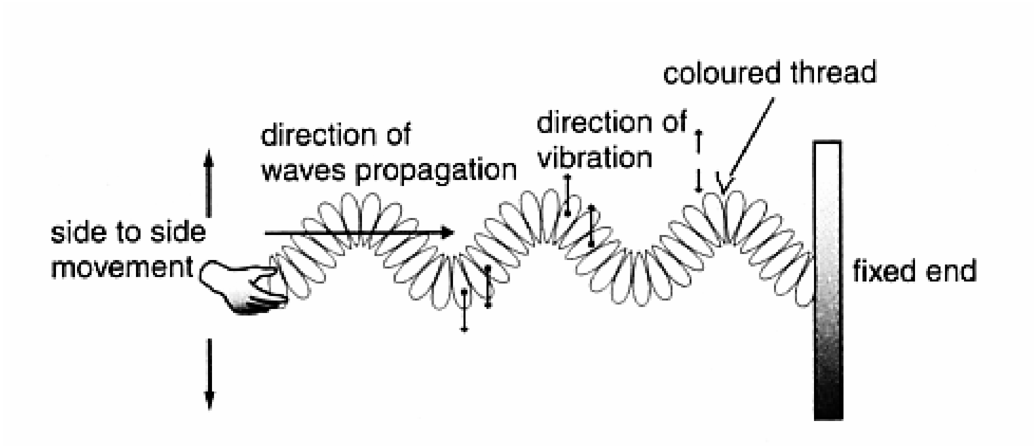
13.10 TYPES OF WAVES

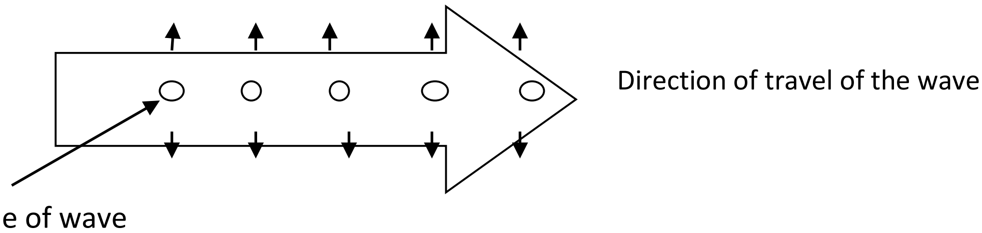
1. **Longitudinal waves**: are waves where the particles of the wave vibrate parallel to the direction of propagation.
   Eg. *Sound waves, pulses on slinky.*

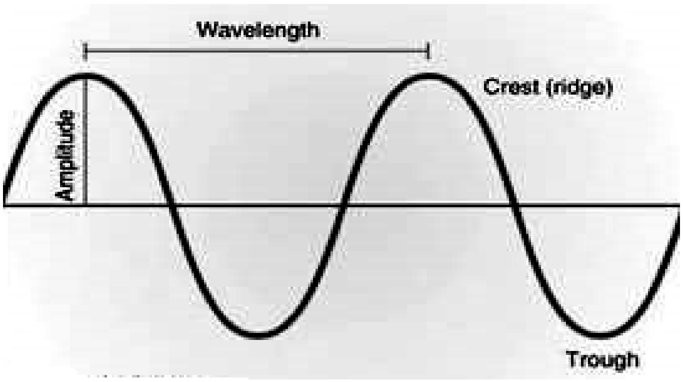




2. **Transverse waves**: where the particles vibrate perpendicular to the direction of propagation of the wave.
   Eg: *Light waves, waves on a string.*







13.20 DEFINITIONS

1. *Amplitude:* is the maximum displacement of the particle from its equilibrium (rest) position.
2. *Frequency*: number of waves passing a point in one second.
   Units: Hertz (Hz)

3. *Period, T*: is the time taken for one wave to pass any point.

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

4. *Wavelength* λ *:* is the distance between two successive corresponding positions in a wave.
   E.g.: distance between crest – crest.

The wave velocity, frequency and wavelength are related by the wave equation:

$$v = f \times \lambda$$

where: v = wave velocity (m/s)

f = frequency (Hz)

λ = wavelength (m)

Note:

$v = f \times \lambda$ but $f = \frac{1}{T}$ *therefore* $v = \frac{\lambda}{T}$

Examples:

1. A string vibrates with a frequency of 400Hz. Find the period and the wavelength of the sound wave produced if the velocity of sound is 332 m/s?
   Frequency= 400Hz

   Period = $\frac{1}{frequency}$

   $= \frac{1}{400\ Hz}$

   = 0.0025 s

   velocity = frequency x wavelength

   332m/s= 400Hz x wavelength

   wavelength= $\frac{332\ \mathrm{m/s}}{400\ \mathrm{Hz}}$

   Wavelength= 0.83 m

2. 6 complete waves of wavelength 2.5 m pass a point in 1 second. Calculate the velocity of the wave.

   Velocity = frequency x wavelength
   Velocity = 6 x 2.5 m
   Velocity = 15 m/s

13.30 ECHO

An echo is the sound you hear when you make a noise and the sound wave reflects off a distant object. Besides the novelty of hearing your words repeated, echoes can be used to estimate the distance of an object, its size, shape and velocity, as well as the velocity of sound itself.

Sound is a waveform made from vibrating matter. The sound wave travels through matter—especially air—in a straight line. When the wave hits a different material, some of it is reflected, absorbed and transmitted through the material. In the case of a sound wave in air hitting a solid wall, most of the sound is reflected then you can hear the reflected waveform or echo.

Since sound travels at approximately 300 meters per second and if a wall is 15 meters away, the sound would return in 0.1 second. This can be seen from the relationship:

$$d = V \times t$$

where d = the distance the sound wave traveled back and forth,
V = velocity of sound, and
t = the time it takes the sound to go back and forth.

t = 30 m / 300 m/s = 0.1 sec.

Note that the distance was doubled to show the back and forth motion of the sound.

13.40 EXERCISES

1. A ship using an echo sounding device receives an echo from the bottom 0.8 s after the sound is emitted. If the velocity of sound in water is 1500 m/s, what is the depth of water?

2. Orange light has a wavelength of 600 nm. Calculate the frequency if the speed of light in vacuum ($c = 3 \times 10^8$ m/s).

3. A particular TV program is transmitted by electromagnetic wave of frequency 7.5×10^8 Hz, which travel at the speed of 3×10^8 m/s. Calculate the wavelength and period of the wave?

4. A man stands 200 m away from a foot of the hill and shouts. The echo is heard 1.2 seconds later. Calculate the speed of sound in air.

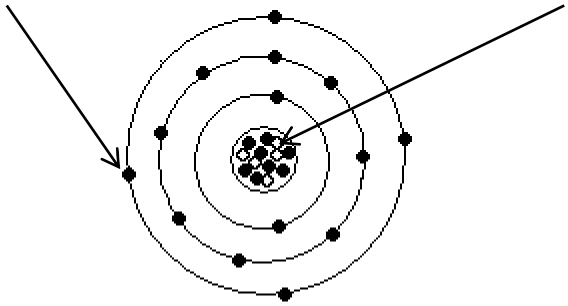
5. A man standing 504 m from a cliff claps his hands and hears the echo 3 s later. Calculate the velocity of sound.

CHAPTER 14: ELECTROSTATICS

14.0 INTRODUCTION

Matter is made up of tiny particles called atoms and at the centre of the atom is the nucleus which is made up of protons (positive charge) and neutrons (uncharged or neutral). Surrounding the nucleus are particles called electrons (negative charge).

electrons protons



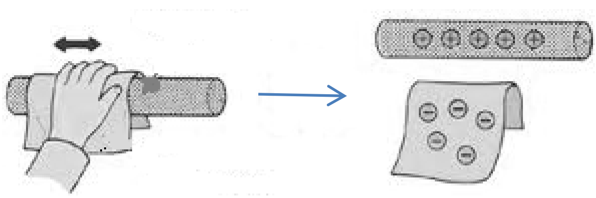
The charging of the body (whether positive or negative) is due to transfer of electrons from one body to another. The electric charge is denoted by the symbol Q.

A body is:

(a) neutral, if it has equal numbers of positive and negative charges.
(b) charged negative, if it has more negative than positive charges. (atom gains electron)
(c) charged positive, if it has more positive than negative charges. (atom losses electron)

14.10 CHARGING BY RUBBING

Glass and Silk



Silk and Glass

Electrons in glass are loosely bound in it than the electrons in silk. So, when glass and silk are rubbed together, the comparatively loosely bound electrons from glass get transferred to silk. As a result, glass becomes positively charged and silk becomes negatively charged.

Fur and Ebonite

Electrons in fur are loosely bound in it than the electrons in ebonite. So, when ebonite and fur are rubbed together, the comparatively loosely bound electrons from fur get transferred to ebonite. As a result, ebonite becomes negatively charged and fur becomes positively charged. Electric charge is denoted by the symbol Q

14.20 UNITS OF CHARGE

In SI system, the unit of charge is coulomb (C).

One coulomb of charge is that charge which when placed at rest in vacuum at a distance of one metre from an equal and similar stationary charge repels it and is repelled by it with a force of 9×10^{9} N.

Charge on one electron = -1.6×10^{-19} C

Charge on one proton = 1.6×10^{-19} C

14.30 PROPERTIES OF CHARGES

1. There exist only two types of charges, namely positive and negative.

2. Like charges repel and unlike charges attract each other.

3. Charge is a scalar quantity.

4. Charge can be added in nature. eg. +2 C + 5 C – 3 C = + 4 C

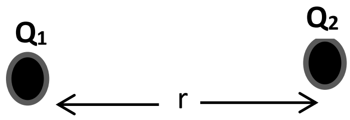
5. Charge exists in discrete packets rather than in continuous amount. It can be expressed in integral multiples fundamental electronic charge ($e = 1.6 \times 10^{-19}$ C)

6. Charge is conserved. The sum of positive and negative charges in an isolated system remains constant for example when a glass rod is rubbed with silk, negative charge appears on the silk and an equal amount of positive charge appear on the glass rod. The net charge on the glass-silk system remains zero before and after rubbing. The Law of conservation of charge states that the net charge of an isolated system remains constant.

14.40 COULOMB'S LAW

The force of attraction or repulsion between two charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them and acts along the line joining the two charges.

If we have two charges and separated by a distance of r



then $$F = k\,\frac{Q_1\,Q_2}{r^2}$$

where k = 9 X 10^9 Nm^2/C^2 and Q_1 and Q_2 are the two charges and r is the distance between the two charges.

Example

Two point charges Q_1 = 25 nC and Q_2 = -75 nC are separated by a distance of 3.0 cm. Find the magnitude and direction of the electric force that Q_1 exerts on Q_2.

$$F = k\,\frac{Q_1\,Q_2}{r^2}$$

$$F = k\,\frac{(25 \text{ x } 10^{-9})\,(\text{-}75 \text{ x } 10^{-9})}{(0.03 \text{ m})^2}$$

= - 0.01875 N

This will be an attractive force.

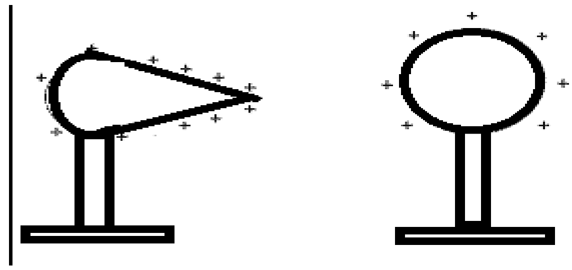
Repulsion force is when the two charges are like charges and attraction if unlike charges.

14.50 CONDUCTOR AND INSULATOR

An insulator is a material through which electric charges do not move. Glass, dry wood, cloth and dry air are all good insulators. A conductor is a material through which electric charges can easily flow. Electrons carry, or conduct, electric charge through the metal. Metals are good conductors because at least one electron on each atom of the metal can be removed easily. These electrons act as if they no longer belong to any one atom, but to the metal as a whole; consequently, they move freely through-out the piece of metal. Copper and aluminium are both excellent conductors and are used commercially to carry electricity.

14.51 Distribution Of Charge Over Surfaces

Since the charges repel, the charge on a hollow or solid metal sphere will move away from the centre as far as it will go. Thus the charge on a conductor of any shape is always found on the surface and never inside the conductor. It has been found that a charged metal sphere has a uniform charge density all over its surface. A pear shaped conductor, however, has a high density at the pointed part.



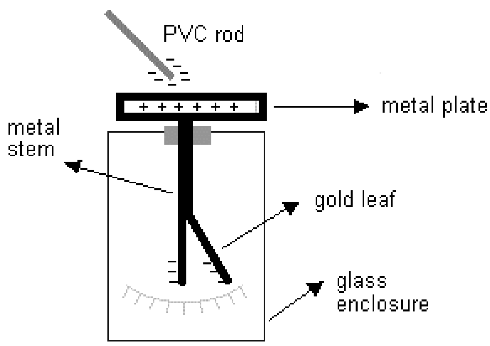
14.52 Sparking

Dry air is an insulator. When two charged bodies are brought close to each other, a very strong electric field is created between them. This field can pull out electrons from the air molecules, that is it ionize the air present in the gap between the bodies. As a result there is a flow of charge between the two charged bodies which will be seen as a flash and is accompanied with a crackling sound. This phenomenon of discharge is called sparking. Lighting is sparking on a very large scale.

14.60 THE GOLD LEAF ELECTROSCOPE

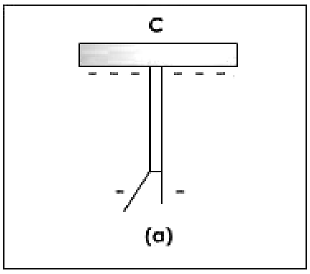
The gold leaf electroscope has a very thin piece of gold foil (called gold leaf) fixed at the top to a piece of copper. The copper has a large round top, called the cap. The whole thing is put inside a glass case. The piece of copper goes through insulation in the top of the glass case, so that charges on the gold leaf cannot escape.

When a charged body is placed in contact with the cap some of the charge on it spreads out on to the cap, metal plate and gold leaf. Since the plate and the leaf have the same charge, the plate repels the leaf.

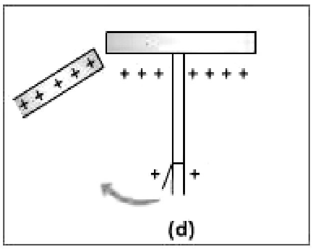


14.61 Identifying Charges

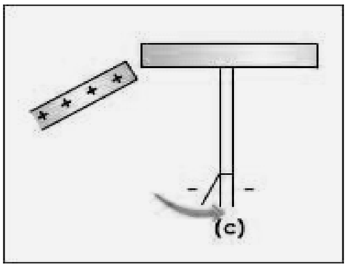
A gold leaf electroscope may be used to detect charge.   In order to identify the charge of a body we should use a charged electroscope. Let us say the electroscope is negatively charged.



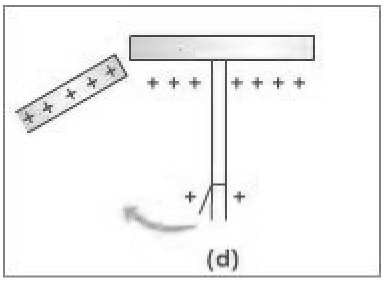
Now bring the unknown charged body near the metal cap of the electroscope.



If the leaves diverge more the charged body must be negative. Suppose that the leaves close a little when the body is brought near the metal cap, then charge body may have a positive charge or it may not have any charge.



In order to confirm the positive charge you must bring the charge rod near the metal cap of a positively charged electroscope.



If the leaves diverge more, then the body has positive charge.

14.70 CHARGING BY CONDUCTION AND INDUCTION

Both conduction and induction involve a movement of electrons. Conduction is the transfer of electrons from a charged object to another object by direct contact. When an object is rubbed with a charged rod, the object shares the charge so that both have a charge of the same sign.

In contrast, induction does not involve direct contact. Instead, induction is the movement of electrons from one part of an object to another as a result of the electric field of the second object. Charging by induction gives an object the charge opposite to that of the charged rod.

14.71 Charging an Electroscope by Induction

The figures below show the four stages to charge an electroscope by induction.

1 Bring a positively charged rod near the metal cap. The leaves will diverge because the negative charges get attracted to the positively charged rod and they get concentrated on the cap. On the other hand, the positive charge gets repelled and they get concentrated at the distant end on the leaves. The leaves diverge as they both have like positive charges.

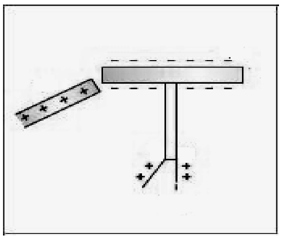


Figure 2

2 Earth the electroscope by touching the cap with a finger. The leaves then collapse. When the cap is touched, the free charges at the leaves attract electrons from the earth. These electrons from earth neutralize the positive charge of the leaves and the leaves close. The bound negative charge however remains at the metal cap.

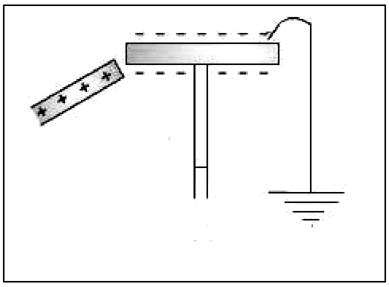


Figure 3

3 Remove the finger from the metal cap, keeping the rod in position. The leaves remain closed because of the presence of the positive charge on the charged rod does not allow the negative charge on the metal cap to spread.

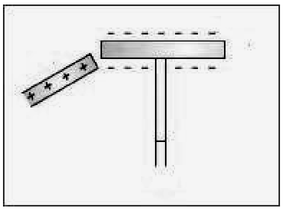


Figure 4

4 Take away the rod. The leaves now diverge. The leaves now have an induced charge so the electroscope is now charged. When the charged rod is taken away, the negative charge at the metal cap spreads over and some of it reaches both the leaves. Thus both the leaves now have similar negative charge and they repel each other. Hence the leaves diverge

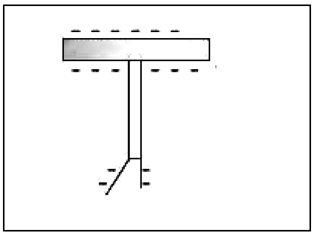
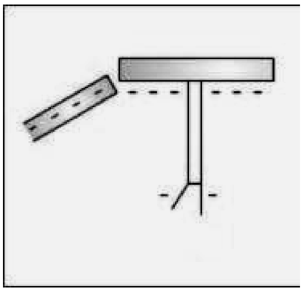


Figure 5

Note that the induced charge is always opposite to the inducing charge.

14.72 Charging An Electroscope By Contact

Touch the metal cap of the electroscope with the rod carrying a negative charge. The leaves will diverge for it is now charged negative as a result of being contacted with the charged rod.



14.80 ELECTRIC FIELD (Electric force per unit charge.)

An electric field exists in a region of space where a small positive charge experiences an electric force. It is denoted by letter E and can be found by the equation

$$E = \frac{F}{d}$$

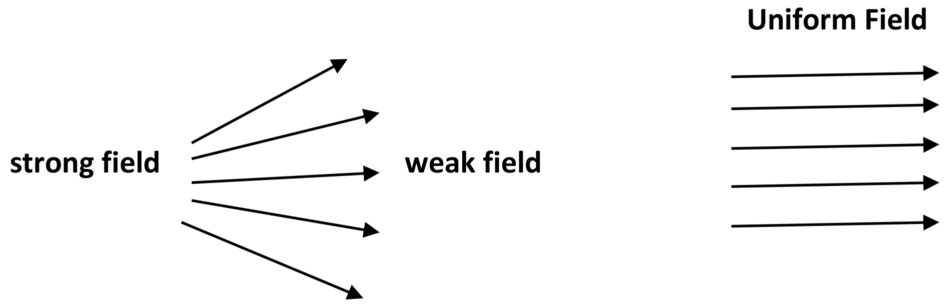
$$= k\frac{Q}{r^2}$$

Electric field is a vector and the direction will be where the positive charge would move. For more than one charge the total electric field equals the vector sum of all electric fields due to each charge.

14.81 Electric Field Lines

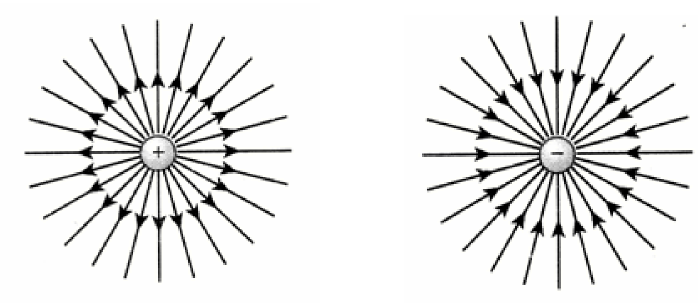
An electric field can be represented diagrammatically as a set of lines with arrows on, called electric field-lines. Field-lines determine the magnitude, as well as the direction, of the electric field. In particular, the field is strong at points where the field-lines are closely spaced, and weak at points where they are far apart.

Electric field lines start on positive charge and end on negative charge.



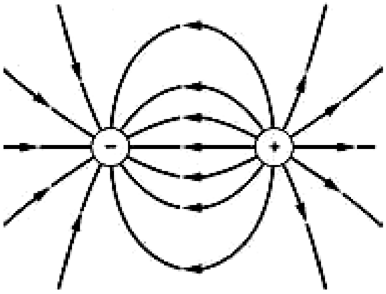
14.82 Electric Lines Of Force Due To A Point Charge

Electric lines of force are closer (crowded) where the electric field is stronger and the lines spread out where the electric field is weaker.



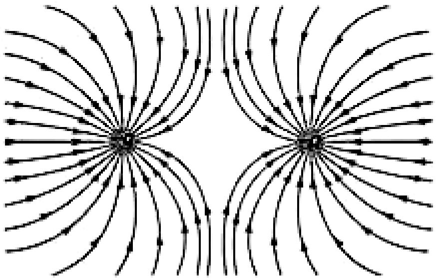
Positive charge **Negative charge**

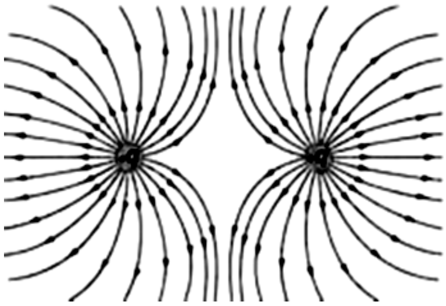
Electric Lines of Force due to a pair of Equal and Unlike Charges: (Dipole)



Unlike charges

Electric Lines of Force due to a pair of Equal and Like Charges:





Negative charges **Positive Charges**

Note: the direction of arrows indicates the directions of the field lines.

14.90 EXERCISES

1. Explain how an object becomes electrically charged.

2. All objects have charges in them. Explain why not all objects have a net charge.

3. If you scuff electrons onto your feet as you walk across a rug, state whether you become positively or negatively charged.

5. Calculate the electrical force between an electron and a proton in a hydrogen atom, given that the distance between the charges' centers is 5.3×10^{-11} m.

6. Explain using diagrams the difference between charging by contact and charging by induction.

7. Draw a diagram showing how a negatively charged balloon can attract your hair which has no net charge.

8. State the meaning of “charge is conserved”.

9. State the difference between a good conductor and a good insulator.

10. State the meaning of "electric dipole"

11. Joeli rubs two latex balloons against his hair, causing the balloons to become charged negatively with 2.0 $X10^{-6}$ C. He holds them a distance of 0.70 m apart.

a) What is the electric force between the two balloons?

b) Is it one of attraction or repulsion?

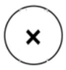
12.Two pieces of puffed rice become equally charged as they are poured out of the box and into Abdul's cereal bowl. If the force between the puffed rice pieces is 4 $X10^{-23}$ N when the pieces are 0.03 m apart, what is the charge on each of the pieces?

13. Explain in your own words what an electric field is.

b) Explain what electric field lines are. Make sure you say what the arrows mean and what the density of the lines represents.

c) Copy the following diagrams and draw electric field lines around them:

i)



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CHAPTER 15: CURRENT ELECTRICITY

15.0 INTRODUCTION

What is electric current, electromotive force, and what makes a landing light turn on or a hydraulic pump motor run? Each of these questions requires an understanding of many basic principles. By adding one basic idea on top of other basic ideas, it becomes possible to answer most of the interesting and practical questions about electricity. Our understanding of electrical current must begin with the nature of matter from the previous chapter. All matter is composed of molecules. All molecules are made up of atoms, which are themselves made up of electrons, protons, and neutrons.

15.10 CURRENT

Current electricity is about moving charged particles**.** If you allow the charge that builds up in static electricity to flow, you get a current.

Current is the rate of flow of charge; it is the amount of charge flowing per second through a conductor.

The equation for calculating current is:

$$I = \frac{Q}{t}$$

Where:

I = current (amps, A)

Q = charge flowing past a point in the circuit (coulombs, C)

t = time taken for the charge to flow (seconds, s)

So a current of 1 amp is 1 coulomb of charge flowing past a point every second. Likewise a coulomb is the same as an ampere-second.

Examples

1. A charge of 12 C passes through the filament of a car headlamp bulb in 4 s. What is the current?

Current = Charge/time = $I = \frac{Q}{t}$ = 12/4 = 3 A

2. A current of 0.5 A flows for 20 s through a small electric motor. How much charge has passed?

Charge = Current x time = $Q = I \times t$ = 0.5 x 20 = 10 C

3. A current of 200 mA flows for 2 minutes. How much charge has passed?
Charge, $Q = I \times t$ = 0.200 x 120 = 24 C (current in amps, time in seconds)

15.11 Conductors and Insulators

The electrons of different types of atoms have different degrees of freedom to move around. With some types of materials, such as metals, the outermost electrons in the atoms are so loosely bound that they are allowed to move in the space between the atoms. Because these virtually unbound electrons are free to leave their respective atoms and float around in the space between adjacent atoms, they are often called *free electrons*.

In other types of materials such as glass, the atoms' electrons have very little freedom to move around. While external forces such as physical rubbing can force some of these electrons to leave their respective atoms and transfer to the atoms of another material, they do not move between atoms within that material very easily.

This relative mobility of electrons within a material is known as electric *conductivity*. Materials with high electron mobility (many free electrons) are called *conductors*, while materials with low electron mobility (few or no free electrons) are called *insulators*.

Simply stated conductors are materials that allow electric current to flow freely, while in insulators it will not allow flow of electric current.

Here are a few common examples of conductors and insulators:

Conductors: silver, copper, gold, aluminium, iron, steel and brass.
Insulators: glass, rubber, oil asphalt fibreglass and porcelain.

15.12 How Can You Get The Charge To Flow?

A battery transforms chemical energy to electrical energy. Because of the chemical action going on inside it, it builds up a surplus of electrons at one of its terminals (the negative) and creates a shortage at the other end (the positive). It is then able to maintain a flow of electrons, i.e. an electric current, in any circuit connected across the terminals as long as the chemical action lasts.

Water doesn't flow in the pipe when both ends are at the same level. Another way of saying this is that water will not flow in the pipe when both ends have the same potential energy (PE). Similarly, charge will not flow in a conductor if both ends of the conductor are at the same electric potential. But tip the water pipe and increase the PE of one side so there is a difference in PE across the ends of the pipe and water will flow. Similarly, increase the electric potential of

one end of an electric conductor so there is a potential difference across the ends, and charge will flow.

A battery is said to have a potential difference (p.d) at its terminals. Potential difference is measured in volts (V). The p.d. of a car battery is 12 V and the domestic mains supply in Fiji is 240 V.

The potential difference (voltage) is measured between two points on the circuit with a voltmeter. It is really measuring the loss of energy of the electricity between one point and the other.

That is, 1 V = 1 Joule per Coulomb (1 V = 1 J/C). In general if W (Joules) is the energy transferred (i.e the work done) when charge Q (Coulombs) passes between two points, the p.d V (volts) between the points is given by

$$V = \frac{W}{Q}$$

where W = amount of energy (joule, J)
V = voltage (volt, V)
Q = charge (coulomb, C)

15.20 OHM'S LAW

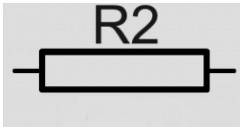
The electric current flowing through a conductor is directly proportional to the potential difference across the two ends of the conductor when physical conditions such as temperature, mechanical strain, etc. remain the same.
You can write this in an equation as:

$$R = \frac{V}{I}$$

Where R = resistance of the wire (ohms)
V = voltage (volt, V)
I = current (amps)

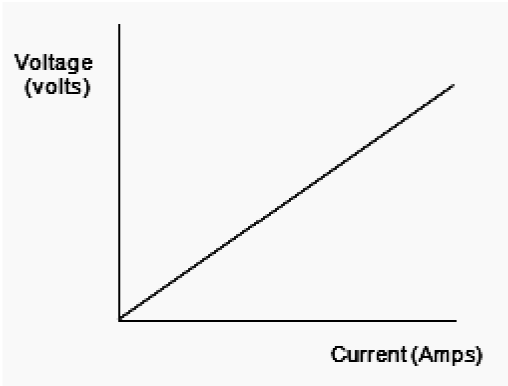
Resistance is measured in units called Ohms (Ω). The resistance of a piece of wire is 1 ohm if a current of 1 A flows through it when a voltage of 1 V is applied between its ends.

or



The symbol for resistor is Ω (ohms)

If you plot a graph of current through a piece of wire against the voltage applied you should get a result like the one shown in the diagram below.



15.21 Factors Affecting The Resistance Of A Wire

There are four factors that affect the resistance of a wire.

- Resistance is proportional to length. If you take a wire of different lengths and give each a particular potential difference across its ends. The longer the wire the less volts each centimeter of it will get meaning current decreases with increased length and resistance increases.
- Resistance is inversely proportional to cross-sectional-area. The bigger the cross sectional area of the wire means the resistance decreases.
- Resistance depends on the material the wire is made of. The more tightly an atom holds on to its outermost electrons the harder it will be to make a current flow
- Resistance increases with the temperature of the wire. The hotter wire has a larger resistance because of increased vibration of the atomic lattice. When a material gets hotter the atoms in the lattice vibrate more. This makes it difficult for the electrons to move without interaction with an atom and increases resistance.

Examples

1. A 6 V battery is connected to a small electromagnet and a current of 1.5 A flows through it. What is the resistance of the electromagnet?

Resistance = voltage/current = 6/1.5= 4 Ω

2. What current will flow through a circuit with a resistance of 2400 Ω if it is connected to a 2 V battery?

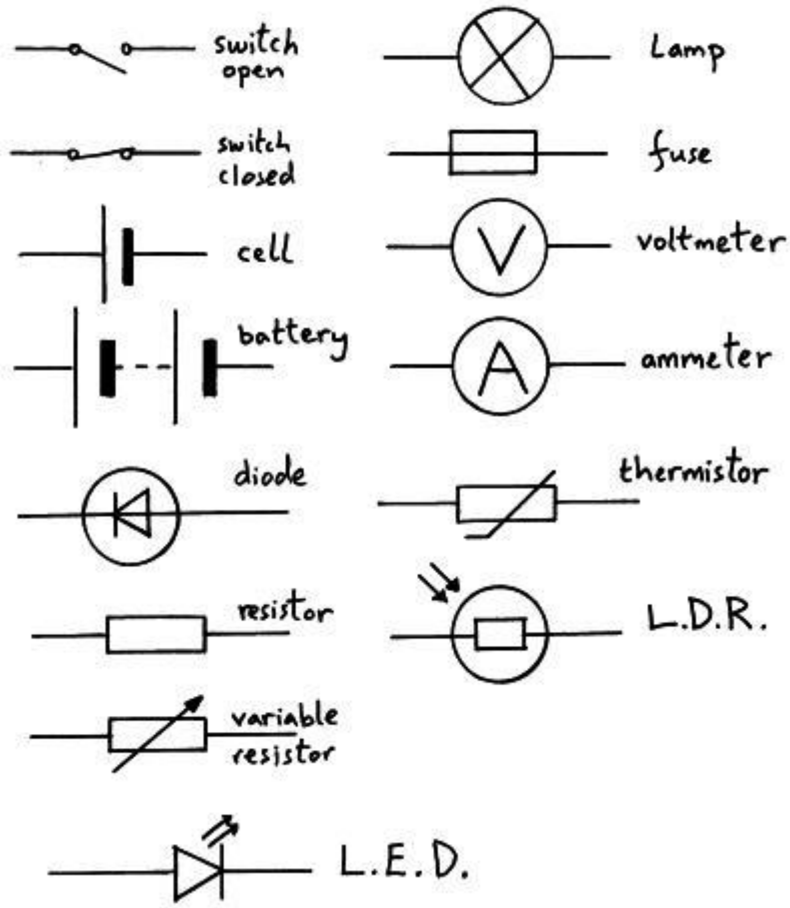
Current = Voltage/Resistance = 2/400 = 1/200 A= 5 mA

3. A current of 0.5 mA flows through a resistor of 100 kΩ . What voltage is needed to do this?

Voltage = Current x resistance = 0.005 x 100 000 = 100 V

15.30 CIRCUIT DIAGRAMS

Below are some of the most common electrical symbols that you are likely to see when looking at diagrams of electrical circuits.

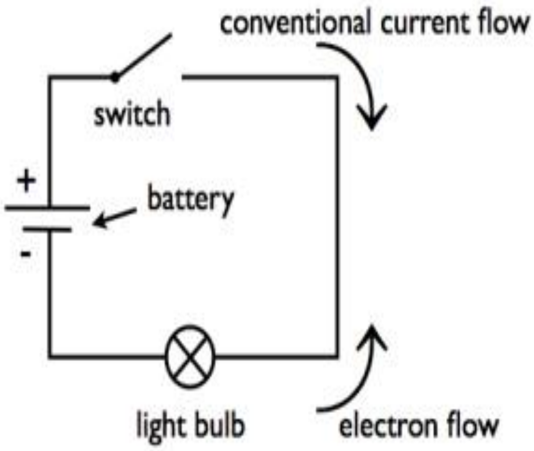


15.31 Electrical Circuits

When one, or more, electrical components are joined together to a cell it is called a circuit. Electricity will not flow if there are any breaks in this circuit.

Battery: provides the power needed to operate the circuit (can also be another power source such as solar energy, wind energy, etc.)

Conventional Current (I): Conventional current is the current whose direction is along the direction of the motion of positive charge under the action of electric field and in the direction opposite to that of motion of electrons.



Electron Flow: movement of electrons; from negative to positive

The current flows out of the positive side, through the circuit, and into the negative terminal of the source. The movement or flow of electrons in a closed circuit produces electricity.

15.32 Circuit Rules

- *As the charged particles flow around a circuit they don't get used up*; it is the energy that the charged particles carry that decreases as they move around the circuit.

  So if you have 12 amps leaving the battery, there will be 12 amps in the circuit and 12 amps returning to the battery.

- *Voltage changes as the charge moves around the circuit*. The potential energy given to the charge is changed into heat energy in the circuit. An electron may leave a battery with 6 V, but will return to the battery with 0 V. This gives a change in potential of 6 V, hence the words 'potential difference'.

15.40 CIRCUITS

In this section we deal with the mathematics of more than one resistor in a series or parallel circuit. There are two main types of circuits you need to know about and each has two rules that make calculations simpler:

15.41 Series Circuit

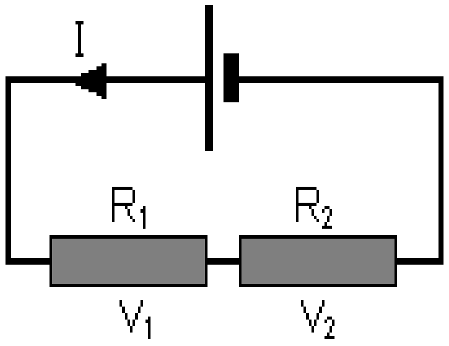


Figure 1

Two resistors in series are shown in Figure 1 above.

The current (I) flowing through R_1 and R_2 is the same and so the potential differences across them are $V_1 = IR_1$ and $V_2 = IR_2$

Since the total potential difference across them is

$$V = V_1 + V_2$$

Therefore $V = IR = IR_1 + IR_2$ where R_T is the effective series resistance of the two resistors.

So: $R_T = R_1 + R_2$

Example

Find the total resistance for two resistors, R1 and R2 connected in series.

$R_1 = 50\ \Omega$, $R_2 = 100\ \Omega$

Solution

$R_T = R_1 + R_2 = 50\ \Omega + 100\ \Omega = 150\ \Omega$

$R_T = 150\ \Omega$

Note:

- the total resistance is larger than either of the individual resistors.
- the current is the same all the way around the circuit.
- the voltage is divided between the components in the circuit.

15.42 Parallel circuits:

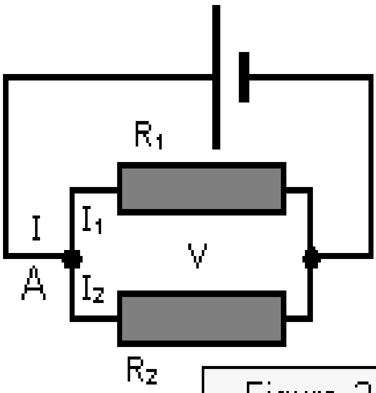


Figure 2

Two resistors in parallel are shown in Figure 2 above.

The potential difference (V) across each of the two resistors is the same, and the current (I) flowing into junction A is equal to the sum of the currents in the two branches therefore:
$I = I_1 + I_2$

But since $V = I_1R_1 = I_2R_2$ $I = V/R = V/R_1 + V/R_2$

so to find the effective resistance we use

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

where R_T is the effective resistance of the two resistors in parallel.

Example

Find the total resistance for two resistors, R1 and R2 connected in parallel.

$R_1 = 50\ \Omega$, $R_2 = 100\ \Omega$

Solution

$1/R_T = 1/R_1 + 1/R_2 = 1/50 + 1/100$

$1/R_T = 0.02 + 0.01$

$= 0.03$

So $R_T = 33.3\ \Omega$

Note:

- the total resistance is smaller than either of the individual resistors in parallel
- the current divides to travel along each loop.
- the voltage is the same across each loop.

Examples
1. Calculate the resistance of the following combinations:
(a) 100 Ω and 50 Ω in series
(b) 100 Ω and 50 Ω in parallel

Solution
(a) $R = R_1 + R_2 = 100 + 50 = 150\ \Omega$
(b) $1/R_T = 1/R_1 + 1/R_2 = 1/100 + 1/50 =$ and so $R = 33\ \Omega$

2. Calculate the current flowing through the following when a p.d of 12 V is applied across the ends:
(a) 200 Ω and 1000 Ω in series
(b) 200 Ω and 1000 Ω in parallel

Solution
(a) resistance = 1200 Ω. Using I = V/R = 12/1200 = 0.01 A = 10 mA
(b) resistance = 167 Ω. Using I = V/R = 12/167 = 0.072 A = 72 mA

3. You are given one 100 Ω resistor and two 50 Ω resistors. How would you connect any combination of them to give a combined resistance of:
(a) 200 Ω (b) 125 Ω

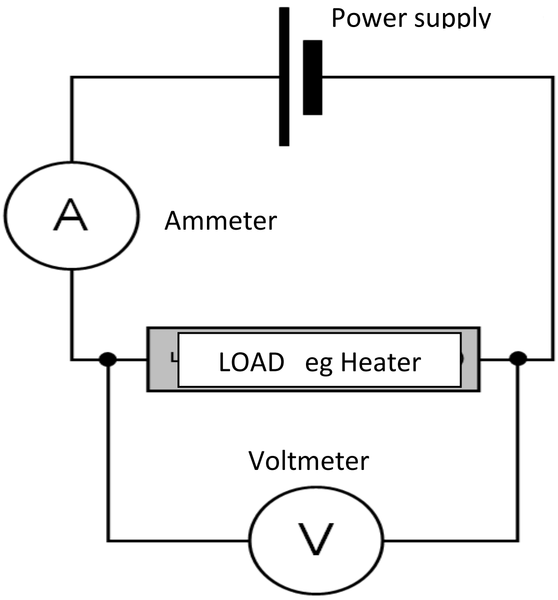
Solution
(a) 100 Ω in series with both the 50 Ω .
(b) the two 50 Ω in parallel and this in series with the 100 Ω

15.50 MEASURING CURRENT AND VOLTAGE

To measure current we use an ammeter**.** It is placed in series in a circuit to measure the amount of charge flowing through it per second.

To measure voltage we use a voltmeter. It is placed in parallel to compare the potential at two different points, either side of a component. It can then measure the potential difference or voltage across the component.

The diagram shows the correct connections for an ammeter and a voltmeter. The ammeter is connected in series with the load and the voltmeter is connected in parallel with the load.



When you make up the circuit connect the cell, load (resistor etc.) and the ammeter first. When this is correct **THEN** connect the voltmeter across the load.

15.60 ELECTRICAL POWER

Most appliances are usually marked with the power at which they run and we can work out how much energy they will use in a certain time. We can do this using the formula:

$$\text{Power} = \frac{\text{Energy}}{\text{Time}}$$

[Power in Watts, time in seconds, energy in Joules]

A light bulb may be marked 100 W.
A normal electric jug heater is usually 1 kW.
A TV may be rated at 250 W.

These figures tell you how POWERFUL the appliance is or much electrical energy it uses in a second. In other words the RATE at which electrical energy is converted to other forms.
In one second the 100 W light bulb uses 100 J of electrical energy and converts some of it into light energy.
However in one second the normal electric jug heater uses 1 kW (1000 W) of electrical energy and converts it into heat energy.

Using the equation:

$$\text{Energy} = \text{Voltage x Current x Time} = \text{Voltage x Charge}$$

And so:

$$\text{Power} = \frac{\text{Energy Converted}}{\text{Time}} = \frac{\text{Voltage x Current x Time}}{\text{Time}}$$

so the formula for electrical power is:

$$\text{P} = \text{VI}$$

where P is the electrical Power.

[Power is measured in Watts with current in amps and voltage in volts].

Using Ohm's law (V = IR) we can derive two alternative versions of the power equation:

Electrical power = VI = I^2R = V^2/R

Examples

1. How much energy is used by a 150 W black and white television if is turned on for 4 hours?

Energy = Power x time = 150 x 4 x 60 x 60 = 2160 000 = 2.16 MJ

2. How much energy is used by a 3 kW immersion heater in 45 minutes?

Energy = Power x time = 3000 x 45 x 60 = 8 100 000 = 8.1 MJ

3. Calculate the electrical power used by an electric motor running from a 240 V supply and taking a current of 0.2 A.

Power = 240 x 0.2 = 48 W

4. Calculate the current drawn from a 12 V battery by a 24 W light bulb.

Current = Power/Time = 24/12 = 2 A

5. Calculate the power of a torch bulb that operates on a current of 60 mA and a voltage of 3 V.

Power = voltage x current = 3 x 0.06 = 0.18 W = 180 mW

15.70 PAYING FOR ELECTRICITY

Electricity, or rather electrical energy costs money. We pay for it when we buy a battery and we pay the electricity board for the electricity that we use from the mains supply.
The electricity board measures the electrical energy that we use not in joules but in units called **kilowatt-hours**.

A kilowatt-hour (kWh) is the energy that a one kilowatt appliance uses in one hour.

Cost = Electrical power x time x cost per unit

Examples
Take the Cost per kWh = $0.33.
1. Calculate the cost of running a 2 kW grill for 20 minutes.

Cost = 2 x 0.33 x 0.331 = $0.22.

2. Calculate the cost of running a 150 W light bulb for 3 hours.

Cost = 0.15 x 3 x 0.33 = $0.15.

A kilowatt-hour (kWh) is also called a UNIT of electrical energy.

Note: From the calculated amount an additional percentage is added as VAT.

15.80 HOUSEHOLD ELECTRICITY

15.81 Direct Current and Alternating Current

Batteries, fuel cells and solar cells all produce something called direct current **(**DC**).** The positive and negative terminals of a battery are always, respectively, positive and negative. Current always flows in the same direction between those two terminals.

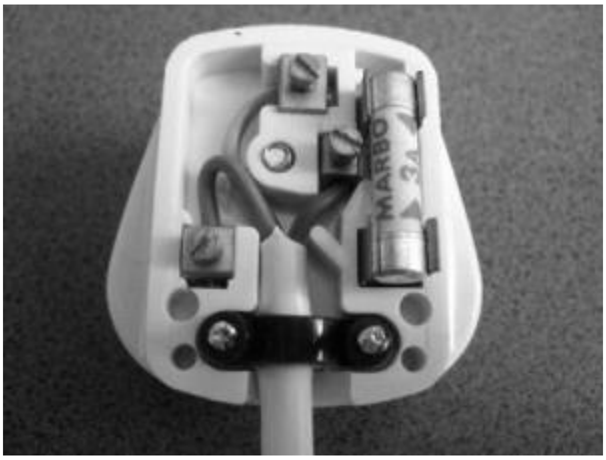
The power that comes from a power plant, on the other hand, is called alternating current **(**AC**).** The direction of the current reverses 50 times per second in Fiji. The power that is available at a wall socket in Fiji is 240V at 50 Hertz.

DC supply **AC supply**

15.82 Three pin plug

The three pin plug contains;

- The blue neutral wire which is held at around 0 volts.
- The green/yellow earth wire.
- The brown live wire which alternates between +240 volts and -240 volts.



15.83 Fuses

The most common fuse sizes are 3A, 5A and 13A (an electric cooker can have a 30A fuse). If the amount of current flowing through the fuse gets bigger than the fuse rating the wire inside the fuse gets hot and melts which disconnects the live wire from the appliance. Fuses are cheap but operate more slowly than circuit breakers.

15.84 Earth Wires

Appliances with metal cases are earthed with an earth wire. Some appliances do not require an earth wire as they are double insulated. If a fault develops and the earth wire connects to the metal case of the appliance, current begins to flow down the earth wire. The extra current being drawn in through the live wire causes the fuse wire in the fuse to heat up and melt. This disconnects the live wire and makes the appliance safe.

15.85 Circuit Breaker

Whenever electrical wiring in a building has too much current flowing through it, these simple machines cut the power until somebody can fix the problem. Without circuit breakers (or the alternative, fuses), household electricity would be impractical because of the potential for fires resulting from simple wiring problems and equipment failures.

Circuit breakers operate much faster than fuses.

There are two types of Circuit Breaker:

- Residual Current Circuit Breakers (RCCB's) which operate by detecting a difference in the current between the live and neutral wires.
- Earth Leakage Circuit Breakers (ELCB's) which detect when current flows through the Earth wire.

Residual Current Circuit Breaker

Earth Leakage Circuit Breakers

15.90 EXERCISES

1. Which has the bigger resistance - a meter of thick silver wire or a meter of thin silver wire?

2. Copy and complete the following table:

Voltage	Current	Resistance
6V	2A	
	0.5A	100Ω
2000V		100Ω
	200mA	5Ω
12V		6Ω
0.5V	50mA	

3. A 50 cm length of constantan wire is connected in series with a bulb and a battery. Should the wire be shortened or lengthened to make the bulb glow brighter?

4. A 6 V battery is connected in turn to a set of lengths of wire. If the currents through the wires are:
(a) 2 A (b) 1.5 A (c) 0.5 A (d) 24 mA (e) 0.002 A
what is the resistance of each piece of wire?

5. A piece of wire with a resistance of 100 Ω is connected in turn to the following batteries. What is the current flowing in each case?
(a) 2 V (b) 5 V (c) 10 V (d) 250 V

6. What is the electrical power of:
(a) a 12 V electric lamp taking 2.5 A
(b) a 240 V kettle taking 5 A
(c) a 12 V model racing car taking 100 mA
(d) a 12 V heater taking 5 A
(e) a power station producing a current of 500 A at 20 000 V

7. Why would you expect the electrical input power of an electric motor to be more than the output mechanical power?

8. Calculate the currents taken by the following appliances:
(a) a 50 W motor running off 10 V
(b) a 150 mW motor running off 1.5 V
(c) a 2 kW heater running off 200 V

9. Calculate the voltages needed:
(a) 3 kW immersion heater taking 12 A
(b) 60 W heater taking 3 A

10. Calculate the powers of the following:
(a) iron, resistance 50 Ω, current 6 A
(b) lamp, resistance 9 Ω, current 3 A

11. Copy and complete the following table:

	Voltage (V)	**Current (A)**	**Resistance (Ω)**	**Power (W)**
1	6	3		
2	20	10		
3	240	0.5		
4		5	100	
5		2	1200	
6	20		10	
7		2		1000
8		3		15
9	12			24
10			2	450

Take the cost of 1 kWh to be $0.331.

12. What does the electrical energy cost to run:
(a) a 3 kW immersion heater for 20 m
(b) a 200 W light bulb for 24 hours
(c) a 2 kW fire for 4 hours a day for 3 months

13. How long can you use the following for $4.00
(a) a 2 kW immersion heater
(b) a 4 kW electric booster
(c) a 150 W light bulb
(d) a 250 W TV

14. Copy and complete the following table:

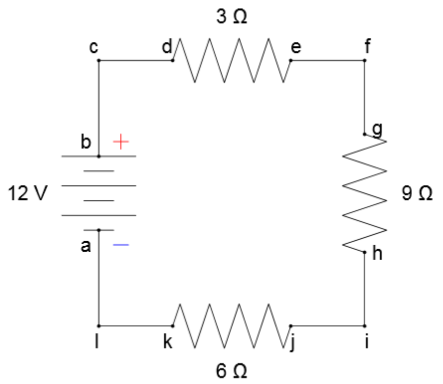
	Appliance	Power	Time	Cost		Appliance	Power	Time	Cost
1	Kettle	2.5 kW	6 min		6	Light bulb	60 W	4 hours	
2	Iron		2 hours	30 cents	7	Light bulb		3 hours	9 cents
3	Washing machine	250 W	45 min		8	Hair drier	0.15 kW		$0.05
4	Stereo	200 W		15 cents	9	Vacuum cleaner	0.5 kW		$0.15
5	Television		4 hours	$0.225	10	Freezer	120 W	6 hours	

15. Copy and complete the following table:
In this table take the cost of one unit to be 33 cents

Power and appliance	Time	Energy (J)	Cost (cents)
2 kW fan heater	2 hours		
200 W light bulb			15
60 W light bulb	5 hours		
3 kW immersion heater			30
2 kW kettle	5 minutes		
150 W stereo	40 minutes		
25 W motor	20 minutes		
500 W cleaner			7.5
300 W hair drier	5 minutes		
250 W drill	40 minutes		
30 W radio			2
120 W TV			2
400 W iron			22.5
7 kW shower	3 minutes		

300 W mower	30 minutes		
75 W electric blanket			45

16. For the given circuit, calculate the following;

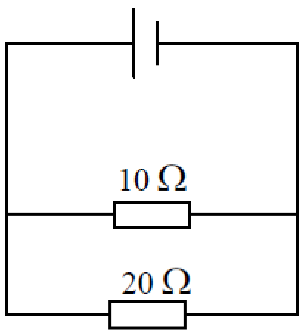


a). equivalent resistance of the circuit.
b). current through the battery

17. Resistors of 5 ohms and 10 ohms are connected in series with a battery supplying 3 V.

a). what is the total resistance?
b). calculate the current which flows in the circuit.

16. in the circuit below, 0.6 A flows through the 10 ohm resistor.



a). calculate the current flowing through the 20 ohm resistor
b). calculate the current flowing through the battery.
c). calculate the voltage supplied by the battery.

CHAPTER 16: ELECTROMAGNETISM

16.0 INTRODUCTION

Electricity involves two charges that attract or repel, and magnetism involves poles that attract or repel. Both electrical charges and magnets possess fields around them. A changing magnetic field creates an electric field, and a changing electric field creates a magnetic field. Magnetism and the electromagnetic effects which have made it possible for us to generate electricity and build electric motors.

16.10 WHAT IS A MAGNET?

A magnet is any piece of material that has the property of attracting iron (or steel). Magnetism may be naturally present in a material or the material may be artificially magnetized by various methods. Magnets may be permanent or temporary. After being magnetized, a permanent magnet will retain the properties of magnetism indefinitely. A temporary magnet is a magnet made of soft iron that is usually easy to magnetize; however, temporary magnets lose most of their magnetic properties when the magnetizing cause is discontinued. Permanent magnets are usually more difficult to magnetize, but they remain magnetized. Materials which can be magnetized are called ferromagnetic materials. Materials with a small attraction to a magnet are called paramagnetic materials. Aluminium, platinum, and manganese are some paramagnetic materials.

Magnetism is the force of attraction or repulsion in and around a material. Magnetism is present is all materials but at such low levels that it is not easily detected. Certain materials such as, iron, steel, nickel, cobalt and alloys of rare earth elements, exhibit magnetism at levels that is easily detectable.

One end of any bar magnet will always want to point north if it is freely suspended. This is called the north-seeking pole of the magnet, or simply the North Pole. The opposite end is called the South Pole. The needle of a compass is itself a magnet, and thus the north pole of the magnet always points north, except when it is near a strong magnet.

Opposite poles will attract and like poles will repel.

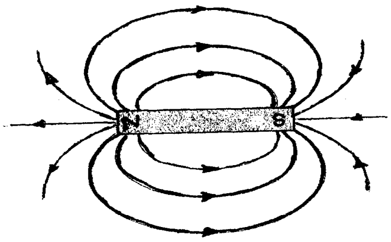
16.11 Magnetic Fields

The poles of a magnet exert forces. The region in which these forces act is known as a magnetic field.

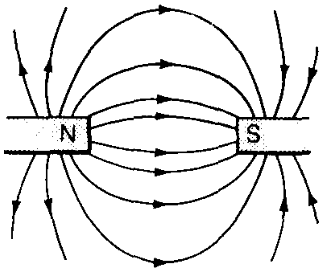
Symbol: B *Units*: Tesla (T)

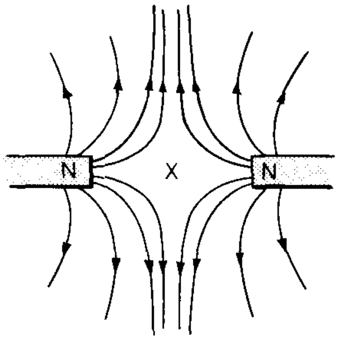
The direction of the field is shown by small arrows on the lines. The magnetic field lines go from a North Pole towards a South Pole. Stronger fields are indicated by closer lines.

16.12 Field around A bar Magnet



16.13 Field between Magnets

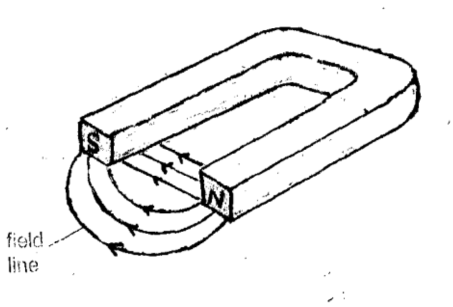




Note: At x the field from one magnet cancels out the field from another.

16.14 Horseshoe Magnet

A horse shoe magnet has the magnetic poles closer so there is a very strong field region between its poles.



16.15 Induced Magnets

Magnetic Induction is one of the ways making magnetic materials like steel and iron into magnets. In other words, magnetic induction is a process of inducing magnetism in an ordinary piece of magnetic material. This method involves simply placing the magnetic material (soft iron) close to a strong magnet without touching. The soft iron bar becomes an induced magnet with the end nearer the magnet having opposite polarity to that of the magnet. Hence, the soft

iron bar is attracted and attached to the permanent magnet. Magnetic induction process reveals how magnetic materials can be attracted to magnets. Induced magnetism is a temporary process. If the permanent magnet is removed, the magnetic material will usually lose its induced magnetism.

16.20 MAGNETIC EFFECT OF A CURRENT

Movement of electric charge is an underlying cause of magnetism. Hence, an electric current, being a flow of charge, produces a magnetic field. If the current is flowing in a wire, the shape of the magnetic field is dependent on the configuration of the wire. The greater the current, the stronger the field it create.

Symbols

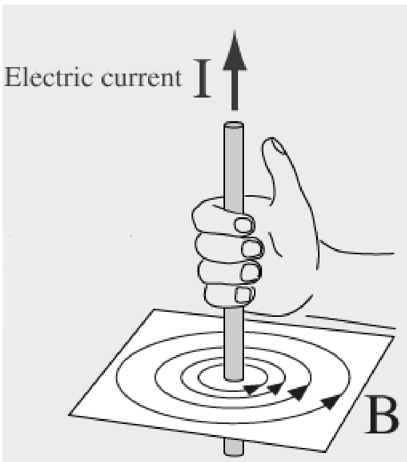
Current into page	Current out of page
$\otimes$	$\odot$

16.21 Field Due To a Current in a Straight Wire

The magnetic field lines produced by a current in a straight wire are in the form of circles with the wire as its centre. Right-hand rule can be used to find the direction of the magnetic field produced due to current flow.

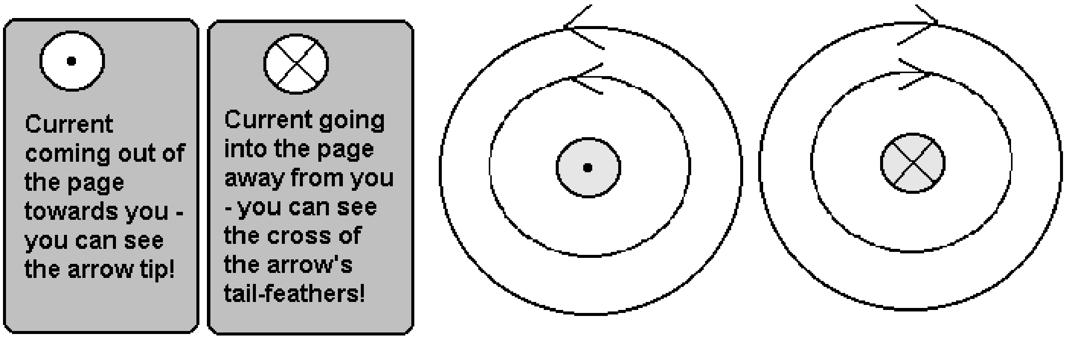
Right-hand rule:

Grasp the wire with right hand so that the thumb points in the direction of the conventional current, then the wrapped fingers will encircle the wire in the direction of the magnetic field.



The magnetic field is strong in the region around the wire and weakens with increasing distance, i.e., the field lines near the wire are drawn closer to another. With increasing distances, concentric circles are further apart.

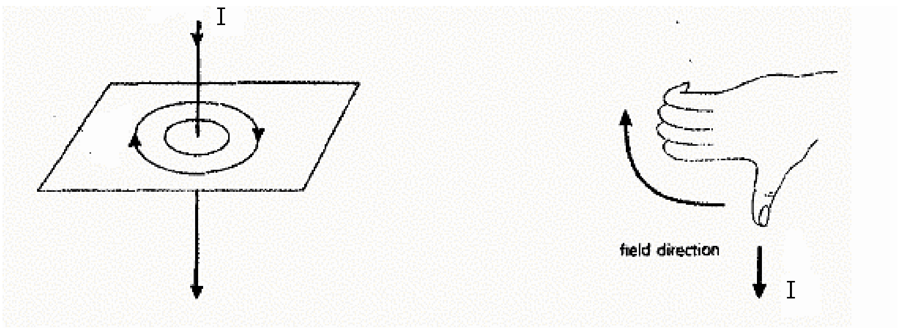
16.22 Current In And Out Of the Page



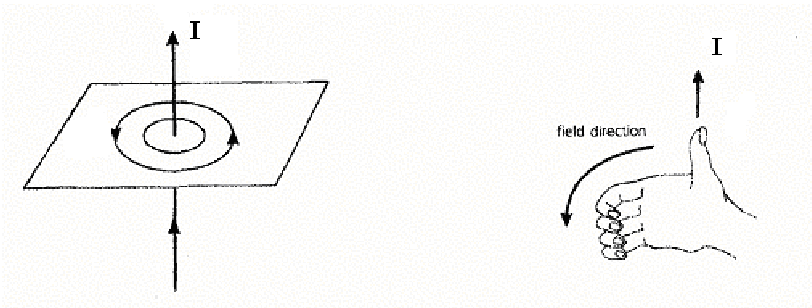
Source: http://www.cyberphysics.co.uk/topics/magnetsm/Electromagntism.htm

Current out of the page will give a field in the anticlockwise direction. The current into the page will give a clockwise direction.

16.23 Current Downwards



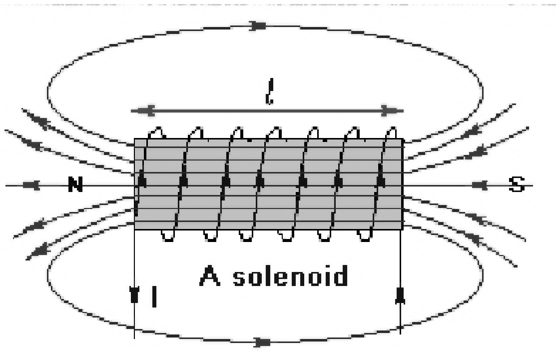
16.24 Current upwards



16.25 Field Due to a Solenoid

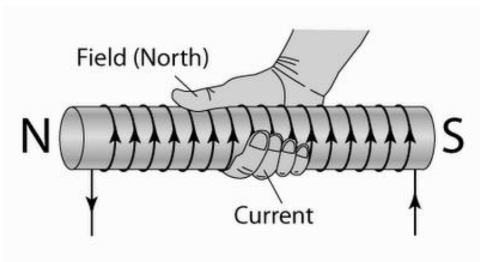
Solenoid consists of a length of insulated wire coiled into a cylinder shape. Current in solenoid produces a stronger magnetic field inside the solenoid than outside. The field lines in this region are parallel and closely spaced showing the field is highly uniform in strength and

direction. Field lines outside the solenoid are similar to that of a bar magnet and it behaves in a similar way – as if it had a north pole at one end and South Pole at the other end. Strength of the field diminishes with distance from the solenoid.



The **right hand grip rule** can be used to indicate the polarity:

"*If the coil is clasped in the right hand so that the fingers curl in the direction of current, the thumb points in the direction of magnetic field.*"



Strength of the magnetic field can be increased by:

1. increasing the current in the coil
2. increasing the number of coils in the solenoid; and
3. Using a soft iron core within the solenoid.

Note

Reversing the direction of the current reverses the direction of the magnetic field.

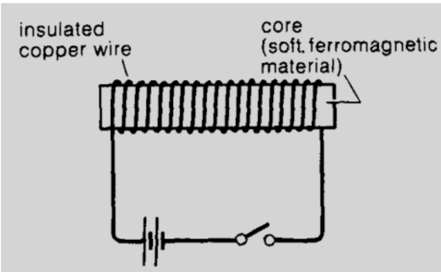
16.30 ELECTROMAGNETS

All currents have a magnetic field around them. All the cables connecting electrical appliances to the mains in your home will have magnetic fields around them. A straight wire has a circular magnetic field around it. A coil of wire has a magnetic field around it, that is the same shape as a bar magnet.

If the conventional current flows the other way, the magnetic field will be in the opposite direction.

These types of magnets are called electromagnets**.** They are temporary magnets as they can be turned on and off with the current. Normal bar magnets are permanent magnets because it is very difficult for them to lose their magnetism.

If the coil is wrapped around a soft iron the strength of the magnetic field can be greatly increased.



Electromagnets can be made stronger by:

(i) Increasing the current.

(ii) Increasing the number of turns.

(iii) Using soft iron core. It is more easily magnetized and demagnetized.

16.31 Advantages of Electromagnet

(i) They can be made stronger than permanent magnets.

(ii) The strength is easily controlled by regulating the current.

(iii) Electromagnets practically lose all magnetism immediately the current is turned off.

Note

Iron and steel behave slightly differently as cores, because iron is magnetically soft and steel is magnetically hard**.**

Electromagnetism.

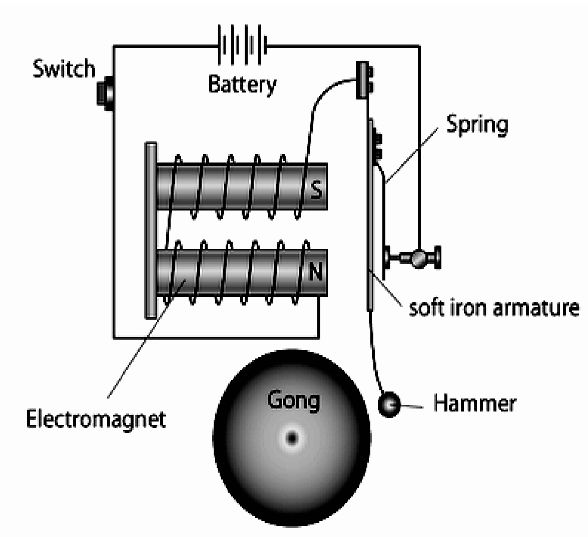
Magnetically hard, for example, steel	Magnetically soft, for example, iron:
Harder to magnetize.	- Easy to magnetize.
- Stays magnetic after the current is switched off.	- Loses its magnetism quickly when the current is switched off.

16.32 Application of Electromagnets

Electromagnets can be used for such tasks as moving cars or sorting metals from other landfill materials. Other applications are in circuit breakers, magnetic relays, electric bells, audio and video tapes transformers etc.

Electric Bell

When the 'push' switch is depressed, the circuit is closed. Current passes through the electromagnet windings and the core becomes magnetized. The magnetized core attracts the iron armature which makes the hammer hits the gong.

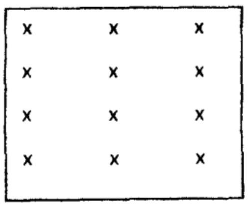


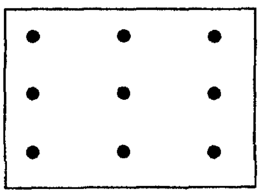
However, the movement of the armature opens the 'make and break' switch which switches the electromagnet off. The iron armature springs back to its original position, closing the 'make and break' switch and start the cycle again.

16.33 Representing Magnetic Field Lines on a Page

Field going into the page

Field out of the page





16.40 THE MOTOR EFFECT

Force on a current carrying conductor in a magnetic field.

When two magnets are close together, they affect each other and produce a force. The same happens when any two magnetic fields are close together. If a wire carrying a current is placed in a magnetic field a force is produced. This is called the **motor effect.** The direction of the force will depend on the direction of the magnetic field and the direction of the current in the field.

Note:

The current, magnetic field and force will always be at right angles to each other, so the wire will not move towards the poles.

When a current carrying conductor is placed in a magnetic field, a **FORCE** is produced.

Current + *Field* = *Force* (motion) ⟶

The magnitude of the force is given by:

$$F = BIL$$

Where: B = magnetic field strength (T)

I = current flowing (A)

L = Length of conductor (wire) in the field (m).

The above formula shows that the size of the force depends on:

(i) the strength of the magnetic field.

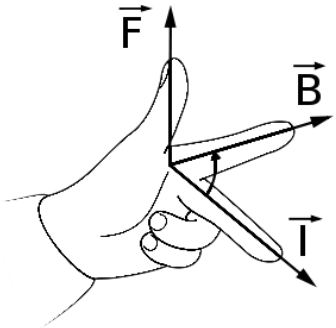
(ii) the size of the current.

(iii) the length of the conductor.

The direction of movement of a current carrying wire in a magnetic field can be determined using Fleming's Left Hand Rule

Fleming's left hand rule (for electric motors) shows the direction of the thrust on a conductor carrying a current in a magnetic field. The left hand is held with the thumb, first finger and second finger mutually at right angles.

- The First finger represents the direction of the magnetic field. (North to South)
- The Second finger represents the direction of the Current (the direction of the current is the direction of conventional current; from positive to negative).
- The Thumb represents the direction of the Force or resultant Motion.



Note:

1. When the wire is perpendicular to the field, force is maximum.
2. If the wire is parallel to the field, then force is zero i.e. **F = 0.**

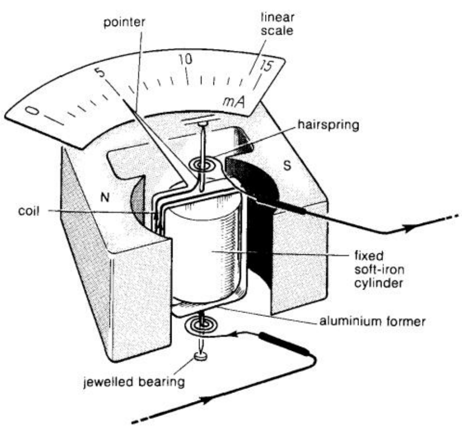
16.50 APPLICATIONS

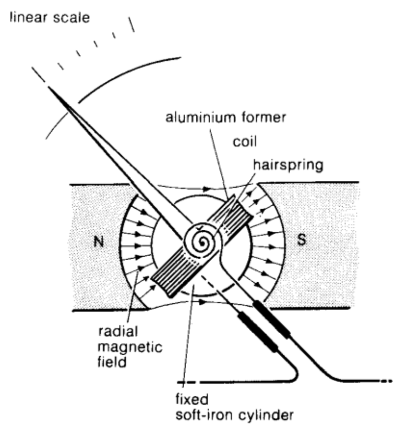
Several devices make use of the fact that a force acts on a current carrying conductor when it is in a magnetic field.

Some common devices are:

1. **Moving coil Galvanometer**

Purpose: used to detect small currents.





The forces on the coil are caused by the motor effect. When a current is passed through the coil, the coil turns in the magnetic field and moves the pointer across the scale. As the coil turns, the hair spring (return spring) is twisted. The coil and the pointer will stop when the restoring forces of the hairspring is equal to the forces produced by the current in the coil. The higher the current the greater is the deflection of the coil and further the pointer moves along the scale. When the current stops the return spring sets the pointer reading back to zero.

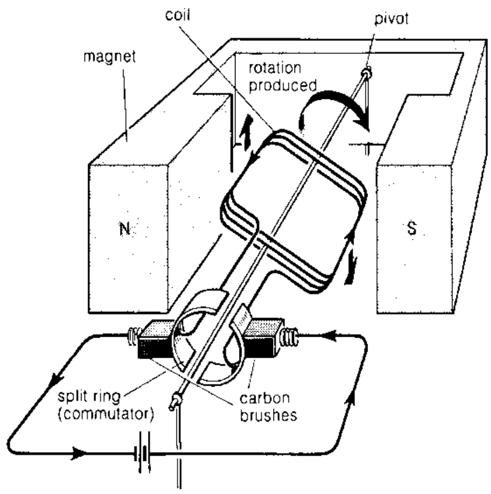
2. Motor

An electrical motor is a device that converts electrical energy to mechanical energy. It works on the principle of the interactions between the magnetic fields of a permanent magnet and the field generated around a coil conducting electricity. The attractive and repulsive forces between the magnet and the coil create rotational motion.

DC electric motor

When a coil of wire is used instead of a single length, the forces on the two sides will act together to turn it.

The current on the left hand side of the coil flows in the opposite direction to the current through the right hand side. From the left hand motor rule it follows that an upward force is acting on one side of the coil and a downward force acts on the other.



Features of a DC Motor

Part	Function
Magnet	Provides the magnetic field
Coil or Armature	Carries a current in the magnetic field
Split Ring	It reverses the current every half a cycle so that the direction of the rotation of the coil is maintained. This provides continuous motion.
Carbon Brushes	Slides over the split ring and conducts electricity into the coil. It is mounted permanently.

16.60 ELECTROMAGNETIC INDUCTION

Faraday found out that if a bar magnet is moved towards a coil of wire then current is induced or generated in a coil. The same thing happened when the magnet is moved away from the coil. No current was induced when the magnet was stationary.

You can see that any current in a magnetic field will produce a force, which may make something move. The opposite affect is that if a wire is moved in a magnetic field, a voltage is produced, and if there is a complete loop, a current will flow. This is how electricity is generated.

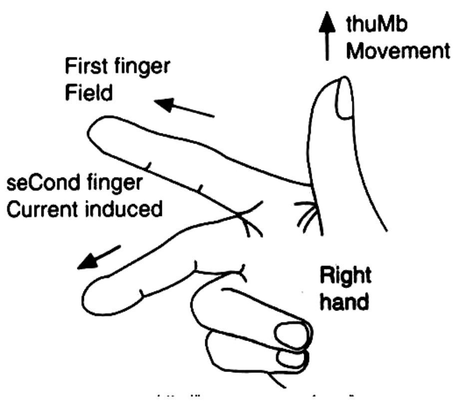
Faraday's Law:

"An *induced voltage is produced across a conductor whenever magnetic field lines move across it"*.

16.61 Direction of induced voltage

Straight wire:

Fleming's right hand rule (for generators) shows the direction of induced current flow when a straight conductor moves in a magnetic field. The right hand is held with the thumb, first finger and second finger mutually perpendicular to each other (at right angles), as shown in the diagram.



- The Thumb represents the direction of Motion of the conductor.
- The First finger represents the direction of the Field. (north to south)
- The Second finger represents the direction of the induced or generated Current (the direction of the induced current will be the direction of conventional current; from positive to negative).

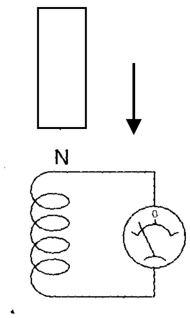
Coil of wire: (Use Lenz's Law)

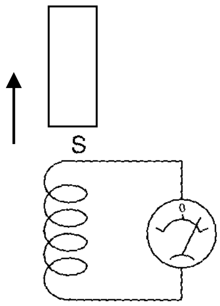
Lenz's Law:

"The direction of the induced current is such as to oppose the cause ".

16.70 THE GENERATOR EFFECT

An induced voltage (hence current) is set up when there is relative movement between the magnetic field and a coil of wire. The direction of induced current is found by Lenz's law.

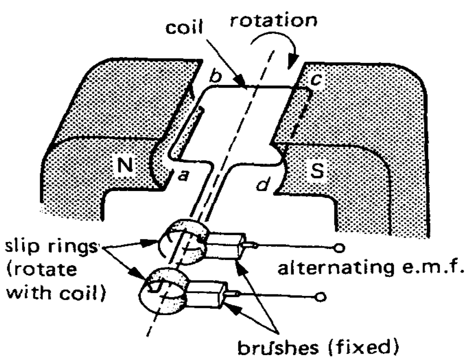




The induced current opposes the motion of the magnet. If a North pole is moved towards the coil then the induced current sets up a North Pole to stop its approach (like poles repel). If the North Pole is moved away then the induced current sets up a South Pole to stop its approach (unlike poles attract).

16.71 The AC Generator

Purpose: produces alternating current (a.c).



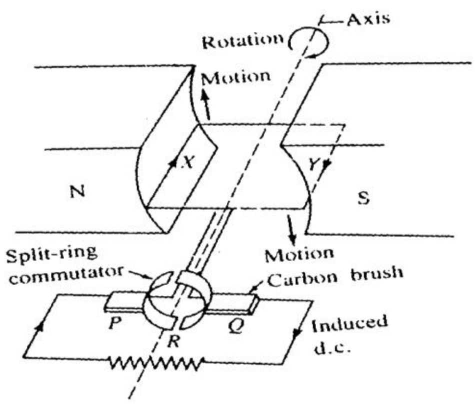
Parts and Functions of AC Generator

Part	Function
Magnets	Provides the magnetic field in which the coil rotates.
Coil of wire	Rotates in the magnetic field. Usually made of copper of a very low resistance wound around a very soft core.
Slip Rings	Are always in contact with the carbon brushes and provides a path for the current to flow.
Carbon Brushes	Two carbon brushes (made of graphite) press around the slip rings to maintain contact at all times.

16.72 Simple DC Generator (Dynamo)

Purpose: produces direct current (DC).

A DC generator uses *split rings* (commutator) instead of *slip rings*. All the other components are same. The commutator reverses the direction of current every half cycle.



Induced voltage or current can be increased by:

- Increasing the number of turns in the coil.
- Using a stronger magnet.
- Increasing the speed of rotation of the coil.

16.73 Comparison between Motor and Generator (Summary)

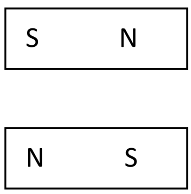
	Motor	**Generator**
Principle	Motion is obtained from a current carrying conductor placed in a magnetic field	Current is induced by moving a conductor in a magnetic field such that it cuts the magnetic field.
Direction	Direction of motion can be determined by left hand motor rule	Direction of motion can be determined by right hand generator rule.

16.80 EXERCISES

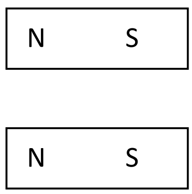
1. Sketch the magnetic field pattern around the following arrangements of permanent magnets and electromagnet.

I

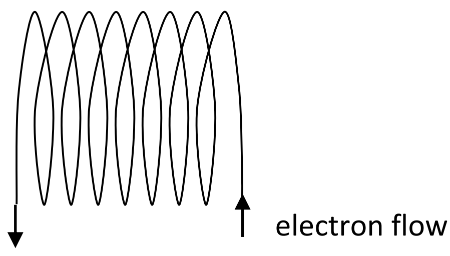
II



III

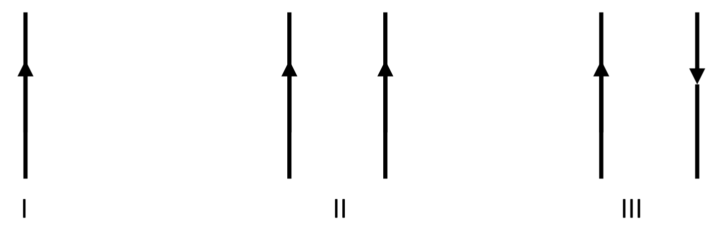


IVV



V

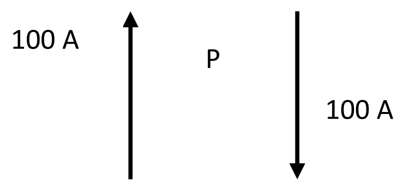
2. In the following diagrams wires are drawn and the arrow direction shows the direction of the electrons in the wires.
Copy the diagrams and on them sketch magnetic field lines around the current-carrying wires.



3. A straight conductor of length 50 mm carries a current of 1.4 A. The conductor experiences a force of 4.5×10^{-3} N when placed in a uniform magnetic field of magnetic induction 90 mT. Calculate the angle between the conductor and the direction of the magnetic field.

4. A straight conductor of length 1.5 m experiences a maximum force of 2.0 N when placed in a uniform magnetic field. The magnetic induction of the field is 1.3 T. Calculate the value of the current in the conductor.

5. Two long straight parallel wires are 0.10 m apart. The current in each wire is 100 A but the currents in the wires are in opposite directions as shown.



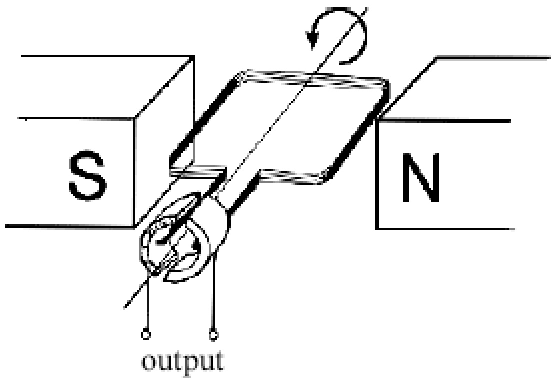
Sketch the magnetic field lines around each of the wires. Use your sketch to determine whether the force between the wires is attractive or repulsive.

6 Define the **motor effect.**

7 State the **two** main ways to generate electricity.

8 State the three ways of increasing the strength of an electric motor.

9. The diagram shows the construction of a simple electrical generator. When the coil is rotated, an alternating voltage is produced at the output.



i) Explain what is meant by an alternating voltage.

ii) State two ways in which the voltage output could be increased.

THE END

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