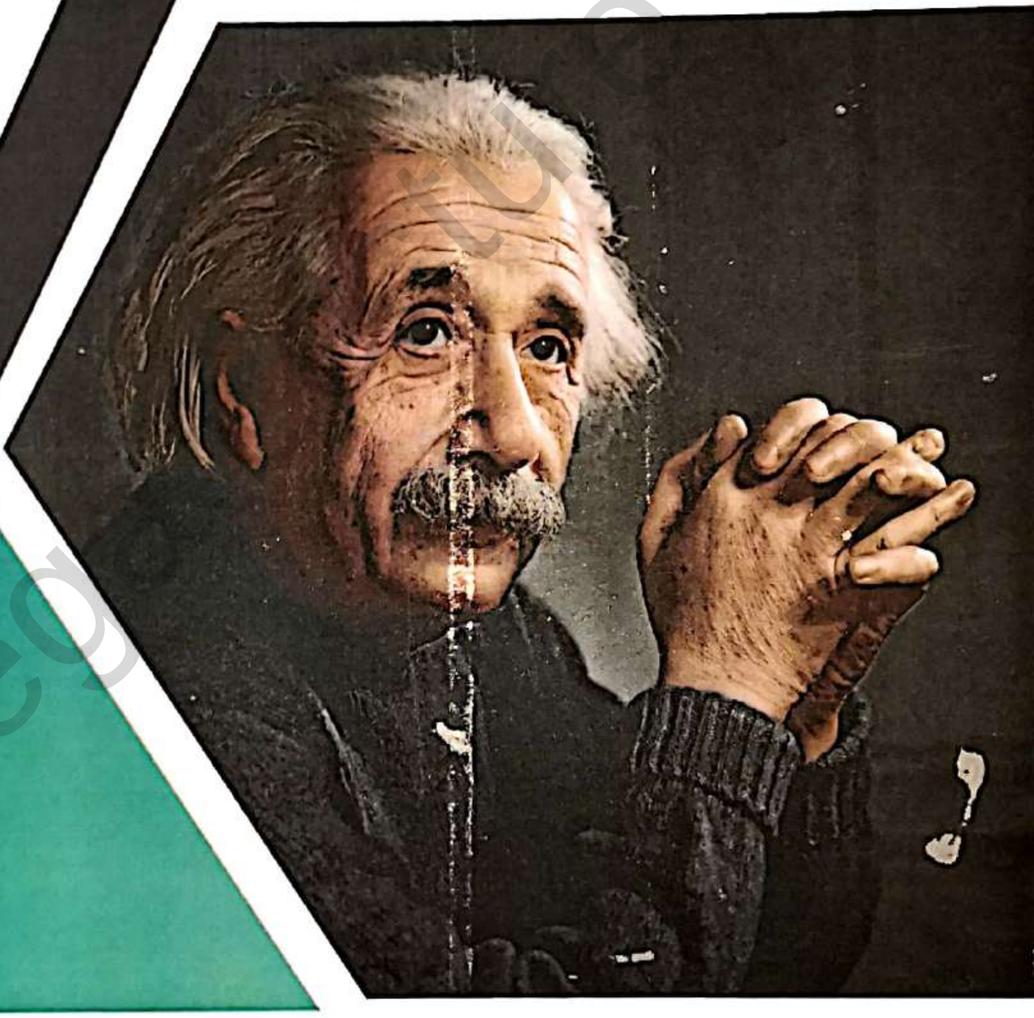
AS Level Notes

PHYSICS



SYED JABRAN ALI KAMRAN

MS BOOKS

Mustafa Asif

AS-Level Physics

Notes

Syed Jabran Ali Kamran

(0336-4864345)

Visiting Teacher AT

LGS (PARAGON)

LGS (PHASE 5)

LACAS (BARKI)

LACAS (GULBERG)

TABLE OF CONTENT

Physical Quantities

Quantitative versus qualitative

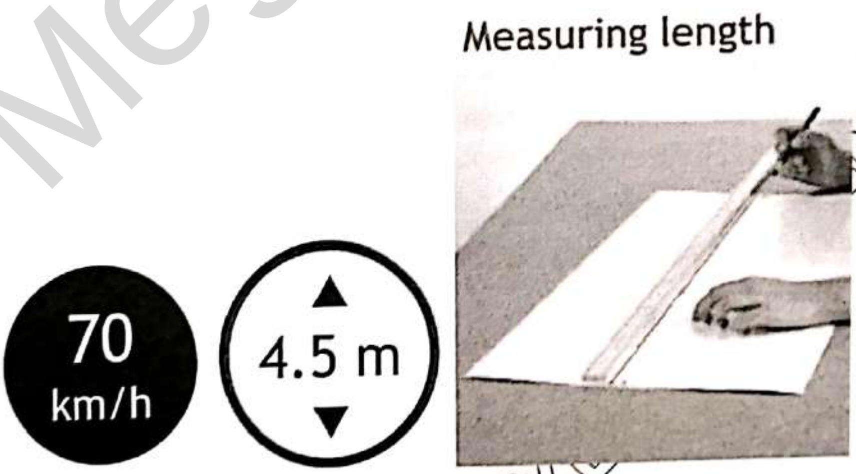
- Most observation in physics are quantitative
- Descriptive observations (or qualitative) are usually imprecise

Qualitative Observations	Quantitative Observations
How do you measure artistic beauty?	What can be measured with the instruments on an aeroplane?
	

Physical Quantities

☞ SI units are used in Scientific works

A physical quantity is one that can be measured and consists of a magnitude and unit.

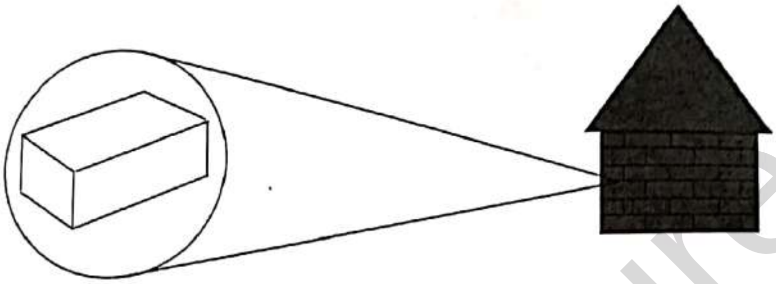


Physical quantities are classified into two types:

1. Base quantities
2. Derived quantities

Base quantity

Base are the quantities on the basis of which other quantities are expressed. For example the brick the basic building block of a house



Derived quantity

The quantities that are expressed in terms of base quantities are called derived quantities. For example is like the house that was build up from a collection of bricks (basic quantity)

SI Units for Base Quantity

SI Units – International System of Units

Base Quantities	Name of Unit	Symbol of Unit
Length	Metre	m
Mass	Kilogram	kg
Time	Second	s
Electrical current	Ampere	A
Temperature	Kelvin	K
Amount of Substances	Mole	Mol

Derived quantity & equations

A derived quantity has an equation which links to other quantities. It enables us to express a derived unit in terms of base-unit equivalent.

Example: $F = ma$; Newton = kg m s^{-2}

$P = F/A$; Pascal = kg m s^{-2}/m^2 = kg m^{-1} s^{-2}

Some derived units

Derived quantity	Base equivalent units	Symbol
Area	Square meter	m^2
volume	Cubic meter	m^3
Speed, velocity	Meter per second	m/s or ms^{-1}
Acceleration	Meter per second squared	m/s/s or ms^{-2}
Density	Kilogram per cubic meter	kg m^{-3}
Amount concentration	Mole per cubic meter	Mol m^{-3}
Force	kg ms^{-2}	Newton
Work/ Energy	kg m^2s^{-2}	Joule
Power	kg m^2s^{-3}	Watt
Pressure	kg $m^{-1}s^{-2}$	Pascal
Frequency	s^{-1}	Hertz

SI Units

1. Equation: area = length × width

   In terms of base units: Units of area = m × m = m^2

2. Equation: volume = length × width × height

   In terms of base units: Units of volume = m × m × m = m^3

3. Equation: density = mass ÷ volume

   In terms of base units: Units of density = kg m^{-3}

Work out the derived quantities for:

1. Equation: $\text{Speed} = \frac{\text{distance}}{\text{time}}$

In terms of base units: Units of speed = ms^{-1}

2. Equation: $\text{Acceleration} = \frac{\text{Velocity}}{\text{time}}$

In terms of base units: Units of acceleration = ms^{-2}

3. Equation: force = mass × acceleration

In terms of base units: Units of force = kg ms^{-2}

4. Equation: $\text{Pressure} = \frac{\text{Force}}{\text{Area}}$

In terms of base units: Units of pressure = $Kgm^{-1}\ s^{-2}$

5. Equation: Work = Force × Displacement

In terms of base units: Units of work = Kgm^2s^{-2}

6. Equation: $\text{Power} = \frac{\text{Work done}}{\text{Time}}$

SI Units – Fill in...

Derived Quantities	Relation with Base and Derived Quantities	Unit	Special Name
Momentum			
Electric Charge			
Potential Difference			
Resistance			

For you to know...

Physical Quantity	Defined as	Unit	Special
Density	Mass (kg) ÷ volume (m^3)	kg m^{-3}	
Momentum	Mass (kg) × velocity (ms^{-1})	kg m^{-1}	
Force	Mass (kg) × acceleration (ms^{-2})	kg m^{-2}	Newton (N)
Pressure	Force (kg ms^{-2} or N) ÷ area (m^2)	kg^{-1} m^{-2} (Nm^{-2})	Pascal (Pa)
Work (energy)	Force (kg ms^{-2} or N) × distance (m)	kg^2 m^{-3} (Js^{-1})	Joule (J)
Power	Wok (kg m^2 s^{-2} or J) ÷ time (s)	Kg m^2 s^{-3} (Js^{-1})	Watt (W)
Electrical charge	Current (A) × time (s)	A s	Coulomb (C)
Potential difference	Energy (kgm^2s^{-2} or J) ÷ charge (A s or C)	kg m^{-2} A s^{-3} (J C^{-1})	Volt (V)
Resistance	Potential Difference (kg^2 A^{-1} s^{-3} or V)	kg m^2 A^{-2} s^{-3} (V A^{-1})	Ohm (Ω)

Reference Link – Physical quantities

http://thinkzone.wlonk.com/Units/PhysQuantities.htm

Key Concepts

1. A physical quantity is a quantity that can be measured and consists of a numerical magnitude and a unit.
2. The physical quantities can be classified into base quantities and derived quantities.
3. There are seven base quantities: length, mass, time, current, temperature, amount of substance and luminous intensity.
4. The SI units for length, mass, time, temperature and amount of substance, electric current are metre, kilogram, second, kelvin, mole and ampere respectively.

Homogeneity of an equation

An equation is homogeneous if quantities on both sides of the equation has the same unit.

• E.g. $s = ut + ½ at^2$

• LHS : unit of s = m

• RHS : unit of ut = ms-1xs = m

• Unit of at2 = ms^{-2} x s^2 = m

• Unit on LHS = unit on RHS

• Hence equation is homogeneous

Non-homogeneous

- $P = \rho g h^2$
- LHS : unit of P = $Nm^{-2} = kgm^{-1}s^{-2}$
- RHS : unit of $\rho g h^2 = kgm^{-3}(ms^{-2})(m^2) = kgs^{-2}$
- Unit on LHS ≠ unit on RHS
- Hence equation is not homogeneous

Homogeneity of an equation

- Note: numbers has no unit
- Some constants have no unit.
- e.g. π,
- A homogeneous eqn may not be physically correct but a physically correct eqn is definitely homogeneous
- E.g. $s = 2ut + at^2$ (homogenous but not correct)
- F = ma (homogeneous and correct)

Magnitude

- Prefix: magnitudes of physical quantity range from very large to very small.
- E.g. mass of sun is 10^{30} kg and mass of electron is 10^{-31} kg.
- Hence, prefix is used to describe these magnitudes.

Significant number

- Magnitudes of physical quantities are often quoted in terms of significant number.
- Can you tell how many sig. fig. in these numbers?
- 103, 100.0, 0.030, 0.4004, 200
- If you multiply 2.3 and 1.45, how many of should you quote?
- 3.19, 3.335, 3.48
- 3.312, 3.335, 3.358

The rules for identifying significant figures

- The rules for identifying significant figures when writing or interpreting numbers are as follows:-
- All non-zero digits are considered significant. For example, 91 has two significant figures (9 and 1), while 123.45 has five significant figures (1, 2, 3, 4 and 5).
- Zeros appearing anywhere between two non-zero digits are significant. Example: 101.1203 has seven significant figures: 1, 0, 1, 1, 2, 0 and 3.
- Leading zeros are not significant. For example, 0.00052 has two significant figures: 5 and 2.

Trailing zeros in a number containing a decimal point are significant. For example, 12.2300 has six significant figures: 1, 2, 2, 3, 0 and 0. The number 0.000122300 still has only six significant figures (the zeros before the 1 are not significant). In addition, 120.00 has five significant figures since it has three trailing zeros.

- Often you will be asked to estimate some magnitudes of physical quantities around you.
- E.g. estimate the height of the ceiling, volume of an apple, mass of an apple, diameter of a strand of hair,

Reference link:

http://www.xtremepapers.com/revision/a - level/physics/measurement.php

Estimates of physical quantities

- When making an estimate, it is only reasonable to give the figure to 1 or at most 2 significant figures since an estimate is not very precise.

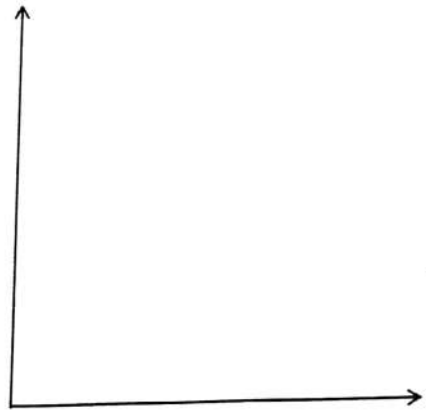
Physical Quantity	Reasonable Estimate
Mass of 3 cans (330 ml) of Pepsi	1 kg
Mass of a medium – sized car	1000 kg
Length of a football field	100 m
Reaction time of a young man	0.2 s

- Occasionally, students are asked to estimate the area under a graph. The usual method of counting squares within the enclosed area is used.

Convention for labelling tables and graphs

- The symbol / unit is indicated at the italics as indicated in the data column left.
- Then fill in the data with pure numbers.
- Then plot the graph after labelling x axis and y axis

t/s	v/ms^{-1}
0	2.5
1.0	4.0
2.0	5.5

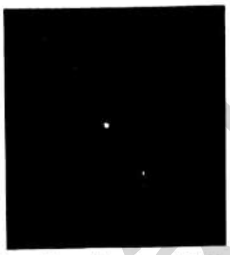


Prefixes

- For very large or very small numbers, we can use standard prefixes with the base units.
- The main prefixes that you need to know are shown in the table.
- Prefixes simplify the writing of very large or very small quantities

Prefix	Abbreviation	Power
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	?	??

- Alternative writing method
- Using standard form
- $N \times 10^n$ where $1 \leq N < 10$ and n is an integer



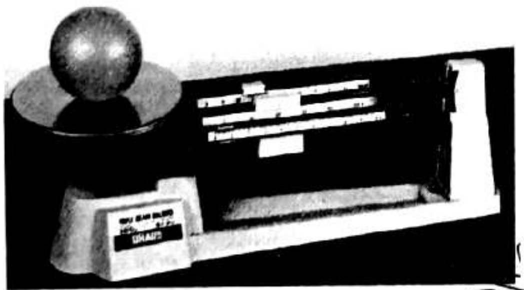
This galaxy is about 2.5×10^6 light years from the Earth.

The diameter of this atom is about 1×10^{-10} m.

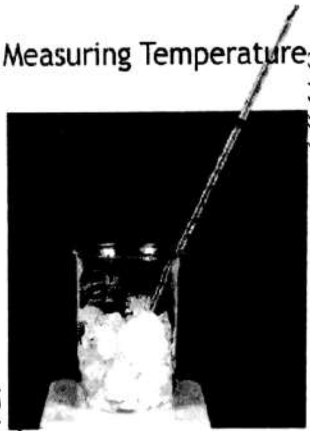
Scalars and Vectors

Scalar quantities are quantities that have magnitude only. Two examples are shown below:

Measuring Mass

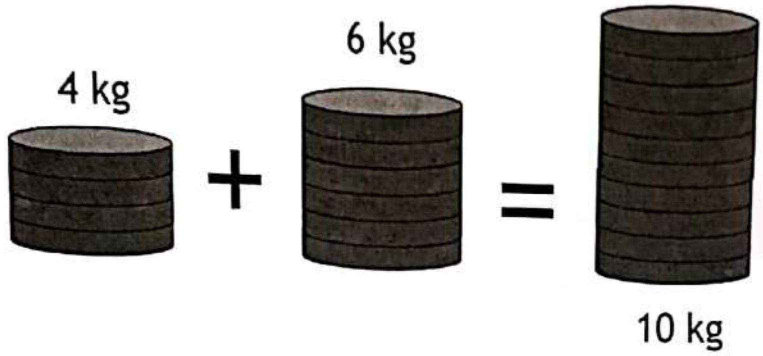


Measuring Temperature



Scalar quantities are added or subtracted by using simple arithmetic.

Example: 4kg plus 6kg gives the answer 10 kg



Vector Quantities

Vector quantities are quantities that have both magnitude and direction

Magnitude = 100 N

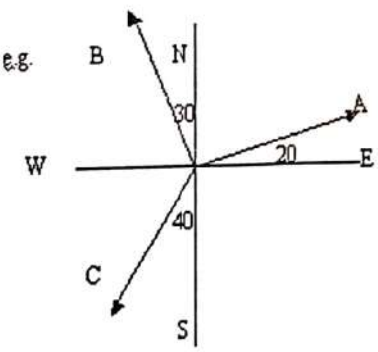
Direction = Left

Examples of scalars and vectors

Scalars	Vectors
Distance	Displacement
Speed	Velocity
Mass	Weight
Time	Acceleration
Pressure	Force
Energy	Momentum
Volume	
Density	

Direction of vector

e.g.



Vector A – E 20° N or N 70° E

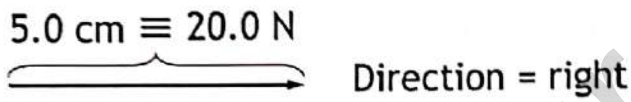
Vector B – N 30° W or W 60° N

Vector C -

Adding/Subtracting Vectors Using Graphical Method

- Parallel vectors can be added arithmetically

- Non – Parallel vectors are added by graphical means using the parallelogram law.
- Vectors can be represented graphically by arrows.

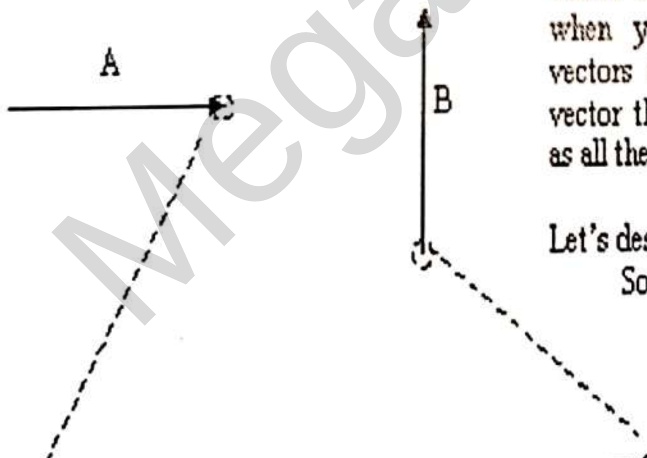


- The length of the arrow represents the magnitude of the vector
- The direction of the arrow represents the direction of the vector
- The magnitude and direction of the resultant vector can be found using an accurate scale drawing.

Vector Addition

(a) Drawing method

E.g. Below are two vectors A and B.



What will be the result of adding them up? The resultant vector is the one that you get when you add two or more vectors together. It is a single vector that has the same effect as all the others put together.

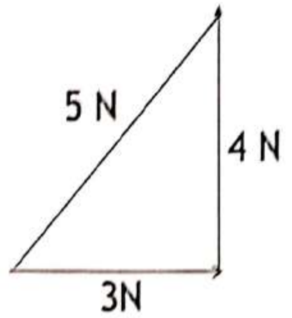
Let's describe the result as C.

So C = A + B

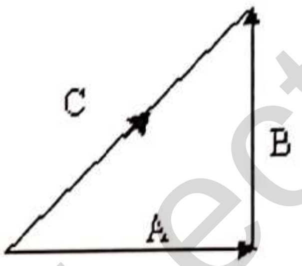
You will connect the two vectors in this manner. The tail of B connects to the head of A

Vector Operation

- Vector problem must be solved vectorically unlike scalar quantity.
- E.g. 3 N + 4 N = 5 N



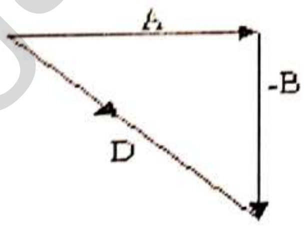
Addition using drawing method



Reference link: Vector addition

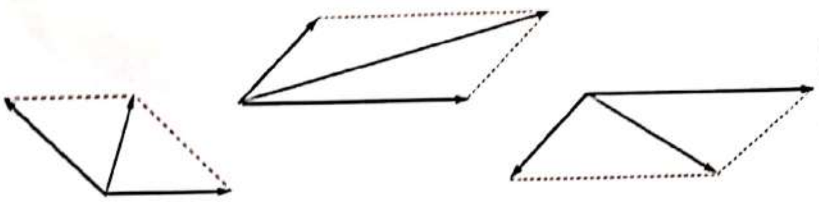
http://www.physicsclassroom.com/class/vectors/u3l1b.cfm

Subtraction using drawing method



Parallelogram law of vector addition

The parallelogram law of vector addition states that if two vectors acting at a point are represented by the sides of a parallelogram drawn from that point, their resultant is represented by the diagonal which passes through that point of the parallelogram



Coplanar Vectors

- When 3 or more vectors need to be added, the same principles apply, provided the vectors are all on the same plane i.e. coplanar
- To subtract 2 vectors, reverse the direction i.e. change the sign of the vector to be subtracted, and add

Change in a Vector

Case 1

If an object changes it's direction but not speed, then velocity vector will only change its direction but not magnitude.

Case 2

If an object changes it's direction and also speed, vector will change its direction as well as magnitude. So the change in the vector would be final minus initial.

Components of a Vector

Any vector directed in two dimensions can be thought of as having an influence in two different directions. That, it can be thought of as having two parts. Each part of a vector is known as a component.

↓ 2N + ↓4N = ↓ 6N (2N and 4N are the components of 6N)

The components of a vector depict the influence of that vector in a given direction. The combined influence of the two components is equivalent to the influence of the single vector. The single vector could be replaced by the two components.

Any vector can be thought of as having two different components. The component of a single vector describes the influence of that vector in a given direction.

$\vec{3}N + \vec{4}N = \vec{7}N$ ($\vec{3}N$ and $\vec{4}N$ are the components of $\vec{7}N$)

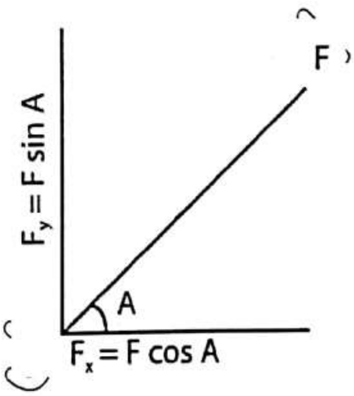
Resolution of vectors

Resolving vectors into two perpendicular components

A vector can be broken down into components, which are perpendicular to each other, so that the vector sum of these two components, is equal to the original vector.

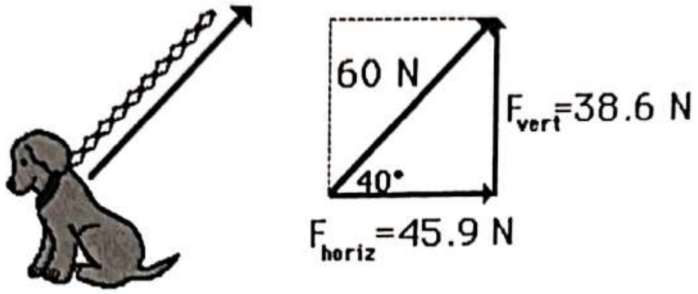
Splitting a vector into two components is called resolving the vector. It is the reverse of using Pythagoras' theorem to add two perpendicular vectors, and so adding the two components will give you the original vector.

Resolving a vector requires some simple trigonometry. In the diagram, the vector to be resolved is the force, F for angle A;



- The horizontal component of $F : F_x = F \cos A$
- The vertical component of $F : F_y = F \sin A$

Note that the two components do not have to be horizontal and vertical. The angle can be changed to any required direction, and both components will still be perpendicular to each other.



$$\sin 40^\circ = \frac{F_{vert}}{60N}$$

$$F_{vert} = 60N \times \sin 40^\circ$$

$$F_{vert} = 38.6N$$

$$\cos 40^\circ = \frac{F_{horiz}}{60N}$$

$$F_{horiz} = 60N \times \cos 40^\circ$$

$$F_{horiz} = 45.9$$

In Short

Vectors addition and subtraction can be performed using diagram method or the resolve and recombine method

Reference links - Vector Resolution

http://www.physicsclassroom.com/class/vectors/u3l1d.cfm

http://www.physicsclassroom.com/class/vectors/U3l1e.cfm

Key Concepts

1. Scalar quantities are quantities that only have magnitudes
2. Vector quantities are quantities that have both magnitude and direction
3. Parallel vectors can be added arithmetically
4. Non-parallel vectors are added by graphical means using the parallelogram law.
5. Vectors addition and subtraction can be performed using diagram method or the resolve and recombine method

Youtube videos links with explanation on:

General Physics - Physical quantities

http://www.youtube.com/watch?v=kuoQUv7bY2Y

http://www.youtube.com/watch?v=Rmy85_EwL0Y&feature=related

Measuring Techniques

Measurement of Length

Length

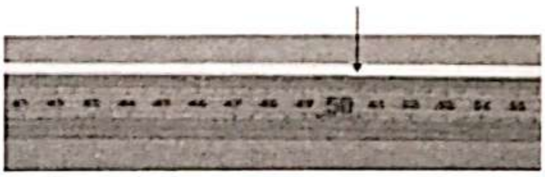
- Measuring tape is used to measure relatively long lengths
- For shorter length, a metre rule or a shorter rule will be more accurate

Methods of measuring length

The metre rule

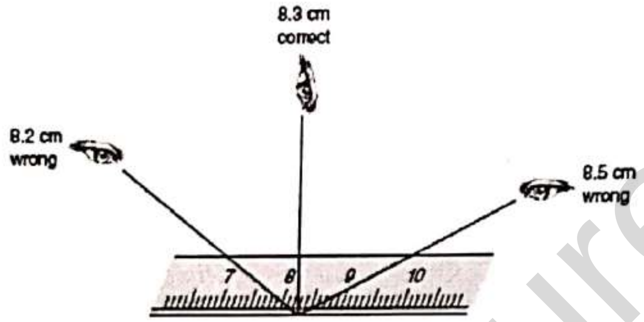
Simplest length-measuring instrument is the metre or half metre rule (i.e 100 cm or 50 cm). Smallest division on the metre rule is 1 mm. Should be able to take a reading with an uncertainty of 0.5 mm. Should be aware of 3 possible errors:

- End of the rule is worn out, giving an end error leading to something called a systematic error
- Calibration of the metre rule i.e. markings on the ruler are not accurate
- Parallax error



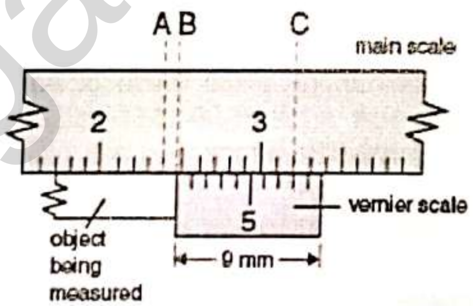
Correct way to read the scale on a ruler

- Position eye perpendicularly at the mark on the scale to avoids parallax errors
- Another reason for error: object not align



Vernier Calipers

- The object being measured is between 2.4 cm and 2.5 cm long.
- The second decimal number is the marking on the vernier scale which coincides with a marking on the main scale.
- Here the eighth marking on the vernier scale coincides with the marking at C on the main scale
- Therefore the distance AB is 0.08 cm, i.e. the length of the object is 2.48 cm

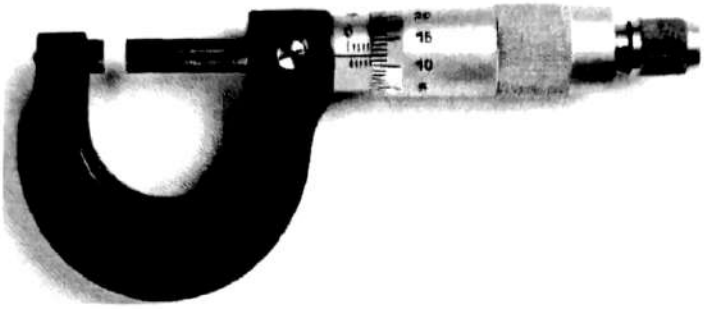


Micrometer Screw Gauge

To measure diameter of fine wires, thickness of paper and small lengths, a micrometer screw gauge is used. The micrometer has two scales:

- Main scale on the sleeve
- Circular scale on the thimble

There are 50 divisions on the thimble. One complete turn of the thimble moves the spindle by 0.50 mm



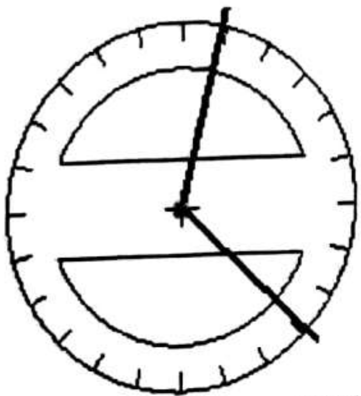
Precautions when using a micrometer

1. Never tighten thimble too much
2. Clean the ends of the anvil and spindle before making a measurement
   - Any dirt on either of surfaces could affect the reading
3. Check for zero error by closing the micrometer when there is nothing between the anvil and spindle.
   - The reading should be zero, but it is common to find a small zero error
   - Correct zero error by adjusting the final measurement

Measurement an Angle

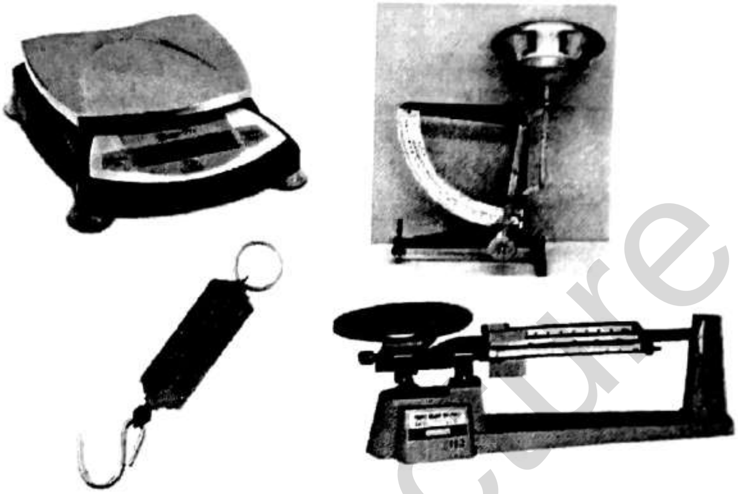
To measure and an angle. Take the Protractor. Place protractor's center at a vertex of the angle (where two lines meet). Click to set the vertex of the angle you will measure. Move the pencil in a circle until it is touching the start of the angle (one of the lines). Click to set the start of the angle.

Move the pencil in a circle until it is touching the end of the angle (other line). Notice that the protractor has marks, indicating 15 degree increments, on its edge. Click to measure angle.



Measurement of Mass

Top-pan balance, The spring balance , Lever balance, Triple Beam Balance



Instruments used are top-pan balance, lever balances and the spring balance. Spring balance measures directly both in force units i.e. Newton and also in kilograms.

Top-pan balance

Ensure that the initial (unloaded) reading is zero. There is a control for adjusting the zero reading, balance may have a tare facility i.e. mass of material added to the container is obtained directly uncertainty will be quoted by manufacturer in the manual, usually as a percentage of the reading shown on the scale

The spring balance

The spring balance is based on Hooke's Law which states that extension is proportional to the load; measurement is made directly by a moving over a circular scale

- Should be careful of zero error, usually has a zero error adjustment screw
- Parallax error

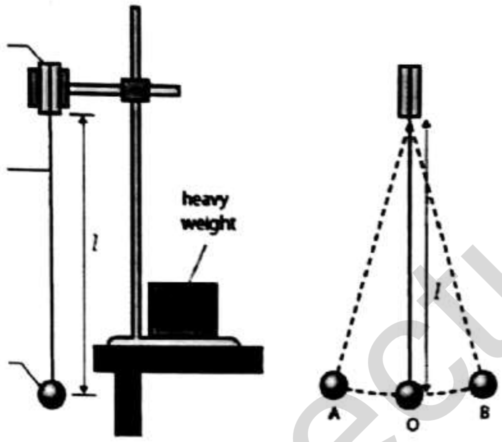
Lever/Beam balances

Lever/Beam balances is based on principle of moments where unknown mass is balanced by a slider, calibrated in mass units. You should be aware of zero error, parallax error.

Measurement of Time

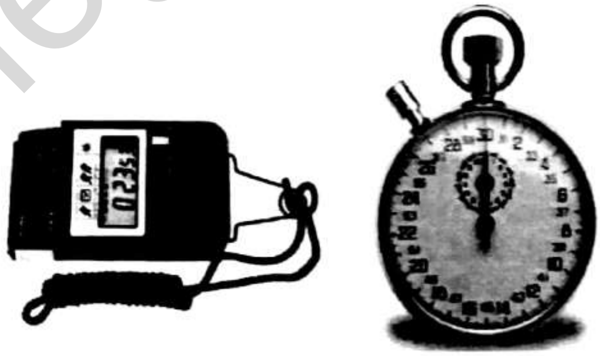
Time

The oscillation of a simple pendulum is an example of a regularly repeating motion. The time for 1 complete oscillation is referred to as the period of the oscillation.



Stopwatch

Stopwatch is used to measure short intervals of time. There are two types: digital stopwatch, analogue stopwatch. Digital stopwatch more accurate as it can measure time in intervals of 0.01 seconds. Analogue stopwatch measures time in intervals of 0.1 seconds.



Errors occur in measuring time

If digital stopwatch is used to time a race, should not record time to the nearest 0.01 s. Reaction time in starting and stopping the watch will be more than a few hundredths of a second

Many instruments do not read exactly zero when nothing is being measured. Happen because they are out of adjustment or some minor fault in the instrument. Add or subtract the zero error from the reading shown on the scale to obtain accurate readings. Vernier calipers or micrometer screw gauge give more accurate measurements.

Application: Measurement of Time

1) Determination of the acceleration of Free Fall

(will study this in detail in chapter : Kinematics)

Reference Notes:

International A level Physics by Chris & Mike

Methods of Measuring Temperature

The Mercury in glass Thermometer

A mercury-in-glass thermometer is a thermometer which provides temperature readings through the expansion and contraction of mercury inside a calibrated tube.

The Thermocouple Thermometer

A thermocouple does not measure absolute temperature, but rather the difference in temperature between two points. When one end of a conductor, such as a metal strip, is hotter than the other, it creates a voltage between the two ends. The greater the temperature difference, the greater the current. Different metals react at different rates, and a thermocouple actually makes use of two metals, joined at the sensor end. At the circuitry end, they are attached to a meter that uses the difference in voltages between the metals to calculate the temperature differential.

Calibration Curves

Calibration curve of a thermometer using a mercury thermometer as a standard

An unmarked thermometer (alcohol in this example.) can be calibrated using a mercury thermometer as a standard. Both thermometers are placed in melting ice (0 degrees C), the length of the alcohol "thread" is noted. A heater is switched on causing the water temperature to gradually increase. For at least six temperature values the corresponding length of the alcohol thread is noted. A graph of length of alcohol thread against temperature is the required calibration curve.

Analysis:

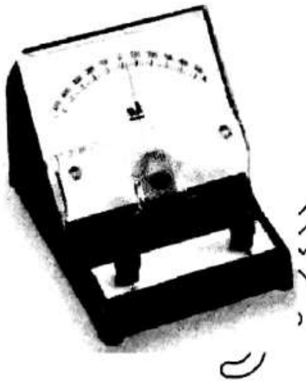
Plot a graph, on graph paper, of length of alcohol thread (y axis) against temperature. Any temperature between 0 and 100 degrees can now be measured using the unmarked thermometer. Place it in a beaker of moderately hot water, measure the length of the alcohol thread and, from the calibration curve, read the corresponding temperature.

Analogue meters

An analogue meter can display any value within the range available on its scale. However, the precision of readings is limited by our ability to read them. For example the meter on the right shows 1.25V because the pointer is estimated to be half way between 1.2 and 1.3. The analogue meter can show any value between 1.2 and 1.3 but we are unable to read the scale more precisely than about half a division.

A Galvanometer

A galvanometer is a type of sensitive ammeter(an instrument for detecting electric current). It is an analog electromechanical transducer that produces a rotary deflection of some type of pointer in response to electric current flowing through its coil in a magnetic field.



Galvanometer – Null method

Any method of obtaining measurements or comparisons, in which the measurement is correct when the deflection of the galvanometer or other indicator is zero, nought or null.

Two obvious advantages attach to null methods in electric galvanometer work - one is that an uncalibrated galvanometer can be employed, the other is that a galvanometer of any high degree of sensitiveness can be employed, there being no restriction as to its fineness of winding or highness of resistance.

Methods of measuring current and potential difference

Digital Meters

A digital meter is a device used by technicians to test and measure electronic circuits. Most of them are portable, battery-powered units. They show measurements as numbers and symbols on an electronic display.

Digital multi-meters measure voltage, current, resistance and related electronic parameters. You select the quantity you want to measure, touch the meter's probe wires to a circuit, then read the results on the display.

Multimeters

A multimeter measures electrical properties such as AC or DC voltage, current, and resistance. Rather than have separate meters, this device combines a voltmeter, an ammeter, and an ohmmeter. Electricians and the general public might use it on batteries, components, switches, power sources, and motors to diagnose electrical malfunctions and narrow down their cause.

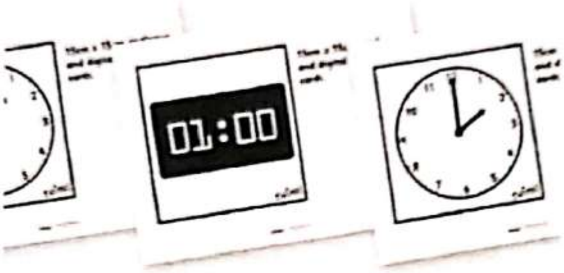
Analogue & Digital

Analogue Scales

Analogue scales have round dials, where a pointer moves clockwise according to the weight applied. Markings are equally spaced between the numbers to indicate fractional amounts.

Digital Scales

Digital scales have LCD or LED number displays. There are no pointers on a digital scale.



Accurate Measurement

Random Errors

Random errors occur in all measurements. They arise when observers estimate the last figure of an instrument reading. It is called random errors because they are unpredictable. You can minimize such errors by averaging a large number of readings.

Systematic Errors

Systematic errors are not random but constant. They can cause an experimenter to consistently underestimate or overestimate a reading due to the equipment being used – e.g. a ruler with zero error. This may be due to environmental factors – e.g. weather conditions on a particular day. It cannot be reduced by averaging, but they can be eliminated if the sources of the errors are known

Difference between	Systematic	Random
Direction of error	---	Both direction (plus/ minus)
Eliminate/ reduce	Can be eliminated Cannot reduce	Can reduce Cannot eliminate

What type of error is

a) Reaction time?

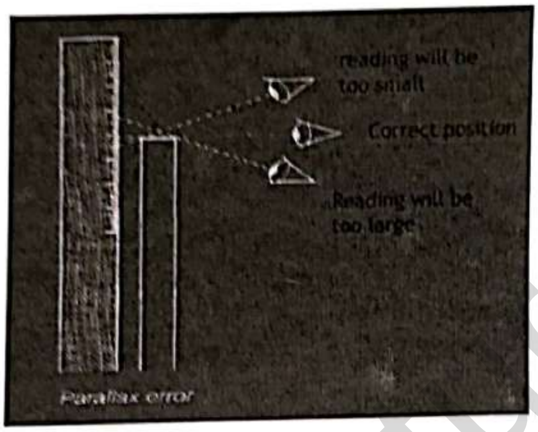
b) Parallax error?

Systematic Errors

These are errors in the experimental method or equipment where readings are either always too big or always too small compared to the actual value. For example, if your newton-meter reads 0.2 N with no weights on it, then your measurements of force will always be 0.2 N too large.

What are zero errors?

Remember to check for any zero errors for your measuring instruments before you start. Another example is if you get parallax when reading scales with your eye in the wrong position, as shown in the diagram.

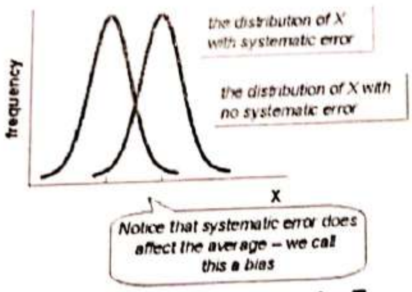


If you heat some water to measure its specific heat capacity, there will always be thermal energy lost to the surroundings. So how will that affect your temperature rise reading in this process? Measurement of the temperature rise of the water would always be too small. This is another systematic error. Therefore, you will need to design your experiment carefully to correct for errors like this thermal energy loss. You will also need to take certain precautions for different types of experiments.

Systematic Errors

- Are TYPICALLY present.

Measurements are given as:



Measurement + Systematic Error

OR

Measurement - Systematic Error

Sources:

Instrumental, physical and human limitations.

Example: Device is out-of calibration.

How to minimize them?

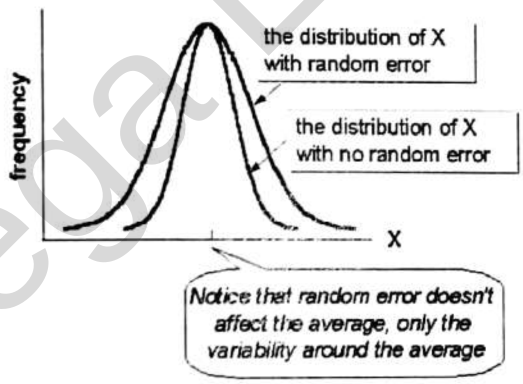
- Careful calibration.
- Best possible techniques.

Random Errors

These are errors which sometimes mean that readings are too big, and sometimes too small compared to the actual value. For example, when you are timing oscillations, what is the common error here? error in your timing because of your reactions.

There are also random errors when reading ammeters or voltmeters. For example, a reading of 1.0 V means that the voltage is between 0.95 V and 1.05 V, and we are not sure if the reading is too high or too low.

- ALWAYS present.
- Measurements are often shown as:



Measurement ± Random Error

Sources:

- Operator errors
- Changes in experimental conditions

How to minimize them?

- Take repeated measurements and calculate their average.

Accuracy and Precision

Precision

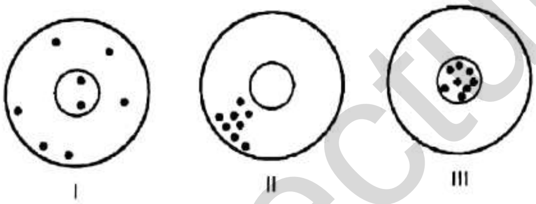
- Precision is the degree of exactness to which a measurement can be reproduced.
- The precision of an instrument is limited by the smallest division on the measurement scale.
- It also means, how close the readings are to each other.

Accuracy

- The accuracy of a measurement describes how well the result agrees with an accepted value.
- It is taken as the difference between the measured value and accepted value.

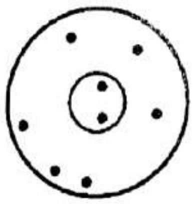
An Analogy

The dots represent bullet holes in the target.

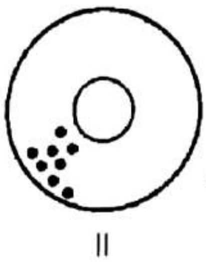


Draw an analogy between accuracy and precision using the above 3 diagrams.

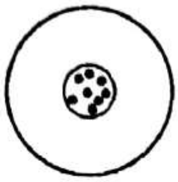
- The first target shows moderate accuracy and poor precision;



- The second shows good precision and poor accuracy.



- The third represents good accuracy and good precision.



III

	Precision	Accuracy
Meaning	Spreading about average values	Nearness to actual value
Affected by	Random error	Systematic error
To improve	Repeat and average/ plot graph	Technique, accurate instrument
Graph feature	Scattering about straight line	Straight line parallel to best fit

No measurement is absolute. Therefore measurements must be written together with uncertainty

E.g. L = 2.5 + 0.1 cm

Youtube reference

http://www.youtube.com/watch?v=QruAxiYSIAY

http://www.youtube.com/watch?v=1dTn2pt5PuA

http://www.youtube.com/watch?v=F2pVw5FOiyA

Limit of Reading and Uncertainty

- The Limit of Reading of a measurement is equal to the smallest graduation of the scale of an instrument.
- The Degree of Uncertainty of a reading (end reading) is equal to half the smallest graduation of the scale of an instrument.
- e.g. If the limit of reading is 0.1cm then the uncertainty range is ± 0.05cm
- This is the absolute uncertainty

Reducing the Effects of Random Uncertainties

Take multiple readings. When a series of readings are taken for a measurement, then the arithmetic mean of the reading is taken as the most probable answer. The greatest deviation from the mean is taken as the absolute error.

Absolute/fractional errors and percentage errors

- We use ± to show an error in a measurement
- (208 ± 1) mm is a fairly precise measurement
- (2 ± 1) mm is highly inaccurate
- In order to compare uncertainties, use is made of absolute, fractional and percentage uncertainties.
- 1 mm is the absolute uncertainty
- 1/208 is the fractional uncertainty (0.0048)
- 0.48 % is the percentage uncertainty.

Uncertainties

Every measurement has an uncertainty or error.

e.g. time = 5 seconds ± 1 second

The ± 1 second is called the absolute uncertainty

There are three main types of uncertainty.

- Random Uncertainties
- Systematic Errors
- Reading Uncertainties

Random Uncertainties

Repeated measurements of the same quantity, gives a range of readings. The random uncertainty is found using:

$$\text{random uncertainty} = \frac{\text{max reading - min reading}}{\text{number of readings}}$$

Taking more measurements will help eliminate (or reduce) random uncertainties. The mean is the best estimate of the true value.

Example 1

Five measurements are taken to determine the length of a card.

209mm, 210mm, 209mm, 210mm, 200mm

(a) Calculate the mean length of card.

(b) Find the random uncertainty in the measurements.

(c) Express mean length including the absolute uncertainty.

(a)

$$\text{mean length} = \frac{209 + 210 + 209 + 210 + 200}{5}$$

$$= \frac{1038}{5}$$

mean length = 208 mm

give the mean to same number of significant figures as measurements

(b)

$$\text{random uncertainty} = \frac{\text{max reading - min reading}}{\text{number of readings}}$$

$$= \frac{210 - 200}{5}$$

= 2 mm

(c) length of card (c) = 208 mm ± 2 mm

The "± 2mm" is the absolute uncertainty.

Question

Repeated measurements of speed give the following results:

9.87 ms^{-1}, 9.80 ms^{-1}, 9.81 ms^{-1}, 9.85 ms^{-1}

(a) Calculate the mean speed.

(b) Find the random uncertainty.

(c) Express mean speed including the absolute uncertainty.

Answer key

Repeated measurements of speed give the following results:

9.87 ms^{-1}, 9.80 ms^{-1}, 9.81 ms^{-1}, 9.85 ms^{-1}

(a) Calculate the mean speed.

9.83 ms^{-1}

(b) Find the random uncertainty.

0.02 ms^{-1}

(c) Express mean speed including the absolute uncertainty.

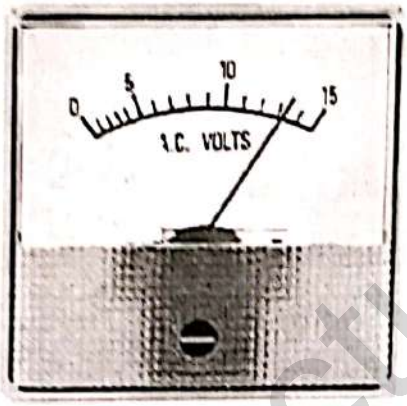
9.83 ms^{-1} ± 0.02 ms^{-1}

Reading Uncertainties

A reading uncertainty is how accurately an instruments scale can be read.

Analogue Scales

Where the divisions are fairly large, the uncertainty is taken as: Half the smallest scale division



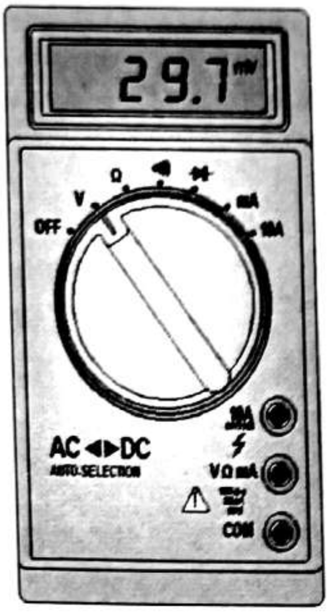
Where the divisions are small, the uncertainty is taken as: The smallest scale division

Digital Scale (example 1)

For a digital scale, the uncertainty is taken as: The smallest scale reading

e.g. voltage = 29.7 mV ± 0.1 mV

This means the actual reading could be anywhere from .....??



Percentage Uncertainty

The percentage uncertainty is calculated as follows:

$$\% \text{ uncertainty} = \frac{\text{aboslute uncertainty}}{\text{reading}} \times 100$$

Example 1

Calculate the percentage uncertainty of the measurement:

$$d = 8\text{cm} \pm 0.5\text{cm}$$

$$\% \text{ uncertainty} = \frac{\text{absolute uncertainty}}{\text{reading}} \times 100$$

$$= \frac{0.5}{8} \times 100$$

$$= 0.0625 \times 100$$

$$= 6.25\ \%$$

(d = 8cm ± 6.25)

Question 1

Calculate the % uncertainty of the following:

a) I = 5A ± 0.5A

b) t = 20s ± 1s

c) m = 1000g ± 1g

d) E = 500J ± 25J

e) F = 6N ± 0.5N

Answer key

Calculate the % uncertainty of the following:

a) I = 5A ± 0.5A

10 %

b) t = 20s ± 1s

5 %

c) m = 1000g ± 1g

0.1 %

d) E = 500J ± 25J

5 %

e) F = 6N ± 0.5N

8.3 %

Combining uncertainties

For addition, add absolute uncertainties

$y = b+c$, then $y \pm \delta y = (b+c) \pm (\delta b + \delta c)$

Example:

Two volumes of water were added to a beaker. The volumes measured are as follow:

Volume A = 15.0 + 0.1 m^3

Volume B = 25.0 + 0.1 m^3

Determine the final volume together with its uncertainty

Ans: 40.0 + 0.2 m3a

For subtraction, add absolute uncertainties

$y = b - c$, then $y \pm \delta y = (b-c) \pm (\delta b + \delta c)$

Example :

A student measured the temperature of a beaker of water before and after heating. The readings are as follow:

Initial temperature = 25.0 + 0.5° C.

Final temperature = 40.0 + 0.5° C.

Determine the temperature rise together with its uncertainty

Ans: 15 + 1° C (final value rounded up to nearest 1° C)

For multiplication and division add percentage /fractional uncertainties

$x = b \times c$, then $\frac{\delta x}{x} = \frac{\delta b}{b} + \frac{\delta c}{c}$

For finding percentage, we have multiply fractional error by 100.

Combining Uncertainties (Example for multiplication & Division)

Multiplication	Division
Determine the momentum together with uncertainty given that mass of object = 1.50 ± 0.01 kg Velocity of object = 2.0 ± 0.2 ms^{-1} **Ans**: uncertainty = 0.32 But final answer = 3.0 ± 0.3 $kgms^{-1}$ **Working:** P = mv $\frac{\delta P}{P} = \frac{\delta m}{m} + \frac{\delta v}{v}$ $\frac{\delta P}{3} = \frac{0.01}{1.5} + \frac{0.2}{2}$	Determine the density of water given the measurements below Mass, m = 50 ± 1 g Volume, V = 52 ± 5 cm^{-3}. **Ans:** density = 1.0 ± 0.1 gcm^{-3} **Working :** D = m/V $\frac{\delta D}{D} = \frac{\delta m}{m} + \frac{\delta V}{V}$ $\frac{\delta D}{0.96} = \frac{1}{50} + \frac{5}{52}$

When using powers, multiply the percentage uncertainty by the power

z = b^a then $\frac{\delta z}{z} = a\frac{\delta b}{b}$

Example:

Determine the density of iron given the measurements below

Mass, m = 37.8 ± 0.1 g

Diameter of sphere, d = 2.10 ± 0.01 cm.

Ans: density = 7.8 ± 0.1 gcm^{-3}

Explanation on Slide No. f1

Determine Density

Given m = 37.8 ± 0.1 g

d = 2.10 ± 0.01 cm

Firstly find density

$$\rho = \frac{m}{v} = \frac{m}{\frac{\pi d^3}{6}} = \frac{6m}{\pi d^3}$$

$$= \frac{6 \times 37.8}{\pi (2.10)^3} = 7.79\, density$$

$$V = \frac{4}{3}\pi r^3$$

$$V = \frac{4}{3}\pi\left(\frac{d}{2}\right)^3 = \frac{4}{3}\pi\frac{d^3}{8}$$

$$V = \frac{\pi d^3}{6}$$

Combining Uncertainties

When using power multiply the % uncertainty by the power

ex ; $z = b^a$ then $\frac{\Delta z}{z} = \frac{a.\Delta b}{b}$

Next find uncertainty of density $\Delta\rho$

So,

$$\frac{\Delta\rho}{\rho} = \frac{0.1}{37.8} + \frac{3 \times 0.01}{2.10}$$

$$\Delta\rho = \left(\frac{0.1}{37.8} + \frac{3 \times 0.01}{2.10}\right)$$

$$= 0.132$$

$$So\ \rho = 7.79\ and\ \Delta\rho = 0.1$$

Final answer is 7.9 ± 0.1 gcm^{-3}

Significant Figures and Calculations

What is the difference between lengths of 4 m, 4.0 m and 4.00 m?

Writing 5.00 m implies that we have measured the length more precisely than if we write 5 m. Writing 5.00 m tells us that the length is accurate to the nearest centimetre.

(First alternative)

How many significant figures should you give in your answers to calculations?

This depends on the precision of the raw numbers you use in the calculation. Your answer cannot be any more precise than the data you use.

(Second alternative)

This means that you should round your answer to the same number of significant figures as those used in the calculation. If some of the figures are given less precisely than others, then round up to the lowest number of significant figures.

Example

The swimmer covers a distance of 100.0 m in 68 s. Calculate her average speed.

$$\text{speed} = \frac{\text{distance travelled}}{\text{time taken}} = \frac{100.0\ \text{m}}{68\ \text{s}} = 1.4705882\ \text{m s}^{-1}$$

Our final answer should be stated as:

- $1.5\ \text{m s}^{-1}$ (2 s.f.)
- $1.47\ \text{m s}^{-1}$ (3 s.f.)

Example : Combining Uncertainties

Use the following data to calculate the speed, and the uncertainty in speed, of a moving object.

Calculation of Speed

$d = 16\ \text{cm} \pm 0.5\ \text{cm}$

$t = 2\text{s} \pm 0.5\ \text{s}$

$v = ?$

$$v = \frac{d}{t}$$

$$v = \frac{16}{2}$$

$V = 8\ \text{cm s}^{-1}$

Calculation of Uncertainty

$$\% \text{ error in d} = \frac{\text{absolute uncertainty}}{\text{reading}} \times 100$$

$$= \frac{0.5}{16} \times 100$$

$$= 3.1\ \%$$

$$\% \text{ error in t} = \frac{\text{absolute uncertainty}}{\text{reading}} \times 100$$

$$= \frac{0.5}{2} \times 100$$

$$= 25\ \%$$

Uncertainty in Speed

The biggest uncertainty is used, so get: $v = 8\ cms^{-1} \pm 25\%$

$v = 25\%$ of $8cm\ s^{-1}$

The absolute uncertainty in the speed: = 0.25% x 8

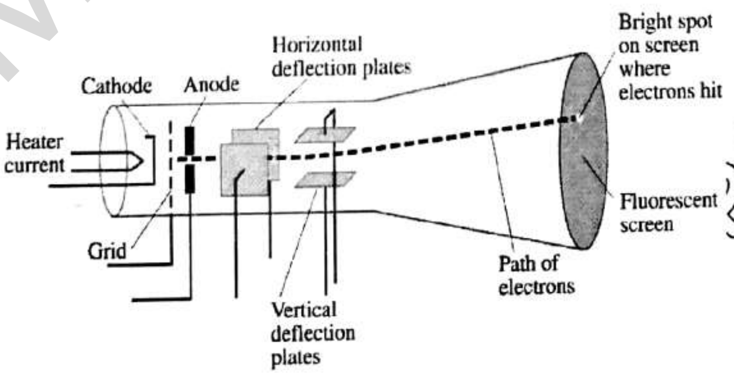
$= 2\ cm\ s^{-1}$

Answer $v = 8cms^{-1} \pm 2cms^{-1}$ OR $v = 8\ cms^{-1} \pm 25\%$

Cathode Ray Oscilloscope

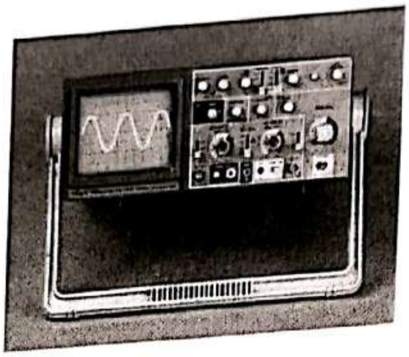
Reference Link

http://www.kpsec.freeuk.com/cro.html



An oscilloscope is a test instrument which allows you to look at the 'shape' of electrical signals by displaying a graph of voltage against time on its screen. It is like a voltmeter with the valuable extra function of showing how the voltage varies with time. The 1cm grid enables you to take measurements of voltage and time from the screen.

The graph, usually called the trace, is drawn by a beam of electrons striking the phosphor coating of the screen making it emit light, usually green or blue. This is similar to the way a television picture is produced.



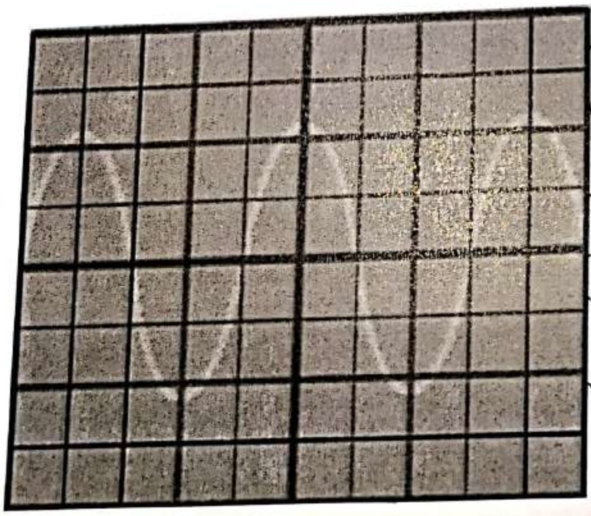
Oscilloscopes contain a vacuum tube with a cathode (negative electrode) at one end to emit electrons and an anode (positive electrode) to accelerate them so they move rapidly down the tube to the screen. This arrangement is called an electron gun. The tube also contains electrodes to deflect the electron beam up/down and left/right.

The electrons are called cathode rays because they are emitted by the cathode and this gives the oscilloscope its full name of cathode ray oscilloscope or CRO.

Obtaining a clear and stable trace

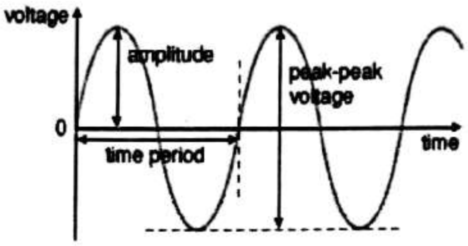
Once you have connected the oscilloscope to the circuit you wish to test you will need to adjust the controls to obtain a clear and stable trace on the screen: The Y AMPLIFIER (VOLTS/CM) control determines the height of the trace. Choose a setting so the trace occupies at least half the screen height, but does not disappear off the screen.

The TIMEBASE (TIME/CM) control determines the rate at which the dot sweeps across the screen. Choose a setting so the trace shows at least one cycle of the signal across the screen. The TRIGGER control is usually best left set to AUTO.



Measuring voltage and time period

The trace on an oscilloscope screen is a graph of voltage against time. The shape of this graph is determined by the nature of the input signal. In addition to the properties labelled on the graph, there is frequency which is the number of cycles per second.



Measuring voltage and time period

Amplitude is the maximum voltage reached by the signal. It is measured in volts, V. Peak voltage is another name for amplitude. Peak-peak voltage is twice the peak voltage (amplitude). When reading an oscilloscope trace it is usual to measure peak-peak voltage. Time period is the time taken for the signal to complete one cycle. It is measured in seconds (s), but time periods tend to be short so milliseconds (ms) and microseconds (μs) are often used. 1ms = 0.001s and 1μs = 0.000001s. Frequency is the number of cycles per second. It is measured in hertz (Hz), but frequencies tend to be high so kilohertz (kHz) and megahertz (MHz) are often used. 1kHz = 1000Hz and 1MHz = 1000000Hz.

Frequency = 1/time period and vice versa

Calculating Voltage

Voltage is shown on the vertical y-axis and the scale is determined by the Y AMPLIFIER (VOLTS/CM) control. Usually peak-peak voltage is measured because it can be read correctly even if the position of 0V is not known. The amplitude is half the peak-peak voltage.

Voltage = distance in cm × volts/cm

Example: peak-peak voltage = 4.2cm × 2V/cm = 8.4V

amplitude (peak voltage) = ½ × peak-peak voltage = 4.2V

Calculating Time period

Time is shown on the horizontal x-axis and the scale is determined by the TIMEBASE (TIME/CM) control. The time period (often just called period) is the time for one cycle of the signal. The frequency is the number of cyles per second, frequency = 1/time period.

Time period = distance in cm × time/cm

Given time/cm as 5ms/cm

Example: time period = 4.0cm × 5ms/cm = 20ms

Youtube links to explanation on:

General Physics – Measurement techniques

- http://www.youtube.com/watch?v=F2pVw5FOiyA
- http://www.youtube.com/watch?v=ilyGPV06Mf4

Kinematics (Newtonian Mechanics)

Mechanics

The study of Physics begins with mechanics. Mechanics is the branch of physics that focuses on the motion of objects and the forces that cause the motion to change. There are two parts to mechanics: Kinematics and Dynamics. Kinematics deals with the concepts that are needed to describe motion, without any reference to forces. Dynamics deals with the effect that forces have on motion.

Introduction

Kinematics is the science of describing the motion of objects using words, diagrams, graphs, and equations. The goal of kinematics is to develop mental models to describe the motion of real-world objects. We will learn to describe motion using:

1. Words
2. Diagrams
3. Graphs
4. Equations

Describing Motion with words

The motion of objects can be described by words. Even a person without a background in physics has a collection of words, which can be used to describe moving objects. For example, going faster, stopped, slowing down, speeding up, and turning provide a sufficient vocabulary for describing the motion of objects. In physics, we use these words as the language of kinematics.

1. Distance and Displacement
2. Speed and Velocity
3. Acceleration

These words which are used to describe the motion of objects can be divided into two categories.

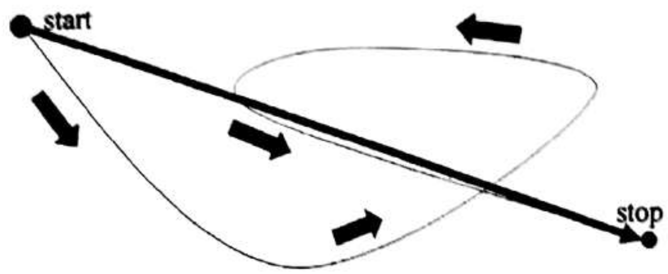
The quantity is either a **vector** or **scalar**.

1. Scalars are quantities which are described by a magnitude only.
2. Vectors are quantities which are described by both a magnitude and a direction.

Distance	Displacement
Distance refers to the total length of travel irrespective of the direction of the motion. It is a scalar quantity. SI unit: metre (m) Other common units: kilometre (km), centimeter (cm)	Displacement refers to the distance moved in a particular direction. It is the object's overall change in position. It is a vector quantity. I unit: metre (m) Other common units: kilometre (km), centimeter (cm)

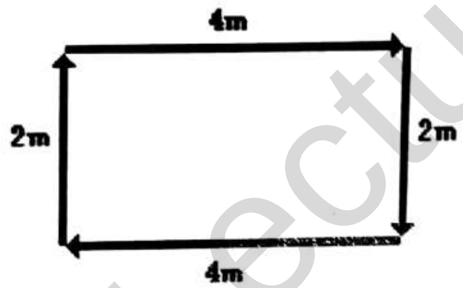
Distance vs. Displacement

- You drive the path, and your odometer goes up (your distance).
- Your displacement is the shorter directed distance from start to stop (green arrow).



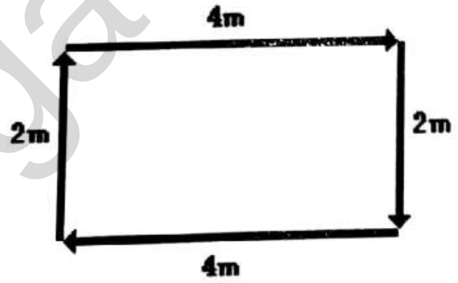
Example 1

A student walks 4 m East, 2 m South, 4 m West, and finally 2 m North.



Total distance = 12 m

During the course of his motion, the total length of travel is 12 m.



Total displacement = 0 m

When he is finished walking, there is no change in his position. The 4 m east is "canceled by" the 4 m west; and the 2 m south is "canceled by" the 2 m north.

Speed	Velocity
Speed is the rate of change of distance. It is a scalar quantity. Speed = $\frac{\text{distance travelled}}{\text{time taken}}$	Velocity is the distance travelled in a specific direction. It is also defined as the rate of change of displacement. It is a vector quantity. Velocity = $\frac{\text{change in displacement}}{\text{time taken}}$

When evaluating the velocity of an object, one must keep track of direction. The direction of the velocity vector is the same as the direction which an object is moving. (It would not matter whether the object is speeding up or slowing down.) For example: If an object is moving rightwards, then its velocity is described as being rightwards. Boeing 747 moving towards the west with a speed of 260m/s has a velocity of 260m/s, west. Note that speed has no direction (it is a scalar) and velocity at any instant is simply the speed with a direction.

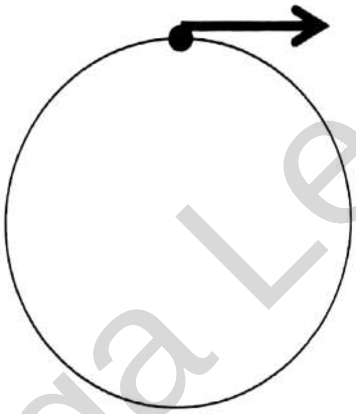
Instantaneous Speed and Average Speed

As an object moves, it often undergoes changes in speed. The speed at any instant is known as the instantaneous speed. (From the value of the speedometer) The average speed of the entire journey can be calculated:

$$\text{Average Speed} = \frac{\text{Total distance travelled}}{\text{time taken}}$$

Speed Vs Velocity

An object is moving in a circle at a constant speed of 10 m s^{-1}. We say that it has a constant speed but its velocity is not constant. Why?



The direction of the object keeps changing.

Acceleration

An object whose velocity is changing is said to accelerate. If the direction and / or speed of a moving object changes, the object is accelerating Acceleration is the rate of change of velocity

Time (s)	Velocity (m/s)
0	0
1	10
2	20
3	30
4	40
5	50

Acceleration is a vector quantity

SI unit: ms^{-2}

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

Where a = acceleration, v =final velocity, u = initial velocity and t = time.

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

Describing Motion with Graphs

1. Plot and interpret a distance-time graph and a speed-time graph.
2. Deduce from the shape of a distance-time graph when a body is:
   (a) at rest
   (b) moving with uniform speed
   (c) moving with non-uniform speed
3. Deduce from the shape of a Velocity-time graph when a body is:
   (a) at rest
   (b) moving with uniform speed
   (c) moving with uniform acceleration
   (d) moving with non-uniform acceleration
4. Calculate the area under a speed-time graph to determine the distance travelled for motion with uniform speed or uniform acceleration.

Key Concepts

Distance-time Graph

Gradient of the Distance-time Graph is the speed of the moving object

Speed-time Graph

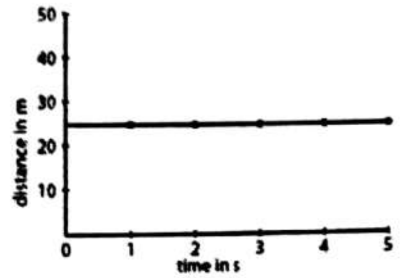
Gradient of the Speed-time Graph is the acceleration of the moving object. Area under the Speed-time Graph is the distance travelled.

Distance-time Graph

A car has travelled past a lamp post on the road and the distance of the car from the lamp post is measured every second. The distance and the time readings are recorded and a graph is plotted using the data. The following pages are the results for four possible journeys. The steeper the line, the greater the speed.

(a) Car at rest

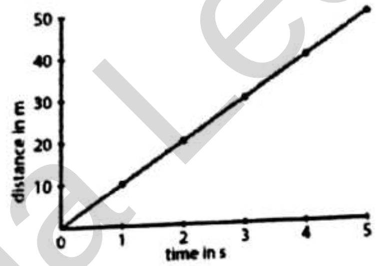
Time in s	0	1	2	3	4	5
Distance in m	25	25	25	25	25	25



The car is parked 25 m from the post, so the distance remains the same.

(b) Car moving with uniform speed of 10 ms^{-1}

Time in s	0	1	2	3	4	5
Distance in m	0	10	20	30	40	50

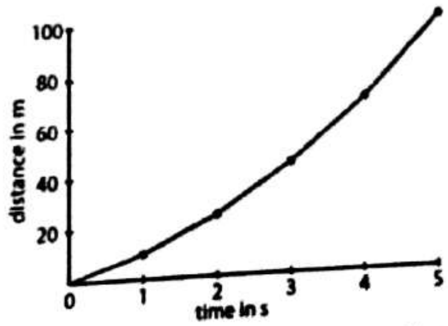


Distance increases 10 m for every 1 s.

(c) Car moving with non – uniform speed

(i) Car Accelerating

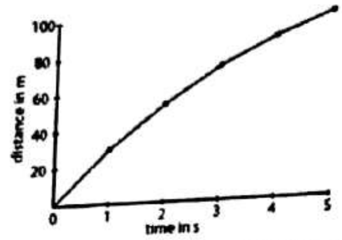
Time in s	0	1	2	3	4	5
Distance in m	0	10	25	45	75	100



Speed increases, so the car travels a longer distance as time increases.

(ii) Car decelerating

Time in s	0	1	2	3	4	5
Distance in m	0	30	55	75	90	100

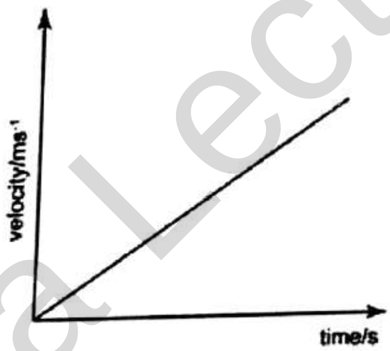


Speed decreases, so the car travels a shorter distance as time increases.

The gradient of the distance-time graph gives the speed of the moving object.

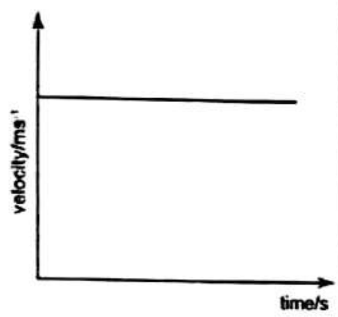
Velocity – Time Graph

- The gradient of the velocity-time gradient gives a value of the changing rate in velocity, which is the acceleration of the object.
- The area below the velocity-time graph gives a value of the object's displacement.

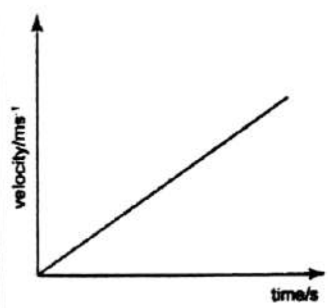


Analysing Velocity - Time Graph

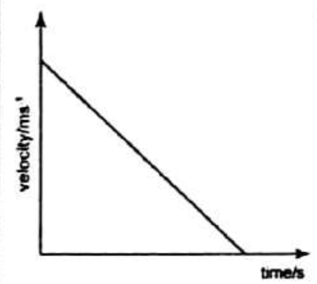
- Uniform Velocity



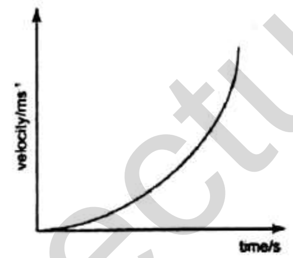
- Uniform Acceleration



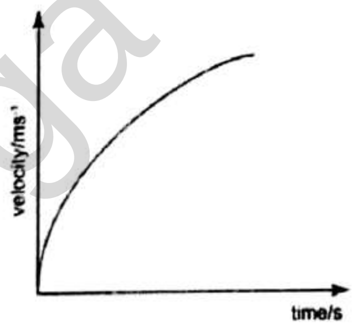
- Uniform deceleration



- Increasing acceleration



Decreasing acceleration



How do you find the gradient of velocity-time graph?

- You need to select two points on the graph, for example (x_1,y_1) and (x_2,y_2).
- Once you have selected the points you put then into the equation $m=(y_2-y_1)/(x_2-x_1)$
- m = the gradient

The gradient represents the acceleration. In other words, We take the vertical reading from the graph where the acceleration finishes and divide it by the horizontal reading where the acceleration finishes.

Example 1

Figure 2.14 shows the speed – time graph of a moving lift.

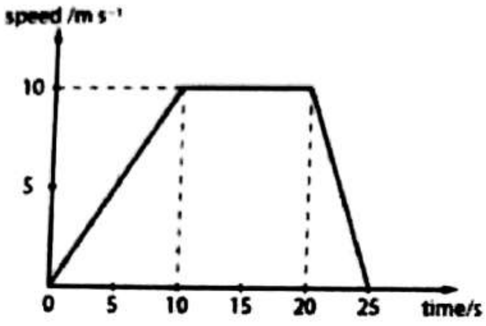


Figure 2.14

(a) What is the maximum speed of the lift?

(b) For how many seconds does the lift move?

(c) How much speed does lift gain in the first 10 seconds? What is its acceleration?

(d) What is the deceleration of the lift in the last 5 seconds?

Solution

(a) The maximum speed of the lift is 10 m s^{-1}

(b) The lift moves for 25 s.

(c) The lift gains 10 m s^{-1} in the first 10 s.

$$\text{Acceleration} = \frac{10 - 0}{10}$$
$$= 1 \text{ m s}^{-2}$$

(d) $$\text{Acceleration} = \frac{0 - 10}{5}$$
$$= -2\text{m s}^{-2}$$

Therefore the deceleration is 2 m s^{-2}.

Example 2

Figure 2.15 shows the speed – time graph for a journey of a boy from his house to school. Look at the shape of the graph and describe the type of motion in each stage.

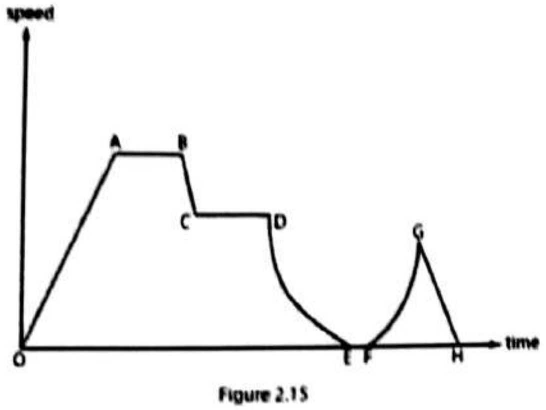


Figure 2.15

Solution

O left home.

O – A moving with uniform acceleration.

A – B moving with uniform speed.

B – C moving with uniform deceleration.

C – D moving with uniform speed (speed lower than A - B).

D – E moving with non – uniform deceleration (decreasing deceleration).

E – F not moving.

F – G moving with non – uniform acceleration (increasing acceleration).

G – H moving with uniform acceleration.

H reached school.

Area under a speed-time graph

The figure below shows the speed-time graph of a car travelling with a uniform speed of 20 ms^{-1}. The distance travelled by the car is given by:

Distance = speed x time = 20 x 5

= 100 m

The same information of distance travelled can also be obtained by calculating the area under the speed-time graph. The area under a speed-time graph gives the distance travelled.

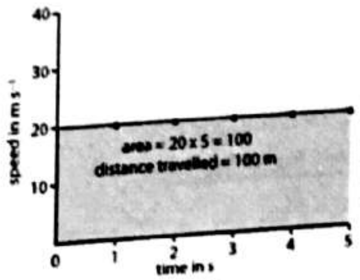


Figure 2.16

Example 3 – Question

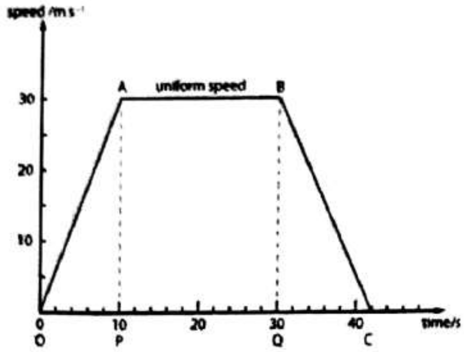


Figure 2.17 Speed-time graph of a car accelerating, moving with uniform speed and then decelerating

Figure 2.17 shows the speed – time graph of a car travelling along a straight road.

(a) What is the distance travelled during the first 10 s?

(b) What is the total distance travelled?

(c) What is the total time taken for the whole journey?

(d) What is the average speed for the whole journey?

Solution

(a) During the first 10 s, distance travelled = area of triangle OAP

$$= \frac{1}{2} \times 10 \times 30$$

$$= 150 \text{ m}$$

(b) Total distance travelled = area of trapezium OABC

$$= \frac{1}{2} \times (20+42) \times 30$$

$$= 930 \text{ m}$$

(c) Time taken for the whole journey = 42 s

(d) Average speed for the whole journey = $\dfrac{\text{Total distance travelled}}{\text{Total time taken}}$

$$= \frac{930}{42}$$

$$= 22.1 \text{ m s}^{-1}$$

Fall Freely...

http://www.youtube.com/watch?v=go9uekKOcKM

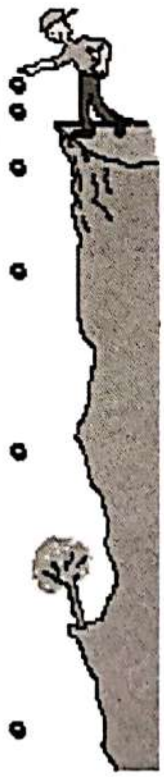
http://www.youtube.com/watch?v=FHtvDA0W34I

Uniformly accelerated motion

Free fall is motion with no acceleration other than that provided by gravity.

In Other Words

A free-falling object is an object which is falling under the sole influence of gravity. Any object which is being acted upon only be the force of gravity is said to be in a state of free fall.



Free Fall

Any object which is moving and being acted upon only be the force of gravity is said to be "in a state of free fall". all objects fall freely at g ≈ 10 m s^{-2} when near the earth and air resistance is negligible.

Speed of a free-falling body increases by 9.8 m s^{-1} every second or when a body is thrown up, its speed decreases by 9.8 m s^{-1} every second. Although the acceleration due to gravity is considered constant, it tends to vary slightly over the earth since the earth is not a perfect sphere.

Examples

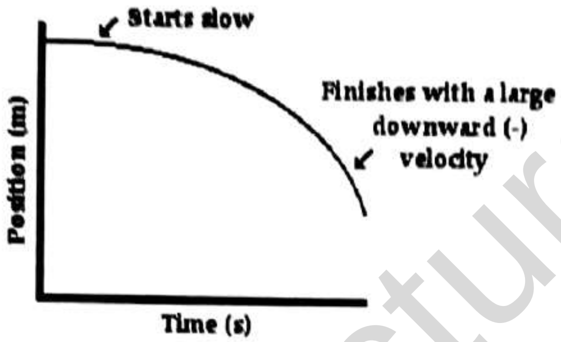
Examples of objects in Free fall

- A spacecraft (in space) with its rockets off (e.g. in a continuous orbit, or going up for some minutes, and then down)
- The Moon orbiting around the Earth.

Examples of objects not in Free fall

- Standing on the ground: the gravitational acceleration is counteracted by the normal force from the ground.
- Flying horizontally in an airplane: the wings' lift is also providing an acceleration.

Representing Free Fall by Graphs



Free fall graphs shows:

- The line on the graph curves.
- A curved line on a position versus time graph signifies an accelerated motion.
- The position-time graph reveals that the object starts with a small velocity (slow) and finishes with a large velocity (fast).

Check your Understanding!!

Questions to answers !

"Doesn't a more massive object accelerate at a greater rate than a less massive object?" "Wouldn't an elephant free-fall faster than a mouse?"

The answer to the question (doesn't a more massive object accelerate at a greater rate than a less massive object?) is absolutely NOT!

- That is, absolutely not if we are considering the specific type of falling motion known as free-fall.
- Free-fall is the motion of objects which move under the sole influence of gravity; free-falling objects do not encounter air resistance.
- More massive objects will only fall faster if there is an appreciable amount of air resistance present.

Force of gravity means the dog accelerates

To start, the dog is falling slowly (it has not had time to speed up). There is really only one force acting on the dog, the force of gravity. The dog falls faster (accelerates) due to this force.

Gravity is still bigger than air resistance

As the dog falls faster, another force becomes bigger – air resistance. The force of gravity on the dog of course stays the same The force of gravity is still bigger than the air resistance, so the dog continues to accelerate (get faster)

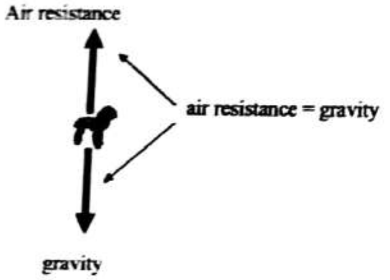
Gravity = air resistance

Terminal Velocity

As the dog falls faster and air resistance increases, eventually the air resistance becomes as big as (equal to) the force of gravity. The dog stops getting faster (accelerating and falls at constant speed. This velocity is called the terminal Velocity.

Terminal Speed

The dog will continue to fall at constant speed (called the terminal speed) until............



Uniformly Accelerated Motion

Acceleration is defined as the rate of change of velocity with respect to time, in a given direction. The SI units of acceleration are ms^{-2}. This would mean that if an object has an acceleration of 1 ms^{-2} it will increase its velocity (in a given direction) 1 ms^{-1} every second that it accelerates. It means that acceleration is constant. This meaning that velocity is varying with respect to time, we see this by this formula (v - u) / t (Time).

It means....

If an object is held stationary in a uniform gravitational field and when it is released, it will fall. It will do so with uniform acceleration. Near the surface of the earth the acceleration is approximately 9.8 ms^{-2}. This means that every second that the object falls its velocity will increase by 9.8 ms^{-1}.

Check your understanding !

What happens if an object is thrown up?

What happens if an object is thrown up?

The acceleration is still downward. If an object is thrown up with an initial velocity of 30 ms^{-1}, after one second it will only be going 20 ms^{-1} up, after 2 seconds it will only be going 10 ms^{-1}, after 3 seconds the object will have zero velocity! Even if the objects velocity is zero the acceleration is not zero.

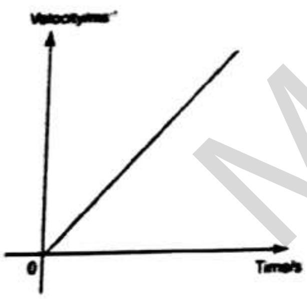
An experiment with "g".

- College building
- Stop watch
- A group of students on top floor
- A group of students on ground floor
- Need to check the distance between top floor and ground, time to calculate velocity.
- (This experiment will be carried out during next lesson)
- Upon investigation, g constant is found with one of the equations we have derived and it is as follows :
- The actual explanation of why all objects accelerate at the same rate involves the concepts of force and mass.

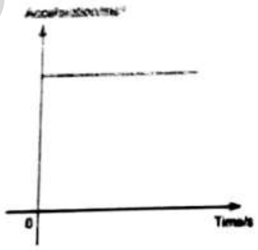
Graph of free falling :

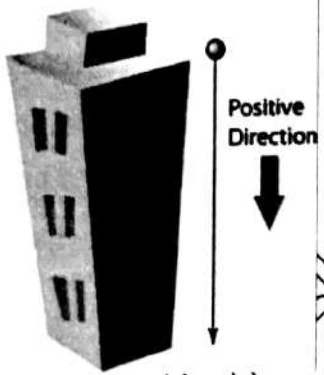
1. Dropping an object from high place

- Velocity - Time Graph



- Acceleration - Time Graph

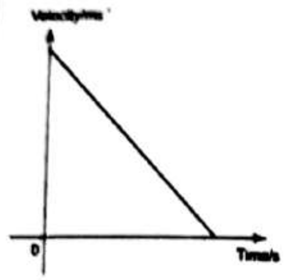




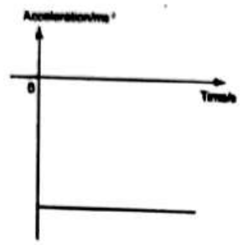
Graph of free falling:

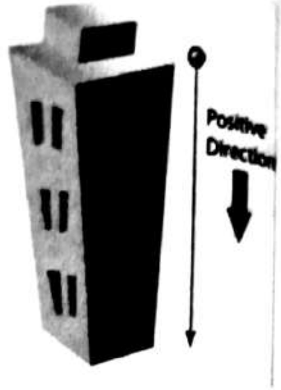
2. Launching Object Upward

- Velocity - Time Graph



- Acceleration - Time Graph

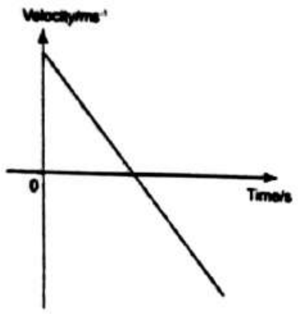




Graph of free falling:

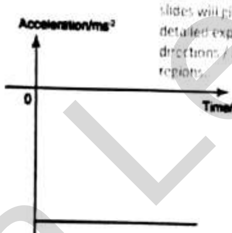
3. Object moving upward and fall back to the ground

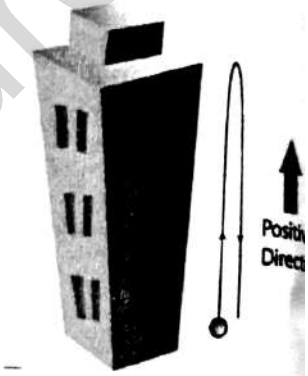
- **Velocity - Time Graph**



- **Acceleration - Time Graph**

Note: The graph here is to show that the acceleration remains same. The following slides will give a detailed explanation on directions / both regions.

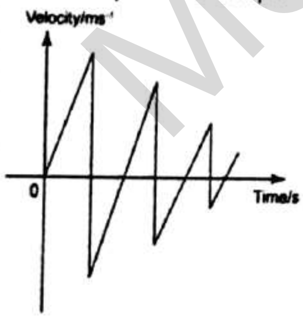




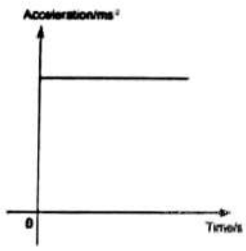
Graph of free falling:

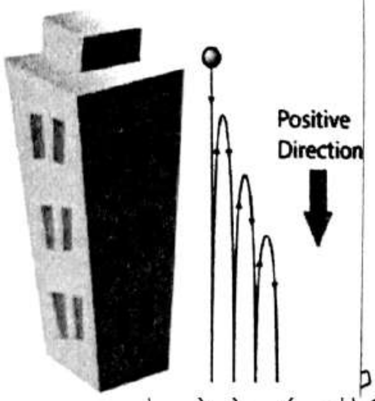
4. Object falling and bounces back

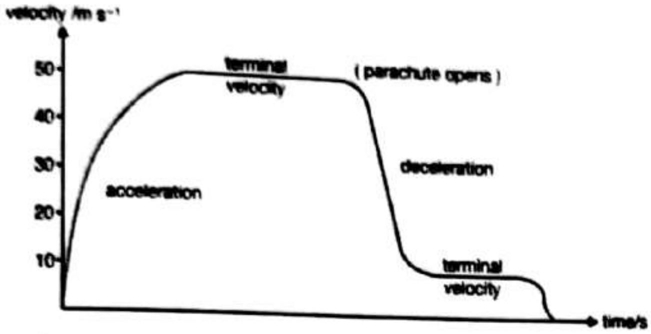
- Velocity - Time Graph



- Acceleration - Time Graph





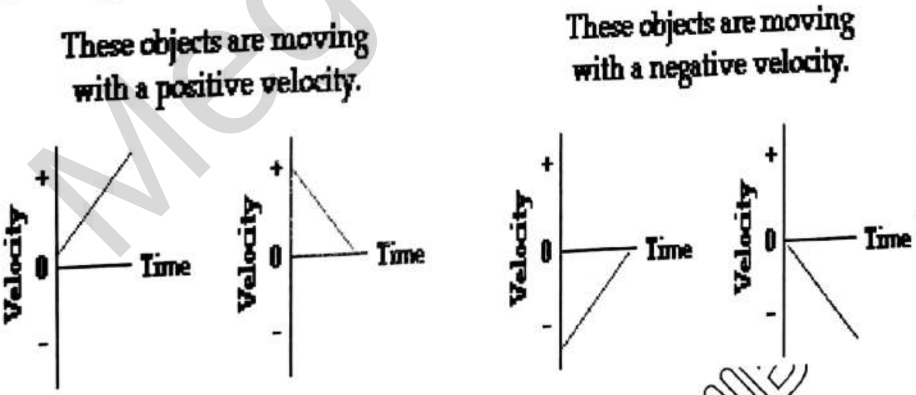


At the point when the air resistance equals to the weight, there is no acceleration and the object will fall with "terminal velocity". A small dense object, like a steel ball bearing, has a high terminal velocity. A light object, like a raindrop, or an object with large surface area like a piece of paper, has a low terminal velocity.

Positive Velocity & Negative Velocity

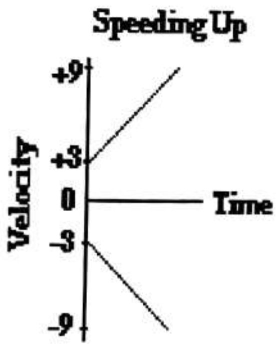
How can one tell whether the object is moving in the positive direction (i.e., positive velocity) or in the negative direction (i.e., negative velocity)? And how can one tell if the object is speeding up or slowing down?

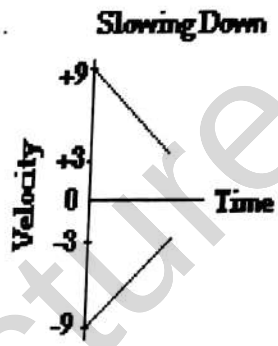
Since the graph is a velocity-time graph, the velocity would be positive whenever the line lies in the positive region (above the x-axis) of the graph. Similarly, the velocity would be negative whenever the line lies in the negative region (below the x-axis) of the graph. A positive velocity means the object is moving in the positive direction; and a negative velocity means the object is moving in the negative direction. So one knows an object is moving in the positive direction if the line is located in the positive region of the graph (whether it is sloping up or sloping down). And one knows that an object is moving in the negative direction if the line is located in the negative region of the graph (whether it is sloping up or sloping down). And finally, if a line crosses over the x-axis from the positive region to the negative region of the graph (or vice versa), then the object has changed directions.



Positive Velocity & Negative Velocity

- Now how can one tell if the object is speeding up or slowing down?
- Speeding up means that the magnitude of the velocity is getting large. For instance, an object with a velocity changing from +3 m/s to + 9 m/s is speeding up. Similarly, an object with a velocity changing from -3 m/s to -9 m/s is also speeding up.
- In each case, the magnitude of the velocity is increasing; the speed is getting bigger.
- Given this fact, one would believe that an object is speeding up if the line on a velocity-time graph is changing from near the 0-velocity point to a location further away from the 0-velocity point. That is, if the line is getting further away from the x-axis (the 0-velocity point), then the object is speeding up. And conversely, if the line is approaching the x-axis, then the object is slowing down.





Equations of Motion

There are 4 equations that you can use whenever an object moves with constant, uniform acceleration in a straight line. The equations are written in terms of the 5 symbols in the box:

s = displacement (m)
u = initial velocity (ms^{-1})
v = final velocity (ms^{-1})
a = constant acceleration (ms^{-2})
t = time interval (s)

Since a = (v - u) / t

$$\mathbf{v = u + at \ldots (1)}$$

If acceleration is constant, the average velocity during the motion will be half way between v and u. This is equal to ½(u + v).

$$\tfrac{1}{2}(u + v) = s/t$$

$$\mathbf{s = \tfrac{1}{2}(u + v)t \ldots (2)}$$

Using equation (1) to replace v in equation (2):

$$s = \tfrac{1}{2}(u + u + at)t$$

$$s = \tfrac{1}{2}(2u + at)t$$

$$\mathbf{s = ut + \tfrac{1}{2}at^2 \ldots (3)}$$

From equation (1), $t = (v - u)/a$

Using this to replace t in equation (2):

$s = ½(u + v)[(v - u)/a]$

$2as = (u + v)(v - u)$

$2as = v^2 - u^2$

$v^2 = u^2 + 2as$ … (4)

Note:

- You can only use these equations only if the acceleration is constant.
- Notice that each equation contains only 4 of our 5 "s, u, v, a, t" variables. So if know any 3 of the variables, we can use these equations to find the other 2.

Example 4

A cheetah starts from rest and accelerates at 2.0 ms^{-2} due east for 10 s.

Calculate (a) the cheetah's final velocity, (b) the distance the cheetah covers in this 10 s.

Solution:

(a) Using equation (1): $v = u + at$

$v = 0 + (2.0\ ms\text{-}2 \times 10\ s) = 20\ ms\text{-}1$ due east

(b) Using equation (2): $s = ½(u + v)t$

$s = ½(0 + 20\ ms\text{-}1) \times 10\ s = 100\ m$ due east

You could also find the displacement by plotting a velocity-time graph for this motion. The magnitude of the displacement is equal to the area under the graph.

Example 5

An athlete accelerates out of her blocks at 5.0 ms^{-2}.

(a) How long does it take her to run the first 10 m?

(b) What is her velocity at this point?

Solution:

(a) Using equation (3): $s = ut + ½at^2$

$10\ m = 0 + (1/2 \times 5.0\ ms^{-2} \times t^2)$

$t^2 = 4.0\ s^2$

$t = 2.0\ s$

(b) Using equation (1): $v = u + at$

$v = 0 + (5.0\ ms^{-2} \times 2.0\ s)$

$v = 10\ ms^{-1}$

Example 6

A bicycle's brakes can produce a deceleration of 2.5 ms^{-2}. How far will the bicycle travel before stopping, if it is moving at 10 ms-1 when the brakes are applied?

Solution:

Using equation (4): $v^2 = u^2 + 2as$

$0 = (10\ ms\text{-}1)^2 + (2 \times (-2.5\ ms^{-2}) \times s)$

$0 = 100\ m^2s^{-2} - (5.0\ ms^{-2} \times s)$

$s = 20\ m$

Example 7

A student flips a coin into the air. Its initial velocity is 8.0 ms-1. Taking = 10 ms^{-2} and ignoring air resistance, calculate:

(a) the maximum height, h, the coin reaches

(b) velocity of the coin on returning to his hand,

(c) the time that the coin is in the air

Solution: (upward motion to be negative)

(a) $v^2 = u^2 + 2as$

$0 = (8.0\ ms\text{-}1)^2 + (2 \times (-10ms^{-2}) \times h)$

$h = 3.2$ m

(b) The acceleration is the same going up and coming down. If the coin decelerates from 8.0 ms^{-1} to 0 ms^{-1} on the way up, it will accelerate from 0 ms^{-1} to 8ms^{-1} on the way down. The motion is symmetrical. So the velocity on returning to his hand is 8.0 ms^{-1} downwards.

(c) $v = u + at$

$0 = 8.0\ ms^{-1} + (-10\ ms^{-2} \times t)$

$t = 0.8$ s

The coin will take the same time between moving up and coming down. So total time in the air = 1.6 s.

You-tube videos links with explanation on :

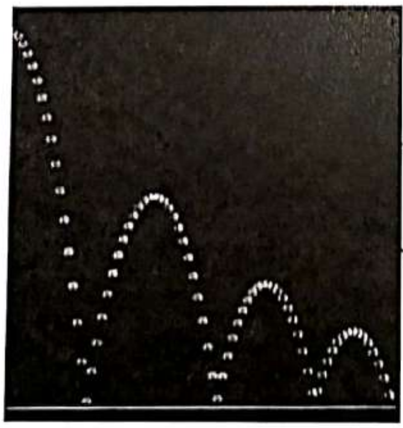
Newtonian Mechanism - Kinematics

- http://www.youtube.com/watch?v=go9uekKOcKM
- http://www.youtube.com/watch?v=xE71aKXjss0&feature=related

The projectile Motion

Kinematics

Describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction.



PROJECTILE is a body which is thrown horizontally or at an angle relative to the horizontal which follows a curved path called trajectory. A projectile is an object moving in two dimensions under the influence of Earth's gravity; its path is a parabola.

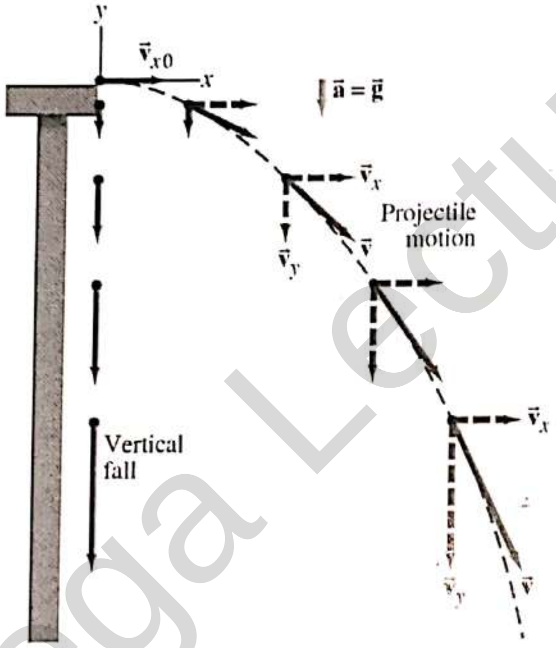
Examples: Ball being thrown, water coming out of the hose, a bullet fired from a gun, arrow shot from a bow, fountains.

What is projectile motion?

Made up of horizontal and vertical components Movement wherein an object is acted upon by gravity and air resistance Motion of a body following a curved path.

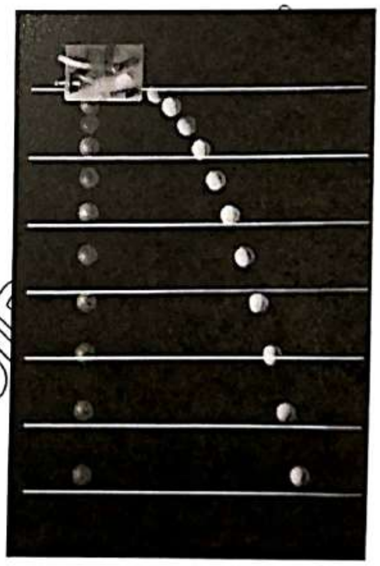
PARABOLIC MOTION OF PROJECTILE

It can be understood by analyzing the horizontal and vertical motions separately.



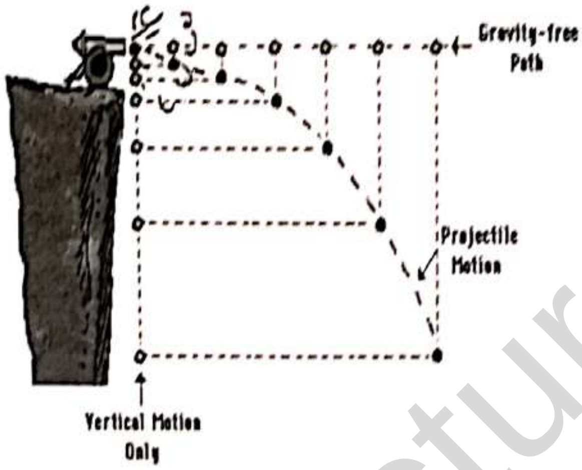
The speed in the x-direction is constant; in the y-direction the object moves with constant acceleration g.

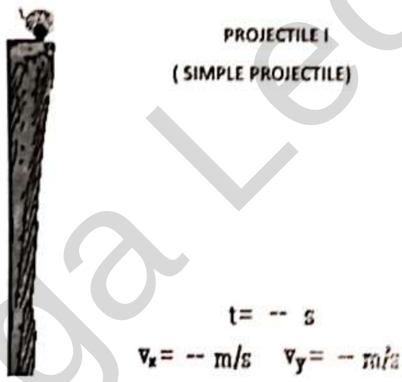
This photograph shows two balls that start to fall at the same time. The one on the right has an initial speed in the x-direction. It can be seen that vertical positions of the two balls are identical at identical times, while the horizontal position of the yellow ball increases linearly.

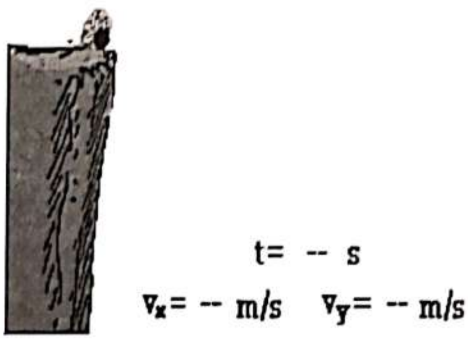


REMEMBER:

1. The horizontal velocity of a projectile is constant (never changing in value),
2. There is uniform vertical acceleration caused by gravity; its value is 9.8 m/s^2
3. The vertical velocity of a projectile changes by ~10 m/s each second, the horizontal motion of a projectile is independent of its vertical motion.







- All vertical components have y subscripts : v_y, d_y, t_y,
- All horizontal components have x subscripts: v_x, d_x

RANGE is the horizontal displacement of the projectile (dx)

MAXIMUM HEIGHT is the vertical displacement of the projectile (d_y)

How to calculate – Projectile Motion (From your reference book)

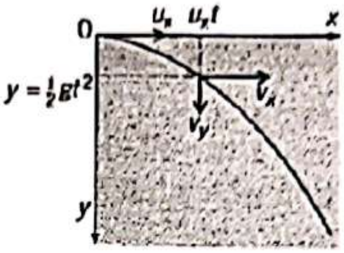


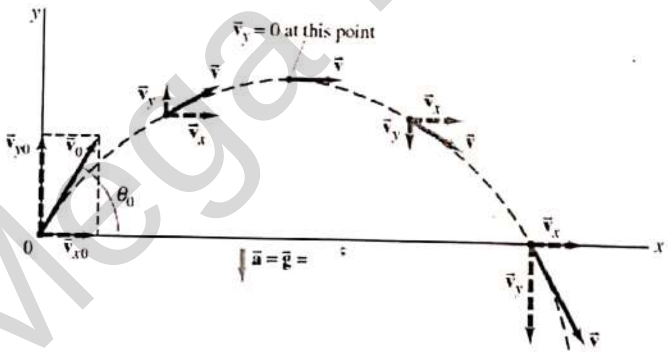
Figure 3.18

This topic is often called projectile motion. Galileo first gave an accurate analysis of this motion. He did so by splitting the motion up into its vertical and horizontal components, and considering these separately. The key is that the two components can be considered independently.

As an example, think about a particle sent off in a horizontal direction and subject to a vertical gravitational force (its weight). As before, air resistance will be neglected. We will analyse the motion in terms of the horizontal and vertical components of velocity. The particle is projected at time t = 0 at the origin of a system of x, y co – ordinates (Figure 3.18) with velocity u_x in the x – direction. Think first about the particle's vertical motion (in the y – direction). Throughout the motion, it has an acceleration of g (the acceleration of free fall) in the y – direction. The vertical component increases continuously under the uniform acceleration g. Using v = u + at, its value v_y at time t is given by $v_y = gt$. Also at time t, the vertical displacement y downwards is given by $y = \frac{1}{2}gt^2$. Now for the horizontal motion (in the x - direction): here the acceleration is zero, so the horizontal component of velocity remains constant at u_x. At time t the horizontal displacement x is given by $x = u_x t$.. To find the velocity of the particle at any time t, the two components v_x and v_y must be added vectorially. The direction of the resultant vector is the direction of motion of particle. The curve traced out by a particle subject to a constant force in one direction is a parabola.

(Not in syllabus, only just for your info)

If an object is launched at an initial angle of $\vartheta 0$ with the horizontal, the analysis is similar except that the initial velocity has a vertical component.



Path of a projectile fired with initial velocity v_0 at angle θ_0 to the horizontal. Path is shown dashed in black, the velocity vectors are green arrows, and velocity components are dashed. The acceleration a = dv/dt is downward. That is, a = g.

If the particle had been sent off with velocity u at an angle θ to the horizontal, as in figure 3.20, the only difference to the analysis of the motion is that the initial y – component of velocity is u sin θ. In the example illustrated in Figure 3.20 this is upwards. Because of the downwards acceleration g, the y – component of velocity decreases to zero, at which time the particle is at the crest of its path, and then increases in magnitude again but this time in the opposite direction. The path is again a parabola.

For the particular case of a particle projected with velocity u at an angle θ to the horizontal from a point on level ground (Figure 3.21), the range R is defined as the distance from the point of projection to the point at which the particle reaches the ground again. We can show that R is given by :

$$R = \frac{(u^2 \sin 2\theta)}{g}$$

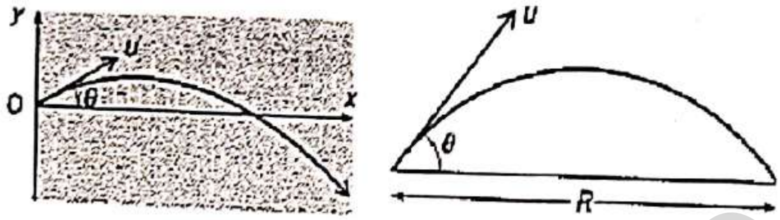


Figure 3.20 Figure 3.21

Sample Problem – Projectile Motion

A stone is thrown from the top of a vertical cliff, 45m high above level ground, with an initial velocity of 15 ms^{-1} in a horizontal direction (Figure 3.22). How long does it take to reach the ground? How far from the base of the cliff is it when it reaches the ground?

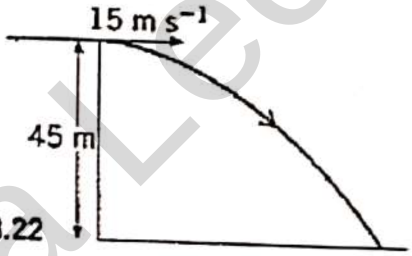


Figure 3.22

To find the time t for which the stone is in the air, work with the vertical component of the motion, for which we know that the initial component of the motion, for which we know that the initial component of velocity zero, the displacement y = 45 m, and the acceleration a is 9.81 ms^{-2}. The equation linking these is $y = \frac{1}{2}gt^2$. Substituting the values, we have 45 = $\frac{1}{2} \times 9.81t^2$. This gives

$$t = \sqrt{(2 \times 45 / 9.81)} = 3.0s$$

For the second part of the equation, we need to find the horizontal distance x travelled in the time t Because the horizontal component of the motion is not accelerating, x is given simply by x - $u_x t$.

Substituting the values, we have x = 15 x 3.0 = 45 m.

Dynamics

Newton's laws of Motion

Newton's laws of motion are three physical laws which provide relationships between the forces acting on a body and the motion of the body.

Newton's Laws: Force and Motion

The First Law: Force and Inertia

The Second Law: Force, Mass and Acceleration

The Third Law: Action and Reaction

Newton's first law of motion

An object at rest tends to stay at rest and object in motion tends to stay in motion unless acted upon by an external force.

What does this mean?

Basically, an object will keep doing what it was doing, unless acted on by an external force. If the object was sitting still, it will remain stationary. If it was moving at a constant velocity, it will keep moving at a constant velocity. It takes force to change the motion of an object.

The definition of force

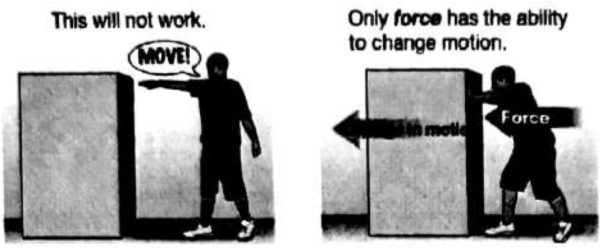
The simplest concept of force is a push or a pull. In other words, force is the action that has the ability to create or change motion.

Force

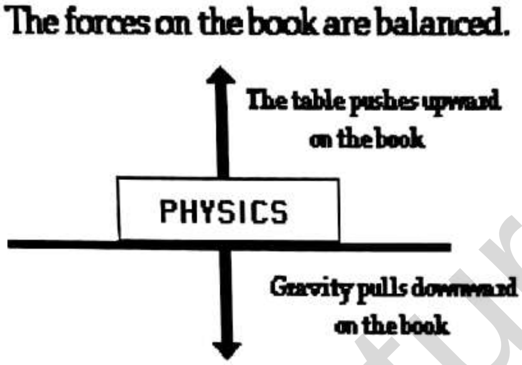
Force is an action that can change motion. A force is what we call a push or a pull, or any action that has the ability to change an object's motion.

Forces can be used to increase the speed of an object, decrease the speed of an object, or change the direction in which an object is moving.

Inertia is the resistance of any physical object to a change in its state of motion or rest, or the tendency of an object to resist any change in its motion.



Balanced force

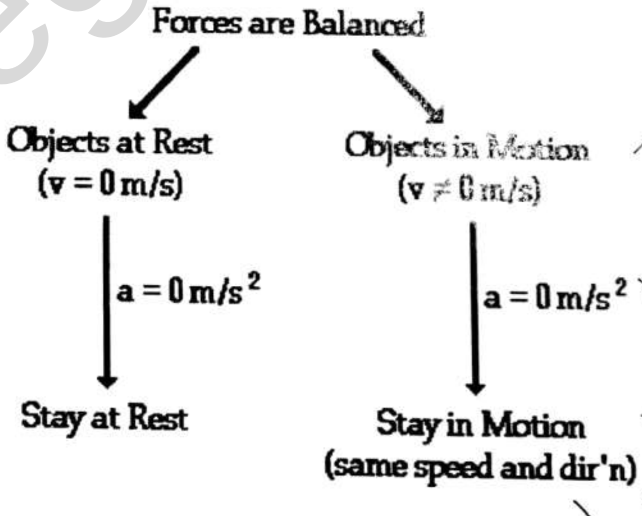


Balanced & Unbalanced

If the forces on an object are equal and opposite or if the total force is zero they are said to be balanced, and the object experiences no change in motion. If they are not equal and opposite or if the total forces is not zero, then the forces are unbalanced and the motion of the object changes.

These are some examples from real life:

A soccer ball is sitting at rest. It takes an unbalanced force of a kick to change its motion.



Newton's First Law Applied to Rocket Liftoff

"Every object persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by forces impressed on it."

Before Firing:

Object in state of rest, airspeed zero.

Engine Fired:

Thrust increases from zero. Weight decreases slightly as fuel burns.

When thrust is greater than weight

Net force (Thrust - Weight) is positive upward. Rocket accelerates upward velocity increases.

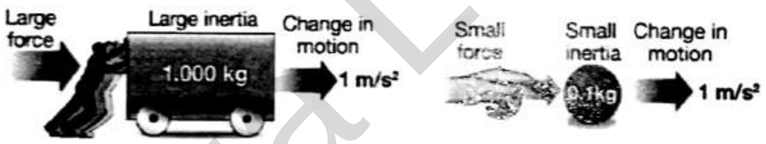
Newton's First Law is also called the Law of Inertia

Inertia: the tendency of an object to resist changes in its state of motion

The First Law states that all objects have inertia. The more mass an object has, the more inertia it has (and the harder it is to change its motion).

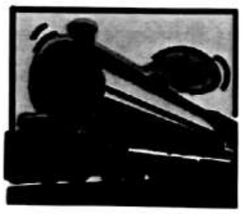
Inertia

Inertia is a term used to measure the ability of an object to resist a change in its state of motion. An object with a lot of inertia takes a lot of force to start or stop; an object with a small amount of inertia requires a small amount of force to start or stop. The word "inertia" comes from the Latin word inertus, which can be translated to mean "lazy."



Examples from Real Life

A powerful locomotive begins to pull a long line of boxcars that were sitting at rest. Since the boxcars are so massive, they have a great deal of inertia and it takes a large force to change their motion. Once they are moving, it takes a large force to stop them.



If objects in motion tend to stay in motion, why don't moving objects keep moving forever?

Things don't keep moving forever because there's almost always an unbalanced force acting upon it.

Example: A book sliding across a table slows down and stops because of the force of friction.

Forces Don't Keep Objects Moving

Newton's first law of motion declares that a force is not needed to keep an object in Motion.

For example: Slide a book across a table and watch it slide to a rest position. The book in motion on the table top does not come to a rest position because of the absence of a force; rather it is the presence of a force - that force being the force of friction – that brings the book to a rest position. In the absence of a force of friction, the book would continue in motion with the same speed and direction - forever! (Or at least to the end of the table top).

If you throw a ball upwards it will eventually slow down and fall because of the force of gravity.

How do these systems in a car overcome the law of inertia?

The engine

The engine supplies force that allows you to change motion by pressing the pedal.

The brake system

The brake system is designed to help you change your motion by slowing down.

The steering wheel and steering system

The steering wheel and steering system is designed to help you change your motion by changing your direction.

There are many more applications of Newton's first law of motion. Several applications are listed below. Perhaps you could think about the law of inertia and provide explanations for each application.

Blood rushes from your head to your feet while quickly stopping when riding on a descending elevator. The head of a hammer can be tightened onto the wooden handle by banging the bottom of the handle against a hard surface.

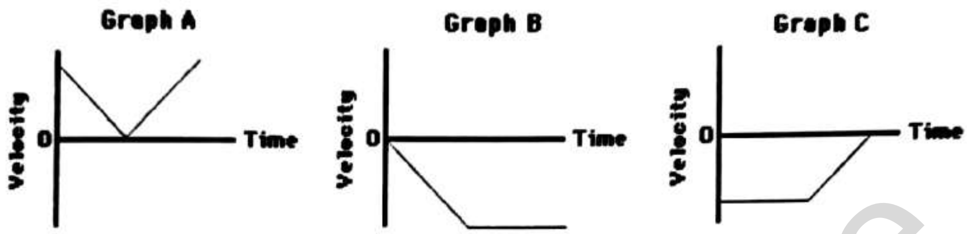
To dislodge ketchup from the bottom of a ketchup bottle, it is often turned upside down and thrusted downward at high speeds and then abruptly halted. While riding a skateboard (or wagon or bicycle), you fly forward off the board when hitting a curb or rock or other object that abruptly halts the motion of the skateboard.

Check your understanding !

Question 1

Luke drops an approximately 5.0 kg fat cat (weight = 50.0 N) off the roof of his house into the swimming pool below. Upon encountering the pool, the cat encounters a 50.0 N upward resistance force (assumed to be constant).

a) Which one of the velocity-time graphs best describes the motion of the cat? Support your answer with sound reasoning.



Answer

Graph B is correct. The cat first accelerates with a negative (downward) acceleration until it hits the water. Upon hitting the water, the cat experiences a balance of forces (50 N downwards due to gravity and 50 N upwards due to the water). Thus, the cat will finish its motion moving with a constant velocity. Graph B depicts both the initial negative acceleration and the final constant velocity.

Newton's Second Law of motion

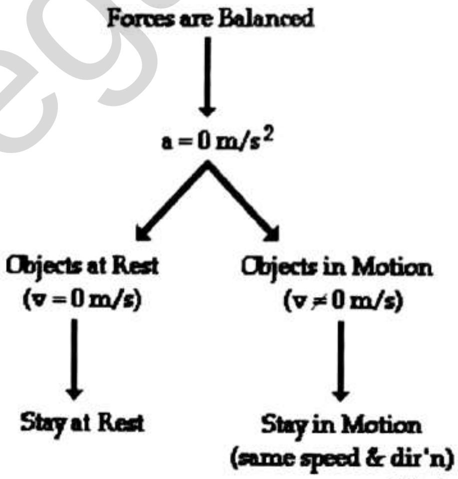
Force equals mass times acceleration

$$F = ma$$

Acceleration:

Acceleration is a measurement of how quickly an object is changing speed.

From 1st law (when forces are balanced.....)



When forces are unbalanced...

Forces are Unbalanced

↓

There is an acceleration

- **The acceleration depends directly upon the "net force"**
- **The acceleration depends inversely upon the object's mass.**

What does F = ma mean?

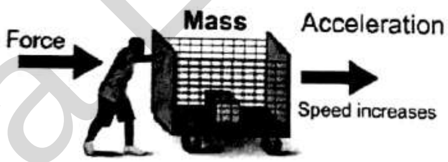
Force is directly proportional to mass and acceleration. Imagine a ball of a certain mass moving at a certain acceleration. This ball has a certain force.

Now imagine we make the ball twice as big (double the mass) but keep the acceleration constant. F = ma says that this new ball has twice the force of the old ball.

Now imagine the original ball moving at twice the original acceleration. F = ma says that the ball will again have twice the force of the ball at the original acceleration.

Newton's Second Law

If you apply more force to an object, it accelerates at a higher rate.



If the same force is applied to an object with greater mass, the object accelerates at a slower rate because mass adds inertia.

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

(a: Acceleration (m/s^2); F: Force (N); m: mass kg)

Mass will resist changes in motion

When you are standing on a bus, and the bus starts very quickly, your body seems to be pushed backward, and if the bus stops suddenly, then your body seems to be pushed forwards. Notice that when the bus turns left, you will seem to be pushed to the right, and when the bus turns right, you will seem to be pushed to the left.

Also consider a full shopping cart. If you try to push it from a stationary position, it will take some effort to get it moving. The same is true if you try to stop it when it is moving at a high speed, or try to turn it left or right.

In both cases, an object with mass is opposing a change in motion. In the first case, it is your body that tries to stay moving as it was before the change. Your body also tries to stay in a straight line when the bus turns, although it appears to be moving to the side. What is really happening is that your body is still moving straight and the bus turns in the opposite direction. The shopping cart exhibits the same behavior. When it is stationary, it tries to stay stationary, and when you try to stop it moving, it will try to continue. Your body and the cart both have mass.

From this, we can define a property of mass:

Mass will resist changes in motion. This says that any object with mass will resist any change in motion. Objects with greater mass will resist change in motion more than objects with less mass. In the SI system, the unit of mass is the kilogram (kg).

Unit of Force

A force of one Newton is exactly the amount of force needed to cause a mass of one kilogram to accelerate at one m/s^2. We call the unit of force the Newton (N).

Units

$$(\text{Acceleration } (m/s^2))a = \frac{F(\text{force (newtons, N)})}{m(\text{Mass (kg)})}$$

More about F = ma

If you double the mass, you double the force. If you double the acceleration, you double the force. What if you double the mass and the acceleration?

$$(2m)(2a) = 4F$$

Doubling the mass and the acceleration quadruples the force.

What does F = ma say?

$$F = ma$$

basically means that the force of an object comes from its mass and its acceleration.

Weight as the effect of a gravitational field on a mass

In everyday usage the term "weight" is commonly used to mean mass, which scientifically is an entirely different concept. On the surface of the Earth, the acceleration due to gravity (the "strength of gravity") is approximately constant; this means that the ratio of the weight force of a motionless object on the surface of the Earth to its mass is almost independent of its location, so that an object's weight force can stand as a proxy for its mass, and vice versa.

Definition of Weight

The word weight denotes a quantity of the same nature as a force. The weight of a body is the product of its mass and the acceleration due to gravity.

Newton's Second Law

Definitions

Differential Form: Force = change of momentum with change of time $$F = \frac{d(mv)}{dt}$$

or:

Force = change in mass X velocity with time $$F = \frac{(m_1V_1 - m_0V_0)}{(t_1 - t_0)}$$

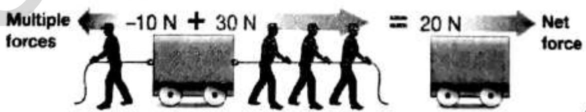
With mass constant: Force = mass X acceleration $$F = m a$$

Force, acceleration, momentum and velocity are all vector quantities.
Each has both a magnitude and a direction.

Using the second law of motion

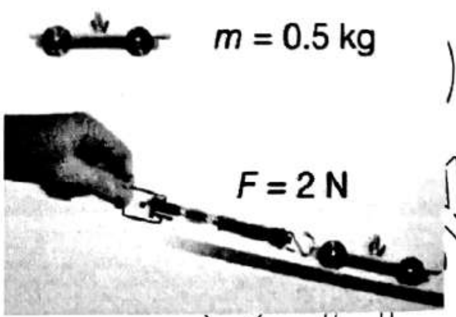
The force F that appears in the second law is the net force. There are often many forces acting on the same object. Acceleration results from the combined action of all the forces that act on an object. When used this way, the word net means "total."

To solve problems with multiple forces, you have to add up all the forces to get a single net force before you can calculate any resulting acceleration.



Calculating acceleration

A cart rolls down a ramp. Using a spring scale, you measure a net force of 2 newtons pulling the car down. The cart has a mass of 500 grams (0.5 kg). Calculate the acceleration of the cart.



1. You are asked for the acceleration (a).
2. You are given mass (m) and force (F).
3. Newton's second law applies: a = F ÷ m
4. Plug in numbers. (Remember: 1 N = 1 kg·m/s2)

Three forms of the second law

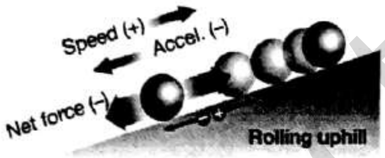
Use...	If you want to find...	And you know...
$a = \frac{F}{M}$	The acceleration (a)	The net force (F) and the mass m
$F = ma$	The net force (F)	The acceleration (a) and the mass (m)
$M = \frac{F}{a}$	The mass (m)	The acceleration (a) and the net force (F).

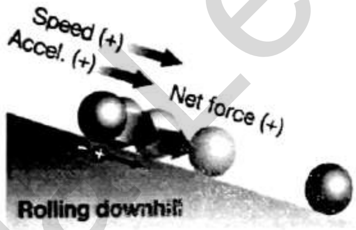
Finding the acceleration of moving objects

The word dynamics refers to problems involving motion. In dynamics problems, the second law is often used to calculate the acceleration of an object when you know the force and mass.

Direction of acceleration

Speed increases when the net force is in the same direction as the motion. Speed decreases when the net force is in the opposite direction as the motion.



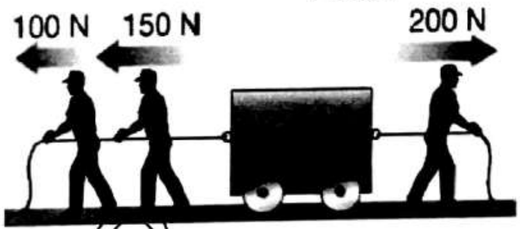


Positive and negative acceleration

We often use positive and negative numbers to show the direction of force and acceleration. A common choice is to make velocity, force, and acceleration positive when they point to the right.

Acceleration from multiple forces

Three people are pulling on a wagon applying forces of 100 N, 150 N, and 200 N. Determine the acceleration and the direction the wagon moves. The wagon has a mass of 25 kilograms.



1. You are asked for the acceleration (a) and direction
2. You are given the forces (F) and mass (m).
3. The second law relates acceleration to force and mass: $a = F \div m$
4. Assign positive and negative directions. Calculate the net force then use the second law to determine the acceleration from the net force and the mass.

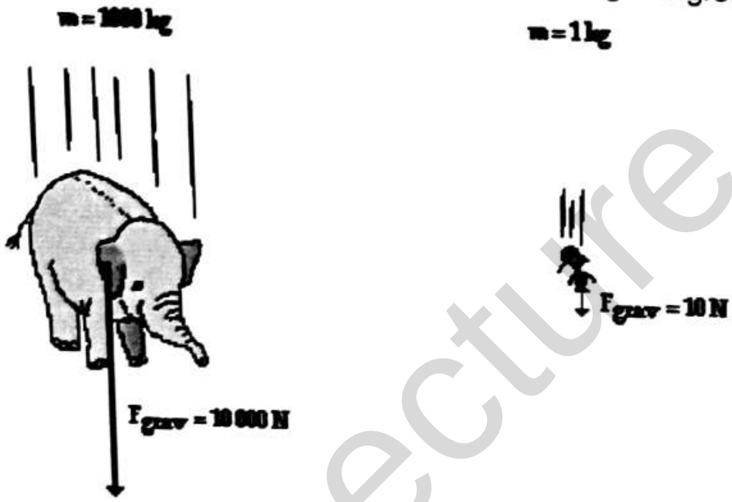
Finding force from acceleration

Wherever there is acceleration there must also be force. Any change in the motion of an object results from acceleration. Therefore, any change in motion must be caused by force.

Coming back to...Free Fall Motion

As learned in an earlier chapter, free fall is a special type of motion in which the only force acting upon an object is gravity. Objects that are said to be undergoing free fall, are not encountering a significant force of air resistance; they are falling under the sole influence of gravity. Under such conditions, all objects will fall with the same rate of acceleration, regardless of their mass. But why?

Consider the free-falling motion of a 1000-kg baby elephant and a 1-kg overgrown mouse.



$a = \frac{F_{net}}{m} = \frac{10\,000\ N}{1000\ kg}$

$a = 10\ m/s/s$

$a = \frac{F_{net}}{m} = \frac{10\ N}{1\ kg}$

$a = 10\ m/s/s$

Explanation on free fall....based on previous diagram

- If Newton's second law were applied to their falling motion, and if a free-body diagram were constructed, then it would be seen that the 1000-kg baby elephant would experiences a greater force of gravity. This greater force of gravity would have a direct affect upon the elephant's acceleration; thus, based on force alone, it might be thought that the 1000-kg baby elephant would accelerate faster. But acceleration depends upon two factors: force and mass. The 1000-kg baby elephant obviously has more mass (or inertia). This increased mass has an inverse affect upon the elephant's acceleration. And thus, the direct affect of greater force on the 1000-kg elephant is offset by the inverse affect of the greater mass of the 1000-kg elephant; and so each object accelerates at the same rate - approximately 10 m/s/s. The ratio of force to mass (F_{net}/m) is the same for the elephant and the mouse under situations involving free fall.

This ratio (Fnet/m) is sometimes called the gravitational field strength and is expressed as 9.8 N/kg (for a location upon Earth's surface). The gravitational field strength is a property of the location within Earth's gravitational field and not a property of the baby elephant nor the mouse. All objects placed upon Earth's surface will experience this amount of force (9.8 N) upon every 1 kilogram of mass within the object. Being a property of the location within Earth's gravitational field and not a property of the free falling object itself, all objects on Earth's surface will experience this amount of force per mass. As such, all objects free fall at the same rate regardless of their mass. Because the 9.8 N/kg gravitational field at Earth's surface causes a 9.8 m/s² acceleration of any object placed there, we often call this ratio the acceleration of gravity

Check your understanding!

Question 1

Determine the accelerations that result when a 12-N net force is applied to a 3-kg object and then to a 6-kg object.

Answer 1

Determine the accelerations that result when a 12-N net force is applied to a 3-kg object and then to a 6-kg object.

Answer: A 3-kg object experiences an acceleration of4 m/s^2. A 6-kg object experiences an acceleration of 2 m/s^2

Question 2

Suppose that a sled is accelerating at a rate of 2 m/s^2. If the net force is tripled and the mass is doubled, then what is the new acceleration of the sled?

Answer 2

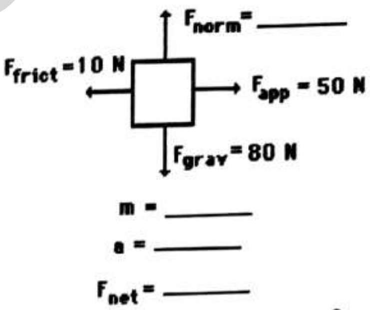
Suppose that a sled is accelerating at a rate of 2 m/s^2. If the net force is tripled and the mass is doubled, then what is the new acceleration of the sled?

Answer: 3 m/s^2

The original value of 2 m/s^2 must be multiplied by 3 (since a and F are directly proportional) and divided by 2 (since a and m are inversely proportional)

Question 3

An applied force of 50 N is used to accelerate an object to the right across a frictional surface. The object encounters 10 N of friction. Use the diagram to determine the normal force, the net force, the mass, and the acceleration of the object. (Neglect air resistance.)



Answer 3

F_{norm} = 80 N; m = 8.16 kg; F_{net} = 40 N, right; a = 4.9 m/s^2, right

(If you are using g = 10, F_{norm} = 80 N; m = 8 kg; F_{net} = 40 N, right; a = 5 m/s^2, right)

Since there is no vertical acceleration, normal force = gravity force. The mass can be found using the equation F_{grav} = m g

The F_{net} is the vector sum of all the forces: 80 N, up plus 80 N, down equals 0 N. And 50 N, right plus 10 N, left = 40 N, right. Finally, a = F_{net} / m = (40 N) / (8.16 kg) = 4.9 m/s^2.

Question 4

An applied force of 20 N is used to accelerate an object to the right across a frictional surface. The object encounters 10 N of friction. Use the diagram to determine the normal force, the net force, the coefficient of friction (μ) between the object and the surface, the mass, and the acceleration of the object. (Neglect air resistance.)

Note: To simplify calculations, an approximated value of g is often used as 10 m/s²

The coefficient of friction (COF), often symbolized by the Greek letter μ, is a dimensionless scalar value which describes the ratio of the force of friction between two bodies and the force pressing them together. The coefficient of friction depends on the materials used; for example, ice on steel has a low coefficient of friction, while rubber on pavement has a high coefficient of friction.

Answer 4

F_{norm} = 100 N; m = 10.2 kg; F_{net} = 10 N, right; "mu" m/s², right (If you are using g=10, F_{norm} = 100 N; m = 10 kg "mu" = 0.1; a =1 m/s², right) Since there is no vertical acceleration, the normal force is equal to the gravity force. The mass can be found using m g.

Using "mu" = F_{frict} / F_{norm}, "mu" = (10 N) / (100 N) = 0.1.

The F_{net} is the vector sum of all the forces: 100 down equals 0 N. And 20 N, right plus 10 N, lef
Finally, a = F_{net} / m = (10 N) / (10.2 kg) = 0.980

Equilibrium

The condition of zero acceleration is called equilibrium. In equilibrium, all forces cancel out leaving zero net force. Objects that are standing still are in equilibrium because their acceleration is zero.Objects that are moving at constant speed and direction are also in equilibrium. A static problem usually means there is no motion.

Calculating force

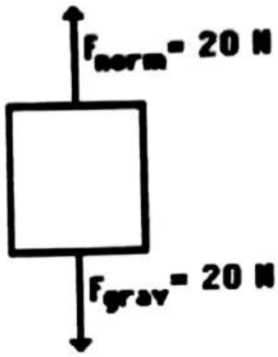
A woman is holding two dogs on a leash. If each dog pulls with a force of 80 Newtons, how much force does the woman have to exert to keep the dogs from moving?

1. You are asked for force (F).
2. You are given two 80 N forces and the fact that the dogs are not moving (a = 0).
3. Newton's second law says the net force must be zero if the acceleration is zero.
4. The woman must exert a force equal and opposite to the sum of the forces from the two dogs.

Check your understanding on balanced forces!!

Who is wrong here? Anna or Noah?

Two students are discussing on an object that is being acted upon by two individual forces (both in a vertical direction). During the discussion, Anna suggests to Noah that the object under discussion could be moving. In fact, Anna suggests that if friction and air resistance could be ignored (because of their negligible size), the object could be moving in a horizontal direction. According to Anna, an object experiencing forces as described at the right could be experiencing a horizontal motion. Noah objects, arguing that the object could not have any horizontal motion if there are only vertical forces acting upon it. Noah claims that the object must be at rest, perhaps on a table or floor. After all, says Noah, an object experiencing a balance of forces will be at rest. Who do you agree with?



Answer

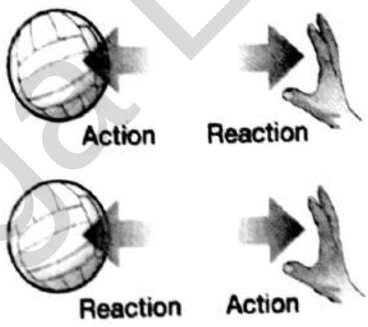
Anna is correct.

Noah may know the formulas but he does not know (or does not believe) Newton's laws. If the forces acting on an object are balanced and the object is in motion, then it will continue in motion with the same velocity.

Remember: forces do not cause motion. Forces cause accelerations.

Newton's third law of motion.....

For every action there is an equal and opposite reaction.



What does this mean?

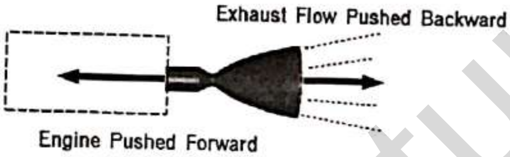
For every force acting on an object, there is an equal force acting in the opposite direction. Right now, gravity is pulling you down in your seat, but Newton's Third Law says your seat is pushing up against you with equal force. This is why you are not moving. There is a balanced force acting on you– gravity pulling down, your seat pushing up.

What happens if....

What happens if you are standing on a skateboard or a slippery floor and push against a wall? You slide in the opposite direction (away from the wall), because you pushed on the wall but the wall pushed back on you with equal and opposite force.

Newton's 3rd Law Demo

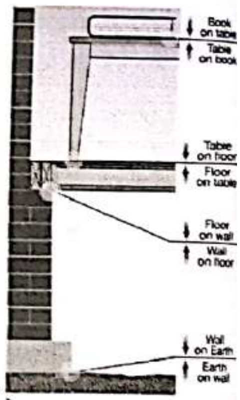
http://www.youtube.com/watch?v=xQh8ji_4fZs



For every action, there is an equal and opposite re-action.

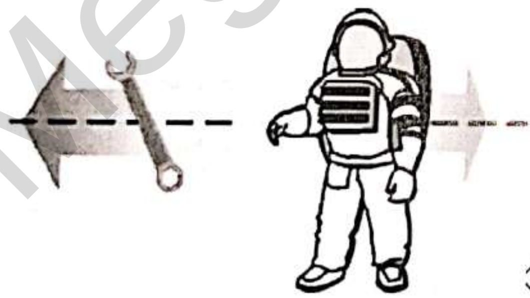
The Third Law: Action and Reaction

"For every action there is an equal and opposite reaction." This statement is known as Newton's third law of motion. Newton's third law discusses pairs of objects and the interactions between them.



Forces occur in pairs

The astronauts working on the space station have a serious problem when they need to move around in space: There is nothing to push on. One solution is to throw something opposite the direction you want to move.



The two forces in a pair are called action and reaction. Anytime you have one, you also have the other. If you know the strength of one you also know the strength of the other since both forces are always equal.

Third Law...

Action and reaction forces act on different objects, not on the same object.

The forces cannot cancel because they act on different objects.

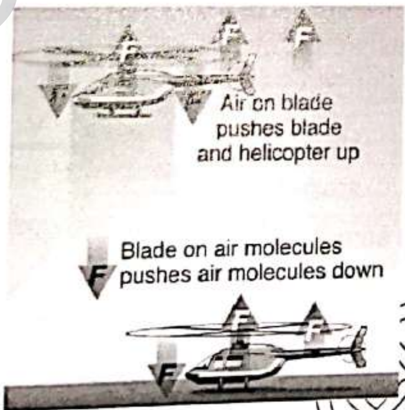
Action & Reaction

The act of moving or the ability to move from one place to another is called locomotion. Any animal or machine that moves depends on Newton's third law to get around. When we walk, we push off the ground and move forward because of the ground pushing back on us in the opposite direction.

Action & Reaction

Jets, planes, and helicopters push air. In a helicopter, the blades of the propeller are angled such that when they spin, they push the air molecules down.

The rotor blades of an helicopter are just like the wings of an airplane or a bird. As they move through the air, they pull the air above them downwards. That's the "action" part of the action-reaction. When the blades push the air downward, the helicopter is lifted. The air has considerable mass and inertia, and resists being pulled down—it tries to push the wings up instead. That's the "reaction" part, and that's also aerodynamic lift. The blades pull air downwards, and the reaction to this pushes the helicopter upwards.



Momentum as the product of mass and velocity

Momentum or Linear momentum or translational momentum is the product of the mass and velocity of an object.

Momentum = mass x velocity

For example, a heavy truck moving fast has a large momentum—it takes a large and prolonged force to get the truck up to this speed, and it takes a large and prolonged force to bring it to a stop afterwards. If the truck were lighter, or moving slower, then it would have less momentum. Like velocity, linear momentum is a vector quantity, possessing a direction as well as a magnitude.

Units: $kgms^{-1}$ or Ns

Force as a rate of change of Momentum

Consider a body of mass m, initially moving with a velocity of magnitude u. A force F acts on the body and causes it to accelerate to a final velocity of magnitude v. We can write Newton's second law in the form and a simple rearrangement shows the relation between force and momentum Remember, momentum = mass x velocity. Now, mv is the final momentum of the body and mu is the initial momentum of the body. Therefore, we have

Force = rate of change of momentum

Principle of Conservation of Momentum

The Principle of the Conservation of Momentum states that: if objects collide, the total momentum before the collision is the same as the total momentum after the collision (provided that no external forces - for example, friction - act on the system).

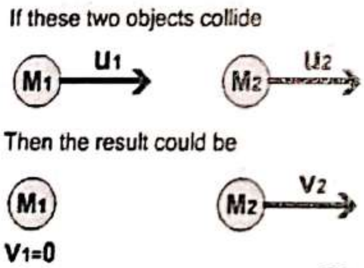
Of course, energy is also conserved in any collision, but it isn't always conserved in the form of kinetic energy.

Case 1

To do any calculations for momentum, there are some simple rules to follow to make it easy:

Always decide which direction is positive and which is negative, then stick to it. Always remember that the total momentum before the collision will be the same as the total momentum after the collision.

So,



The conservation of momentum states:

$Momentum_{before} = Momentum_{after}$

So, $(P_1 + P_2)$ before= $(P_1 + P_2)$ after

Or, $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

But notice that in this example, $v_1 = 0$. So that term cancels and makes finding an answer much easier.

Case 2

If the objects change direction in the collision or are going in different directions before the collision, make sure that you have got the signs for the velocities and therefore the momentums correct.

Example 1

If these two objects collide

Because the objects are moving in opposite directions, we have to treat one of the velocities as negative. And so:

Initial P=m_1u_1+($-m_2u_2$)

Example 2

Initially:

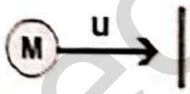
Becomes, after a collision:

Note that the direction and sign of velocity (and therefore momentum) of M_1 changes after the collision.

Case 3

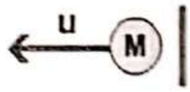
When objects bounce back after a collision, be careful about the change in momentum.

Example **Initially:**



Then there is an elastic collision (ie v and u have the same magnitude but opposite directions)

Finally:



So change in momentum = final P - initial P

= -mu - (+ mu)

= - 2mu

Explosions

Explosions are a special type of collision. Momentum is conserved in an explosion. This is made easier by the fact that usually, the momentum before an explosion is zero. The Principle of the Conservation of Momentum states that the momentum after the explosion must therefore be zero as well.

What's the momentum of the universe?

If the universe began with a Big Bang (for instance - an explosion), the momentum of the universe before the explosion was zero.

So what is its momentum?

F = ma

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

So, $F = m\left(\frac{v - u}{t}\right) = \frac{mv - mu}{t} = \frac{\text{change in momentum}}{\text{time}}$

Principle of Conservation of Momentum elastic and Inelastic collisions

Perfectly Elastic collisions

All momentum is conserved. Kinetic energy is conserved as well. Relative speed of approach = relative speed of separation. (So if one is catching the other at 10m/s before the collision, it will be moving apart from it at 10m/s after the collision)

Perfectly Elastic collisions are surprisingly common. All collisions between atoms are Perfectly Elastic according to the Kinetic Theory of Gases.

Principle of Conservation of Momentum

Elastic and Inelastic collisions

Perfectly Inelastic collisions

All momentum is conserved (as always).

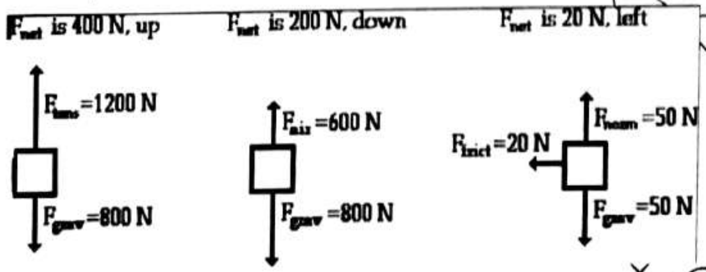
Kinetic energy is not conserved.

The relative speed of separation is zero.

(In other words, that means the objects stick together after the collision, they will move together, so just consider them as one object whose mass is the same as that of the two original masses combined).

Why is kinetic energy not conserved while momentum is conserved in a perfectly inelastic collision?

It goes into heat, sound, work done to deform the colliding bodies etc. Other forms of energy, in other words. Momentum is not a type of energy. Momentum and energy are totally different physical quantities with different physical dimensions. (Energy is the capacity to do work) Conservation of momentum in a system occurs provided that there are no external forces acting on a system. This is a consequence of Newton's 2nd law and Newton's 3rd law. Newton's 2nd law says that the net force acting on a body is equal to the rate of change of its momentum. This is the full, general statement of the 2nd law. F = Δp/Δt. If the mass of the body is constant, this reduces to F = m(Δv/Δt) = ma. Therefore, if a net force acts on an object, its momentum will change with time. If there is no net force, then its momentum will not change.



How and when momentum is conserved ?

Now, consider a system of interacting particles. The particles are moving around randomly. Every once in a while, two particles (1 and 2) may collide. While this is happening, particle 1 exerts a force on particle 2. However, Newton's 3rd law says that particle 2 must therefore, at the same time, exert a force on particle 1 of equal strength and opposite direction. These forces are also exerted over the same time interval (while the particles are in contact). Therefore, the change in momentum of particle 1 will be equal in magnitude and opposite in direction to the change in momentum of particle 2. These two momentum changes therefore cancel each other out. Each particle may individually change its momentum, but there will be no change to the total momentum of the system. In other words, since Newton's 3rd says that these internal forces always occur in matched "action-reaction" pairs, they cannot ever cause a change to the overall momentum of the system. Only an external force (a force from something that is not part of the system of particles) can cause a change in the total momentum of the system. In the absence of a net external force, $F_{tot} = 0$ and hence $\Delta p_{tot} = 0$. In the absence of external forces, momentum is conserved.

Work, Energy and Power

Energy possessed by a body is the capacity of the body to do work.

State the principle of conservation of energy.

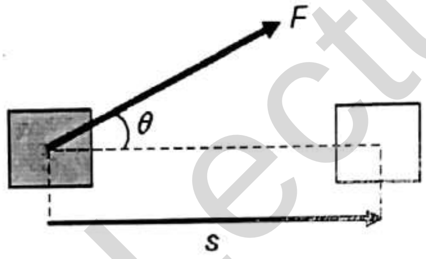
Energy can neither be created nor destroyed, but can be converted from one form to another (or others).

The total amount of energy in any closed system is constant.

Energy and work are both scalar quantities, and have the unit Joule.

Work in terms of the product of a force and displacement in the direction of the force

In physics, work is done when a force moves its point of application so that some resolved part of the displacement lies along the direction of the force.



1. **Define work**

   The work W done on an object by an agent exerting a constant force F on the object is defined as the product of the force and the displacement in the direction of the force

$$W = Fs\cos\theta$$

Where W is the work done on the object by the constant force F (joule, J)

F is the constant force acting on the object (Newton, N)

s is the displacement of the object (metre, m)

θ is the angle between F and s (degree, °)

In cases, where no angle is given, you may use the equation

$$W = Fs$$

Unit of Work

The S.I. unit for work is the joule.

One joule (1 J) is defined as the work done by a constant force of one newton (1N) on an object when the object moves one metre (1 m) in the direction of the force.

The unit Newton meter (N m) is usually used for moment, while Joule (J) is usually used for work.

Scenario	Work done on object	Example
Force does not move the object	Zero	A man pushing a wall
Force is perpendicular to the object's movement	Zero	Weight of a trolley moving along a horizontal
Force has a resolved part in the same direction as the object's displacement	Positive	A man pushing a trolley
Force has a resolved part in the opposite direction as the object's displacement.	Negative	Friction opposing the trolley's motion.

In the above example, positive work done on an object increase the kinetic energy of the trolley, while negative work done decreases its kinetic energy. Zero work done means the kinetic energy remains constant.

Note:
Even though work is a scalar, it can be positive or negative.

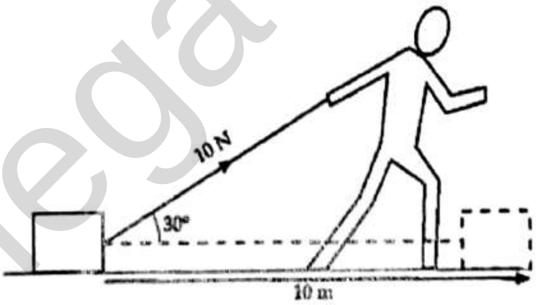
Work done by a constant force

Sample problem -1

Fig 6.3 Positive work done

The following are examples of work done by a constant force.
(a) Work done by the man on a box (Fig 6.3).

$$W = Fs\cos\theta$$
$$= (10)(10)\cos 30°$$
$$= 86.6\text{ J}$$
$$= 87\text{ J}$$

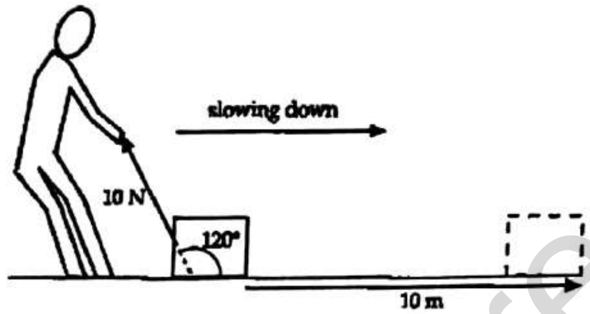


Sample Problem 2 – Solve It

Fig 6.4 Negative work done

(b) Work done by the man in opposing the sliding box (Fig 6.4).

$$W = Fs\cos\theta$$
$$= (10)(10)\cos 120^\circ$$
$$= -50\ J$$

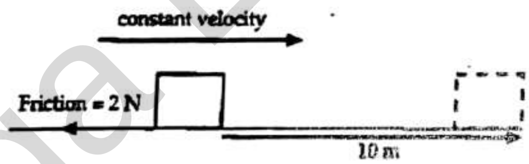


Sample Problem 3 – Solve it

Fig 6.5 Work done by friction

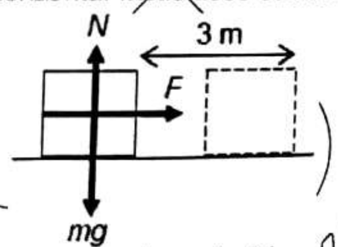
(c) Work done by the frictional force in opposing the sliding box (Fig 6.5).

$$W = Fs\cos\theta$$
$$= (2)(10)\cos 180^\circ$$
$$= -20\ J$$



Sample Problem 4 – Solve it

A man pushes a box of mass 5 kg with a force of 2 N along a horizontal frictionless surface. The box is moved through a distance 3 m.



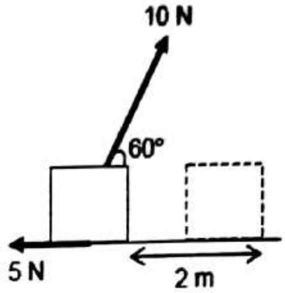
Calculate the work done on the box by

(a) The pushing force:
(b) The normal contact force;
(c) The weight of the box.

(a) W = Fs cosθ = 2 x 3 = 6J
(b) W = 0 J
(force perpendicular to displacement)
(c) W = 0J

Example 5 – Solve it

A block is pulled along a rough horizontal surface by a rope pointing at 60° above the horizontal. The tension in the rope is 10 N and the frictional force is 5 N. The block moves a distance of 2 m along the surface.



Calculate the work done on the box by

(a) The tension in the rope
(b) The frictional force

(a) $W = Fs\cos\theta = (10\cos 60^\circ)2 = 10$ J
(b) $W = (-5)2 = -10$J

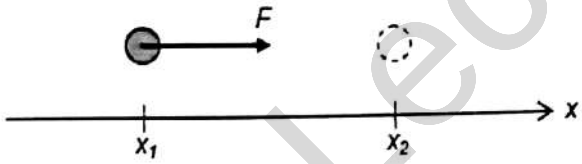
Example 6 – Solve it

How much work is done by a person who uses a force of 27.5 N to move a trolley 12.3 m?

$W = F \times d = (27.5\text{ N})(12.3\text{ m}) = 338.25$ J

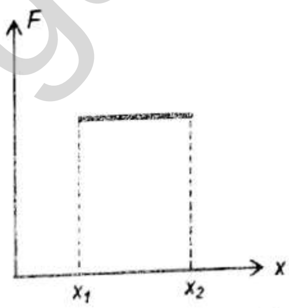
Special Case

Suppose a force F is acting on an object along the x – direction and the object moves a distance $(x_2 - x_1)$ along the same direction



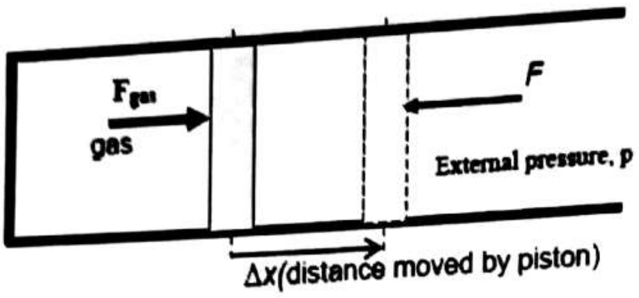
If F is constant,

work done is given by $W = F(x_2 - x_1)$



Work done = area under __force-displacement__ **graph**

For work done by a gas which is expanding against a constant external pressure



Symbol

F is the force exerted by external pressure on piston

p is the constant external pressure

Δx is the distance moved by piston

A is the cross – sectional area of piston

For a piston with a cross – sectional area A, the force F acting normal to it is given by F = pA.

For a gas with pressure = external pressure p, if the piston is allowed to move outwards slowly by a displacement Δx, the gas will expand against the constant external pressure p, and F_{gas} = F

The work done W by the gas against this constant pressure p is given by W = FΔx = (pA) = Δx = p (AΔx) = p ΔV where ΔV is the change in volume.

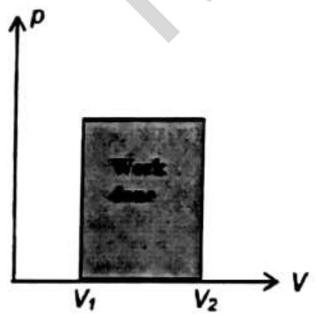
Hence, when a gas expands with a change in volume ΔV against constant pressure p, work done by gas is given by:

1. W = pΔV

Where W is the work done by gas (J)
p is the external pressure (Pa)
ΔV is the change in volume of the gas (m^3)

> Note:
> $\Delta V = V_{final} - V_{initial}$

2. If p is constant,
Work done is given by $W = p(V_2 - V_1)$



Work done = area under **pressure volume** graph

	When gas expands	When gas is compressed
Piston moves	Outwards	Inwards
Force exerted by gas on surroundings and displacement moved	In same direction	In opposite direction
Work done by gas on surroundings	Positive	Negative
Work done by surroundings on gas	Negative	Positive
We say	Gas does work on surroundings	Surroundings do work on gas.

Try to solve it

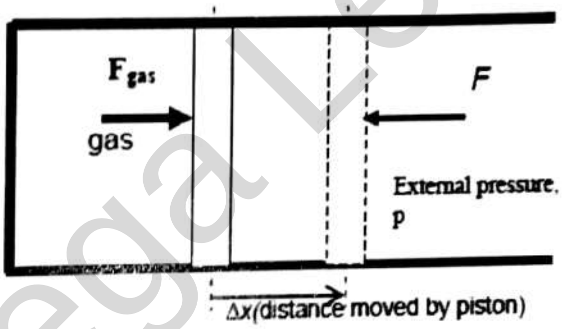
A gas in a cylinder is kept at a constant pressure of 1.1×10^5 Pa. The gas is heated and expands by 25 cm^3

Calculate the work done by the gas

1 cm = 10^{-2} m

1 cm^3 = 10^{-6} m^3

$W = p\Delta V = 1.1 \times 10^5 \times 25 \times 10^{-6} = 2.75$ J



Derive from Equations of motion (KE)

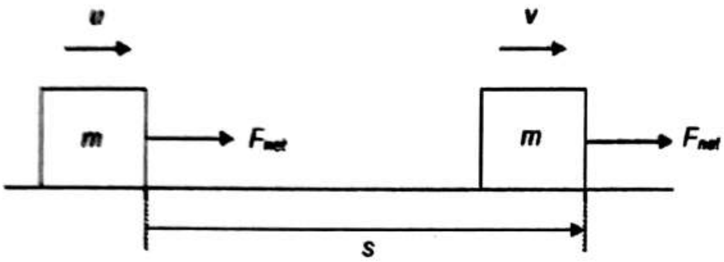
1. The kinetic energy (K.E.) is a positive scalar quantity that represents the energy associated with the body due to its **motion.**

   It is equal to the work done by the resultant force in accelerating the body from rest to an instantaneous speed v.

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

Where E_k is the kinetic energy of the body moving at speed v (J).
m is the mass of the body (kg).
v is the speed of the body (ms^{-1})

Derive, from the equations of motion, the formula $E_k = ½ m v^2$



Body initially at rest, u = 0

Work done by net force = change in K.E. of body

$(F_{net}) s = E_k$

$mas = E_k$

using $v^2 = u^2 + 2as$: $½ mv^2 - ½ m (0)^2 = E_k$

Note:
1. E_k is a scalar quantity and has the same units as work i.e. joules, J.
2. Work done by net force = Change in K.E of body ($W = ½ mv^2 – ½ mu^2$)

Sample Problem 1 – Solve it

A car of mass 800 kg and mass moving at 30 m s^{-1} along a horizontal road is brought to rest by a constant retarding force of 5000 N.

Calculate the distance travelled by the car in coming to rest.

Using work done = change in K.E.:

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$(-5000)s = 0 - \frac{1}{2}(800)(30)^2$$

s = 72 m

Using Kinematics equation

$$v^2 = u^2 + 2as$$

$$0 = 30^2 + 2\left(\frac{-5000}{800}\right)s$$

s = 72 m

Energy in different forms, its conversion and conservation, and apply the principle of energy conservation to simple examples

Types of energy and their sources:

Energy	Source
Mechanical	
Kinetic energy	Energy possessed by all objects in motion
1. Gravitational P.E	Energy possessed by an object by virtue of its position in a gravitational field. E.g. from waterfall and from raised object.
2. Elastic P.E	Energy possessed by an object by virtue of its state of deformation. e.g. Compressed or stretched springs, a bent diving board, the stretched elastic band of a catapult.
Electrical	Due to charge or current.
Current	Energy possessed by a fuel by virtue of its chemical composition e.g. oil, wood, food, chemicals in electrical cells
Nuclear	Energy in nucleus of atoms due to nuclear composition. e.g energy released in atomic bombs, produced by nuclear reactors.
Radiant	Energy in the form of electromagnetic waves e.g. visible light, radiowaves, ultraviolet, X – rays
Internal Energy	Energy possessed by atoms/ molecules of matter in the form of kinetic energy due to motion of the particles in the matter and potential energy which depends on the separation between atoms / molecules.

Renewable and Non – renewable energy

Renewable sources

Renewable sources of energy are those that can be replaced or replenished each day by the Earth's natural processes. E.g. wind power, geothermal, solar energy, tidal energy.

Non - renewable sources

Non - renewable sources of energy are those that are finite or exhaustible because it takes several million years to replace them e.g. fossil fuels like coal, oil and natural gas, energy sources that are tapped from minerals e.g. nuclear energy from the fission of Uranium nuclei.

Gravitational potential energy, Electric potential energy and Elastic potential energy

1. Potential energy (P.E.) is the energy possessed by a system by virtue of the relative positions of its component parts.
2. Gravitational potential energy (G.P.E.) is associated with the interaction between bodies due to their masses.
3. Electric potential energy is associated with the interaction between bodies due to their electric charges.
4. Elastic potential energy is possessed by an object due to its state of deformation.

Give examples of energy in different forms and its conversion

Check your understanding

- http://www.youtube.com/watch?feature=endscreen&NR=1&v=Idl8wnQOkIM
- http://science.howstuffworks.com/engineering/structural/roller-coaster3.htm

More Examples of Energy conversion

Example: Diver jumping off a diving board

The driver uses his gravitational potential energy to do work in bending the diving board. The wo done is stored as elastic potential energy, which is then converted into kinetic energy of the div as he is pushed upwards and off the diving board. At the same time, some of the elastic potenti energy is lost as heat and sound due to dissipative forces in the diving board.

Example: Burning of fossil fuel

When fuels such as oil, coal and wood are burnt, the chemical energy stored in these materials i converted into thermal energy (heat) and light energy.

Example: Hammering a nail into a wooden block

A person uses the chemical energy in his muscles to work against the gravitational pull in order to lift the hammer. The work done is converted into the gravitational potential energy of the hammer in its raised position.

As the hammer falls, its gravitational potential energy is converted into Kinetic energy. When the hammer hits the nail, its kinetic energy is used to do work in driving the nail into the wooden block, producing sound energy in the air and thermal energy in the block, nail and hammer.

Example: Falling Plasticine

During impact, all kinetic energy is converted into thermal and sound energies as the plasticine is permanently deformed.

Example: Bouncing Ball

As the ball falls, its gravitational potential energy is converted into its kinetic energy. When the ball hits the ground, the ball is deformed during the collision. Its kinetic energy is converted into elastic potential energy. Some kinetic energy may be lost as thermal energy or sound energy.

The elastic potential energy is converted back into kinetic energy as the ball regains its original shape. The kinetic energy is converted into gravitational potential energy as the ball bounces upwards, until it reaches its highest position.

During the flight, presence of air resistance will cause kinetic energy to be dissipated as thermal energy, thus reducing the total energy in the ball and its subsequent height after each bounce.

Internal Energy

Matter consists of atoms and molecules and these are made up of particles having kinetic energy and Potential energy.

We can define the Internal energy of a system as the sum of the kinetic energy of all its constituent particles plus the sum of all the potential energy of interaction among these particles in the system.

> **Note:** The internal energy does not include potential energy arising out of interaction between the system and it surroundings.

The implications of energy losses in practical devices and use the concept of efficiency to solve problems

1. For practical devices to work, energy input is needed. Most modern practical devices run on electrical energy (e.g. television, computer) or chemical energy (e.g. vehicle).
   When a practical device works, it converts the energy input into both useful energy output and wasted energy output.

2. Efficiency of a practical device is a measure of how much useful work that device produces form a given amount of energy input.
   Its value does depend on what energy output we consider as useful.
   Efficiency is dimensionless and can be expressed as a ratio or percentage.

$$\text{Efficiency, } \eta = \frac{\text{useful energy output}}{\text{energy input}} \times 100\ \%$$

3. We can never make a practical device with 100 % efficiency because:
   (a) We have limited control over physical processes (e.g. a filament bulb must heat up before it produces light, but the heat produced becomes wasted energy);

4. **Sample Problem**
   A car has a mass of 800 kg and the efficiency of its engine is rated at 18%. Determine the amount of fuel used to accelerate the car from rest to 60 km h^{-1}, given that the energy supplied by 1 litre of fuel is 1.3 x 10^{6} J.

> **Note:** In this case, the useful energy output is defined to be the **change in kinetic energy** of the car as it accelerates from rest to 60 kmh^{-1}.

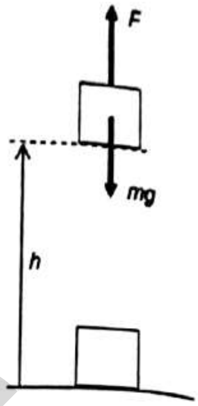
$$\text{Useful energy output} = \text{K.E. of car} = \frac{1}{2}(800)\left(\frac{60000}{60 \times 60}\right)^2 = 111111\ \text{J}$$

$$\eta = \frac{\text{useful energy output}}{\text{energy input}} \times 100\% \quad \Rightarrow \quad 18\% = \frac{111111}{\text{energy input}} \times 100\%$$

$$\Rightarrow \quad \text{energy input} = 617284\ \text{J}$$

$$\text{Amount of fuel} = \frac{617284}{1.3 \times 10^{6}} = 0.0047\ \text{litres}$$

Derive, from the defining equation W = Fs, the formula Ep = mgh for the potential energy changes near the Earth's surface



Suppose we want to lift an object of mass m to a height h above the ground, so that its velocity remains constant.

To do so, we must apply a force F that is equal but opposite to the weight mg of the object, where g is the acceleration of free fall.

The work done W by force F on the object is:

$$W = Fh = (mg)h$$

Since the object's velocity is constant, its kinetic energy is also constant. Hence, by conservation of energy, the work done W on the object must be equal to the gain in G. P. E. of the object.

Change in G.P.E. near Earth's surface = mgh

Sample problem

Figure shows a dam with storage of water. The outlet of the dam is 20 m below the surface of the water in the reservoir. Water leaving the dam is moving at 16m/s. Calculate the % of G.P.E that is lost when converted into K.E.

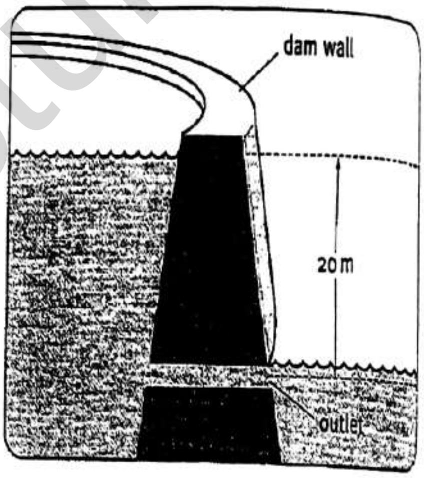


Figure 5.18 Water stored behind the dam has gravitational potential energy; the fast-flowing water leaving the foot of the dam has kinetic energy.

Solution

Step 1: We will picture 1 kg of water, starting at the surface of the lake (where it has g. p.e., but to k.e.) and flowing downwards and out at the boot (where it has k.e., but less g.p.e.). then:

Change in g.p.e. of water between surface and outflow = mgh = 1 x 9.81 x 20 = 196 J

Step 2: Calculate the k.e. of 1 kg of water as it leaves the dam:

$$\text{k.e. of water leaving dam} = \frac{1}{2}mv^2$$

$$= \frac{1}{2} \times 1 \times (16)^2$$

$$= 128 \text{ J}$$

Step 3: For each kilogram of water flowing out of the dam, the loss of energy is:

$$\text{loss} = 196 - 128 = 68 \text{ J}$$

$$\text{percentage loss} = \frac{68}{196} \times 100\% \approx 35\%$$

Define power as work done per unit time and derive power as the product of force and velocity.

Define Power

Power is defined as:

(i) The work done per unit time, or
(ii) The rate of work done, or
(iii) The rate of energy conversion.

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

Where

P is the power (watt, W)

W is the work done (joule, J)

E is the energy converted (joule, J)

t is the time taken (second, s)

The S.I unit for power is the watt.

One watt is defined as the power when one joule of work is done, or one joule of energy is converted, per second.

1 W = (1 J) / (1 s)

3. Derive power as the product of force and velocity.
Suppose a constant force F displaces an object, moving at a constant velocity v, by a distance s over a time interval t, and that F, v and s all point along the same line.

$$P = Fv$$

4. If force F and / or velocity is / are not constant, then

(i) The average power <P> is given by $\langle P \rangle = \frac{\text{total work done}}{\text{total time taken}}$

(ii) The instantaneous power is given by P = Fv, where F and v take the values at the instant considered

Sample problem 1

A car moves along a horizontal road at a constant velocity of 15 m s^{-1}. If the total resistive force experienced by the car is 5000 N, calculate the power output of the car's engine.

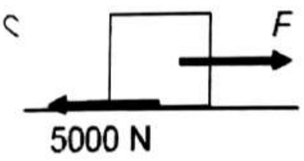
At constant velocity, $F_{net} = 0$

∴ F = 5000 N

P = Fv

= (5000)(15)

= 75000 W



Sample Problem 2 – Solve It

A trolley of mass 7 kg is initially rest at t = 0 s.

A cyborg pushes this trolley with a constant force of 95 N along a horizontal floor.

The frictional force acting on the trolley is 11 N.

Calculate

- **(i)** The acceleration of the trolley;
- **(ii)** The speed of the trolley at t =4 s;
- **(iii)** The kinetic energy of the trolley at t = 4 s;
- **(iv)** The distance travelled during the first 4 s;
- **(v)** The instantaneous power supplied to the trolley by the cyborg at t = 4 s;
- **(vi)** The average power supplied to the trolley by the cyborg during the first 4 s;
- **(vii)** The average power dissipated by friction during the first 4 s;
- **(viii)** The net average power gained by the trolley during the first 4 s, and hence, the total energy gained by the trolley during the first 4 s.

Solution

(i) $F_{net} = ma \Rightarrow 95 - 11 = 7a \Rightarrow a = 12\ ms^{-2}$

(ii) $v = u + at = 0 + 12(4) = 48\ m\ s^{-1}$

(iii) $E_k = \frac{1}{2}mv^2 = \frac{1}{2}(7)(48)^2 = 8064\ J$

(iv) $S = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2}(12)(4)^2 = 96\ m$

(v) $P = Fv = (95)(48) = 4560\ W$

(vi) $\langle P_{supplied} \rangle = \frac{1}{2}(4560) = 2280\ W$

(vii) $\langle P_{dissipated} \rangle = \frac{W_{friciton}}{\Delta t} = \frac{F_r s}{\Delta t} = \frac{(11)(96)}{4} = 264\ W$

(viii) $\langle P_{net} \rangle = 2280 - 264 = 2016\ W$

Check: $\langle P_{net} \rangle \Delta t = (2016)(4) = 8064\ J$ = K.E. gain by trolley

Relationship between force and potential energy in a uniform field

In a uniform field, a body experiences the same force F at all points.

If this force F moves the body along a distance Δx in its direction, then the work done W by this F is $W = F\Delta x$.

However, by conservation of energy, this work must be compensated by a decrease in potential energy, $-\Delta U$.

$$W = F\Delta x = -\Delta U$$

$$F = -\frac{\Delta U}{\Delta x}$$

$$F = - -\frac{dU}{dx}$$

Where:

F is the force acting on the point mass/ charge placed at that particular point in the force field. (units : N)

$\frac{dU}{dx}$ is the change in the potential energy of a point mass/ charge with a variation o the distance from the source of the force field (units : J m^{-1}).

Sample Problem – Solve it

A mass experiences a gravitational force of 24 N in a uniform gravitational field. Calculate the change in its potential energy if it moves a distance of 5.0 m

(a) along the same direction as the gravitational force;
(b) along the opposite direction as the gravitational force.
(c) In a direction perpendicular to the gravitational force.

For each case, indicate whether the change is an increase or decrease.

(a) $\Delta U = - F\,\Delta x = -24 \times 5.0$
$= -120$ J (decrease)

(b) $\Delta U = - F\,\Delta x = -24 \times (-5.0)$
$= +120$ J (increase)

(c) $\Delta U = - F\,\Delta x = -24 \times 0$
$= 0$ J (no change)

Deformation of Solids (Matter)

Stress:

Stress is a measure of the force required to cause a particular deformation.

Strain:

Strain is a measure of the degree of deformation.

Elastic Modulus:

Elastic Modulus is the ratio of stress to strain

$$\text{Elastic Modulus} = \frac{Stress}{Strain}$$

The elastic modulus determines the amount of force required per unit deformation. A material with large elastic modulus is difficult to deform, while one with small elastic modulus is easier to deform.

Changes in Length

To stretch or compress something you must exert a force on it at either end.

Tensile Stress

Tensile Stress is the force per unit cross sectional area exerted on the ends.

Tensile Strain is the fractional change in original length

Note: (The surface whose area we wish to measure is perpendicular to the force.)

Young's Modulus

Young's Modulus (Y) is the ratio of tensile stress to tensile strain:

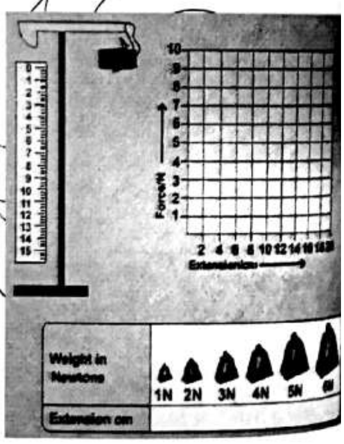
$$Y = \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{F/A}{\Delta L / L_o} = \frac{FL_o}{A\Delta L}$$

where F is the applied force, L_o is the original length of the object, A is the cross-sectional area of the object, and ΔL is the change in the length of the object. Notice that Y has S.I. units of N/m^2.

Hooke's Law

Hooke's Law states that, for relatively small deformations of an object, the displacement of the deformation is directly proportional to the deforming force or load. Forces can cause objects to deform. The way in which an object deforms depends on its dimensions, the material it is made of, the size of the force and direction of the force.

If you measure how a spring stretches (extends its length) as you apply increasing force and plot extension (e) against force (F);



The graph will be straight line

This force shows that Force is proportional to extension. This is Hooke's law. It can be written as:

Note:
Because the force

$$F = ke$$

Where:

F = tension acting on the spring.

e is the gradient = ($l - l_o$); l is the stretched length and l_o is original length, and.

k is the gradient of the graph above. It is known as the spring constant.

The above equation can be rearranged as

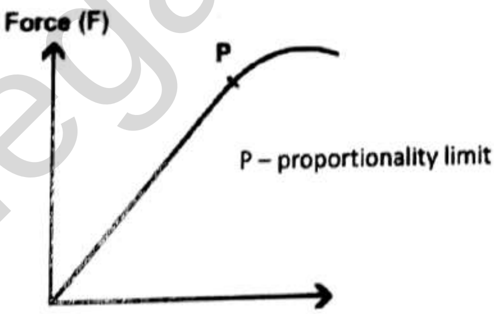
$$k = \frac{F}{e}$$

Spring constant = Applied force/ extension

The spring constant k is measured in Nm^{-1} because it is the force per unit extension. The value of k does not change unless you change the shape of the spring or the material that the spring is made of.

A stiffer spring has a greater value for the spring constant.

In fact, a majority obey Hooke's law for at least a part of the range of their deformation behavior. (e.g. glass rods, metal wires).



In the diagram above, if you extend the spring beyond point P, and then unload it completely; it won't return to its original shape. It has been permanently deformed. We call this point the elastic limit – the limit of elastic behavior.

If a material returns to its original size and shape when you remove the forces stretching or deforming it (reversible deformation), we say that the material is demonstrating elastic behavior.

If deformation remains (irreversible deformation) after the forces are removed then it is a sign of plastic behavior.

Calculating stress

Stress

Stress is a measure of how strong a material is. This is defined as how much force the material can stand without undergoing some sort of physical change. Hence, the formula for calculating stress is the same as the formula for calculating pressure: $\sigma = \frac{F}{A}$

where σ is stress (in Newtons per square metre but usually Pascals, commonly abbreviated Pa).

Stress causes strain.

Applying force on an object causes it to stretch. Strain is a measure of how much an object is being stretched. Strain is the ratio of extension to the original length.

The formula for strain is: $\epsilon = \frac{\Delta l}{l_o} = \frac{l - l_o}{l_o} = \frac{l}{l_o} - 1$

Where is the original length of some bar being stretched, and l is its length after it has been stretched. Δ l is the extension of the bar, the difference between these

two lengths.

Quantity	Equation	Symbol	Units
Stress	Tension/ cross sectional area = F/ A	(sigma) σ	$N\ m^{-2}$ = Pa
Strain	Extension per original length = $\Delta L / L$	(epsilon) ε	No units (because it's a ratio of two lengths)
Young Modulus	Stress / strain	E	$N\ m^{-2}$ = Pa

Tensile strength & Yield strength

Tensile Strength

Tensile strength which is also known as Ultimate tensile strength or ultimate strength is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking. Tensile strength is the opposite of compressive strength and the values can be quite different

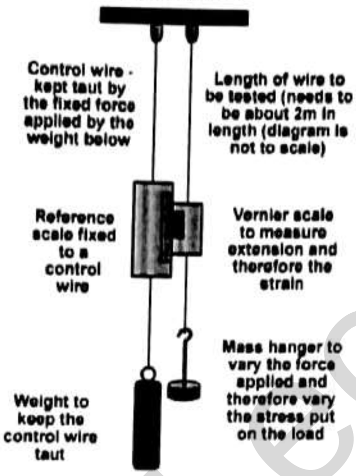
Yield Stress or Yield strength or Yield point

The yield stress is the level of stress at which a material will deform permanently. This is also known as Yield strength or Yield point. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed.

It can be experimentally determined from the slope of a stress strain curve created during tensile tests conducted on a sample of the material.

The value of the Young's Modulus is quoted for various materials but the value is only approximate. This is because Young's Modulus can vary considerably depending on the exact composition of the material. For example, the value for most metals can vary by 5% or more, depending on the precise composition of the alloy and any heat treatment applied during manufacture. If a big force only produces a small extension then the material is 'stiff' and E is a big value. If a force produces a big extension then the material is not very stiff - it is easier to stretch and the value of E will be smaller.

An experiment to measure the Young's Modulus



To minimize errors the control wire is the same length, diameter and material as the test wire. This means that errors due to expansion (from the surroundings) during the experiment are avoided as the test wire and control wire would both expand by the same amount and the scale would adjust position and eliminate the error.

The wire must have no kinks in it otherwise there will be big extensions due to the wire straightening out rather than just stretching.

Care must be taken that the limit of proportionality is not exceeded. This can be checked by removing the load after each addition of the weight. If the limit has not been exceeded the wire should return to the length it was before the weight was added.

The wire is as long as possible (usually about 2m long) and it is as thin as possible so that as big an extension as possible can be recorded. (A typical extension for a 5N loading will be 1mm).

The test wire is loaded with the weight hanger so that it is taut before readings are taken.

The vernier scale is read and the result recorded as addition of 0N.

Weights - usually starting at 0N and increasing in 5N increments to 100N - are then added and a reading of the vernier scale is taken at each addition. The experiment should be repeated twice and any anomalous results repeated and checked.

A graph of load against extension is plotted. It should be a straight line through the origin (provided measurements are accurate). The gradient of that graph will be F/e. Using that value w can find the value of Young's Modulus for the wire.

$$E = \frac{\text{stress}}{\text{Strain}}$$

$$= \frac{\frac{F}{A}}{\frac{e}{\ell}} \qquad = \frac{F\ell}{Ae}$$

$$= \frac{\ell}{A} \times \text{Gradient}$$

Proportionality limit and Yield strength

Proportionality limit and Elastic limit

Maximum amount a material can be stretched by a force and still (or may) return to its original shape depends on the material.

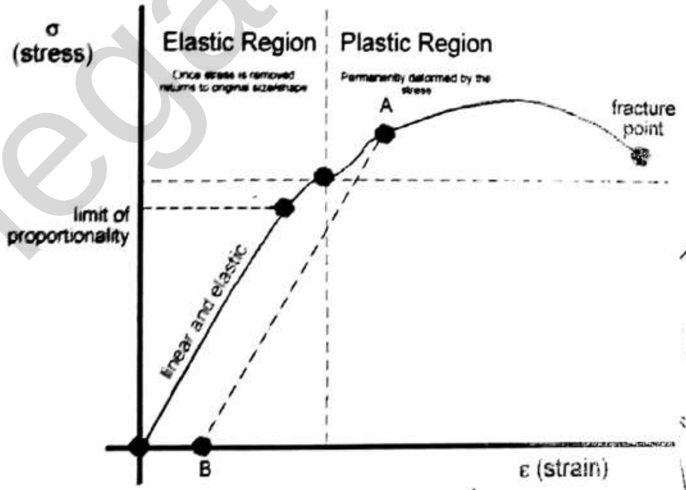
Yield point or Yield strength

The point where there is a large permanent change in length with no extra load force.

yield point :- interface between elasticity and plasticity

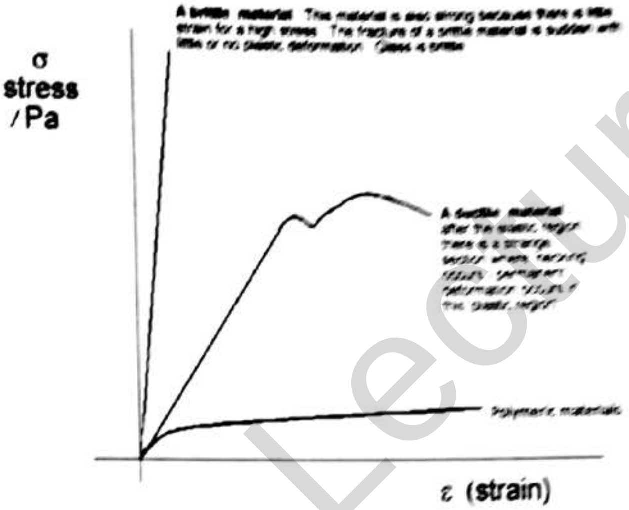
Elastic limit - up to which material can sustain the load and return back to its original position.

Although these two points are so close to each other it can be treated as one, on a case to case basis. It depends upon material whether it's brittle or ductile.

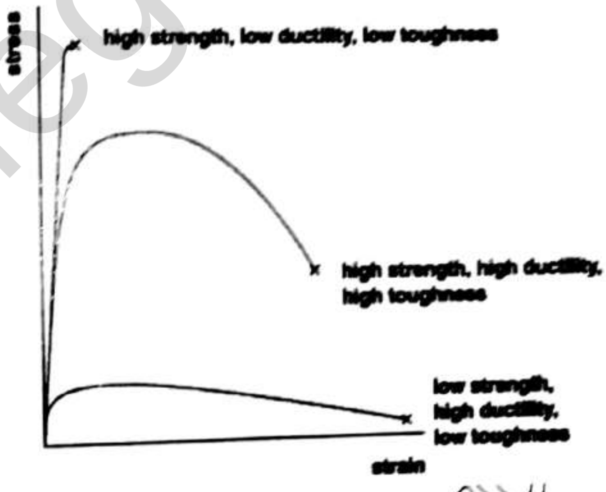


Explaining Graph in the previous slide.....

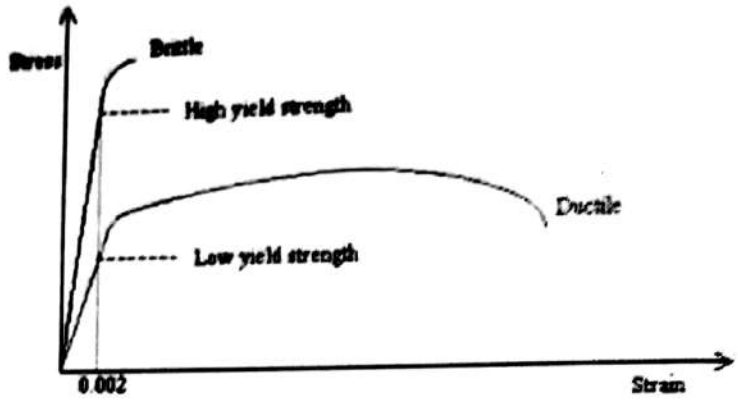
The stretching behavior is summarized in a stress-strain graph in the previous slide. As the stress is increased initially Hooke's Law is obeyed - the stress-strain relationship for the wire is linear & elastic. Just before the plastic region is reached we get the limit of proportionality - beyond this for a small section we see non-linear behaviour but the stretching is still elastic. After the yield strength, the material enters the plastic deformation region, which means that the stretch of the wire is permanent. (For example, if the wire is stressed to point A on the graph and the stress is slowly decreased, the stress-strain curve follows the dotted line instead of the original curve to point B and there is a permanent extension when all stress is removed.) At the facture point the wire snaps. Differences in the shape and limits of the stress-strain diagram determines whether a material is considered ductile or brittle, elastic or plastic.



Strength, Ductility & Toughness



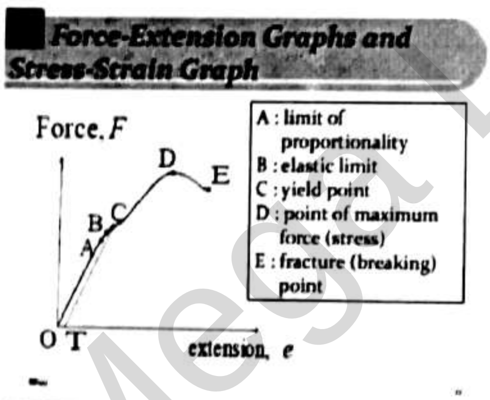
High Yield strength & Low yield strength

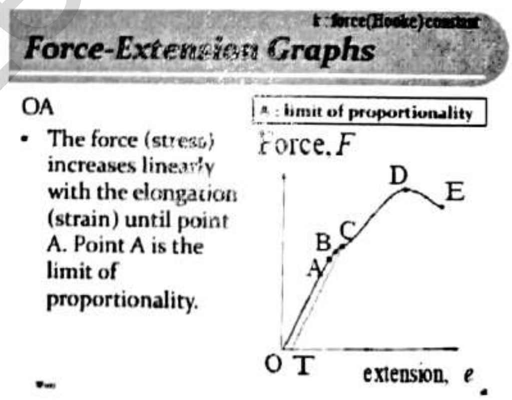


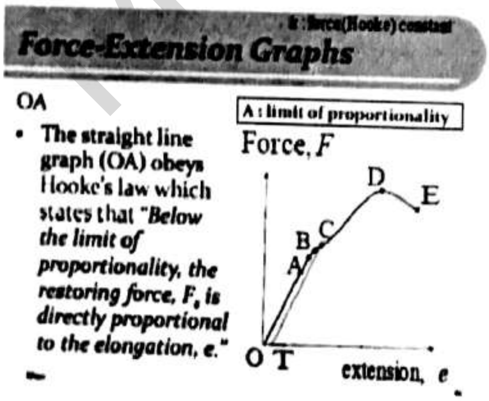
Energy in deformations

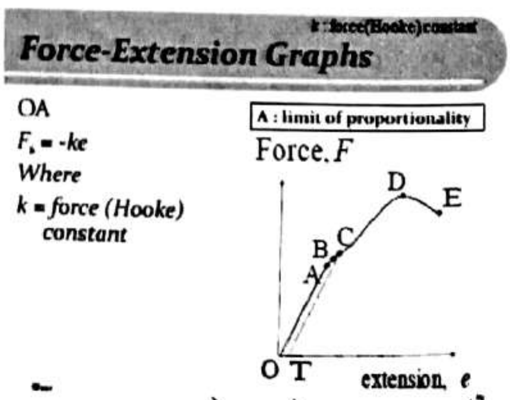
Whenever we apply force to an object, it will cause deformation. If the deformation caused is within the elastic limit, the work done in deforming the object is stored within it as potential energy. We call this (elastic) 'strain energy'. It can be released from the object by removing the applied force. The strain energy then performs work in un deforming the object and returns to its original state.

Force-extension graphs for typical ductile, brittle and polymeric materials, including an understanding of ultimate tensile stress.







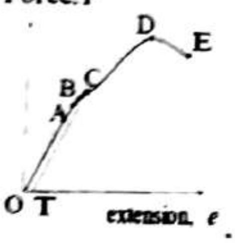


Force-Extension Graphs

OA

- $F_s = -kx$
  Where
  k = force (Hooke) constant
- The negative sign indicates that the restoring force is the opposite direction to increasing elongation.

A : limit of proportionality

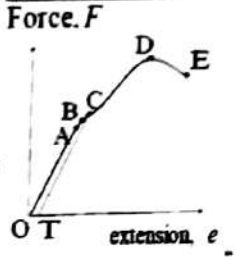


Force-Extension Graphs

B: This is the elastic limit of the material.

- Beyond this point, the material is permanently stretched and will never regain its original shape and length. If the force (stress) is removed, the material has a permanent elongation of OT.

B : elastic limit



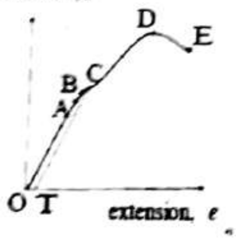
Force-Extension Graphs

k : force(Hooke) constant

OB

- The area between the two parallel line (AO and CT) represents the work done to produce the permanent elongation OT.
- OB region is known as elastic deformation.

B : elastic limit



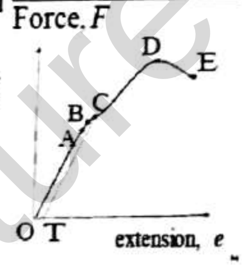
Force-Extension Graphs

k : force(Hooke) constant

C -The yield point marked a change in the internal structure of the material.

- The plane (layer) of the atoms slide across each other resulting in a sudden increase in elongation and the material thins uniformly.

C : yield point



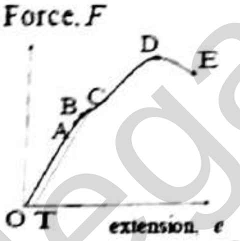
Force-Extension Graphs

k : force(Hooke) constant

D

- The force (stress) on the material is maximum and is known as the breaking force (stress). This is sometimes called the Ultimate Tensile Strength (UTS).

D : point of maximum force (stress)



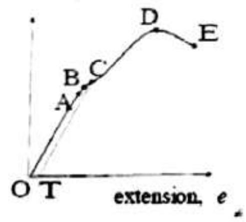
Force-Extension Graphs

k : force(Hooke) constant

E

This is the point where the material breaks or fractures.

E : fracture (breaking) point



Force-Extension Graphs

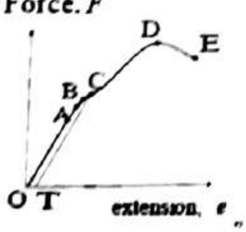
k : force(Hooke) constant

CDE

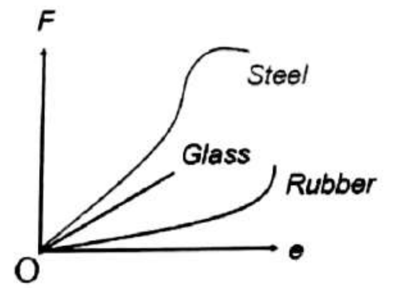
This region is known as plastic deformation.

- When the force (stress) increases, the elongation (strain) increases rapidly.

C : yield point
D : point of maximum force (stress)
E : fracture (breaking) point



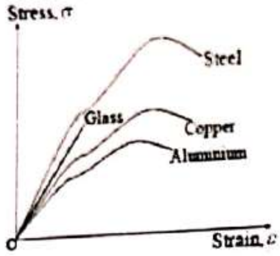
Extension-Force Graphs



Types of materials

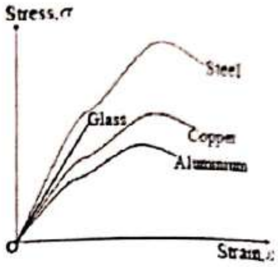
- Ductile materials - undergo plastic deformation before breaking.
- such as steel, copper, aluminium.

Stress-Strain Graph



Types of materials

- Brittle materials - do not show plastic behaviour (deformation).
- such as glass.



Young's Modulus (Y @ E)

- Definition – is defined as *the ratio of the tensile stress to the tensile strain if the limit of proportionality has not been exceeded.*

$$Y = \frac{\text{Tensile stress}}{\text{Tensile strain}} \quad Y = \frac{\left(\frac{F}{A}\right)}{\left(\frac{e}{l_0}\right)} \Rightarrow Y = \frac{F\,l_0}{Ae}$$

Young's Modulus (Y @ E)

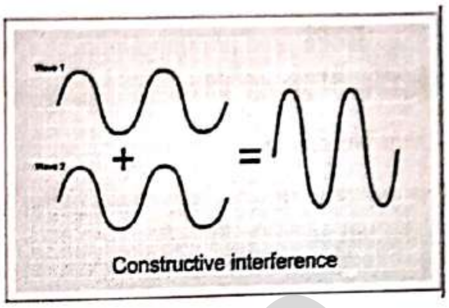
- Its dimension is given by

$$[Y] = \frac{[F][l_0]}{[A][e]} = ML^{-1}T^{-2}$$

- The unit of Young's modulus is $kg\ m^{-1}\ s^{-2}$ @ $N\ m^{-2}$ @ Pa.

Oscillations & Waves

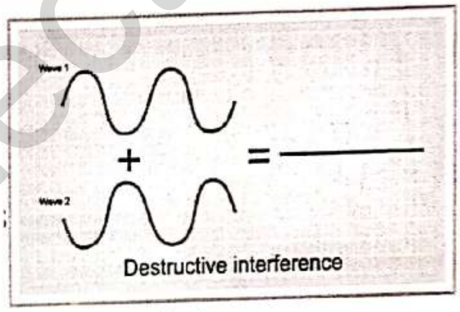
Constructive Interference



Constructive interference

- Refer the figure on right with two waves arriving at a point at the same time in opposite directions.
- If they arrive in Phase - that is, if their crests arrive at exactly the same time - they will interfere constructively.
- A resultant wave will be produced which has crests much higher than either of the two individual waves and troughs which are much deeper.
- If the 2 incoming waves have the same frequency and equal amplitude A, the resultant wave produced by constructive interference has amplitude of 2A.
- The frequency of the resultant is the same as that of incoming waves.

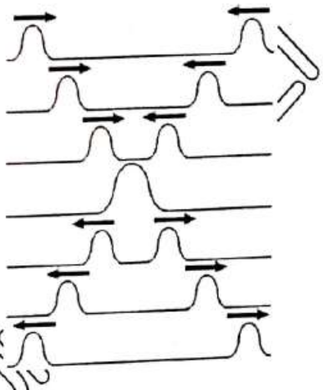
Destructive Interference



Destructive interference

- Refer the figure on right with two waves arriving at a point at the same time.
- If they arrive out of Phase - that is, if the crests of one wave arrive at same time as the troughs from the other - they will interfere destructively.
- A resultant wave will have smaller amplitude. (based on case to case)
- In the case shown in figure where the incoming waves have equal amplitude, the resultant wave has zero amplitude.

Interference and Superposition of Waves



- When two waves meet they will interfere and superpose. After they have passed they return to their original forms. This is true if they are coherent or not.
- At the point they meet, the two waves will combine to give a resultant wave whose amplitude (or intensity) may be greater or less than the original two waves.
- The resultant displacement can be found by adding the two displacements together. This phenomenon leads to the Principle of Superposition.

The principle of Superposition

- The Principle of Superposition states that when two or more waves meet at a point, the resultant displacement at that point is equal to the sum of the displacements of the individual waves at that point.

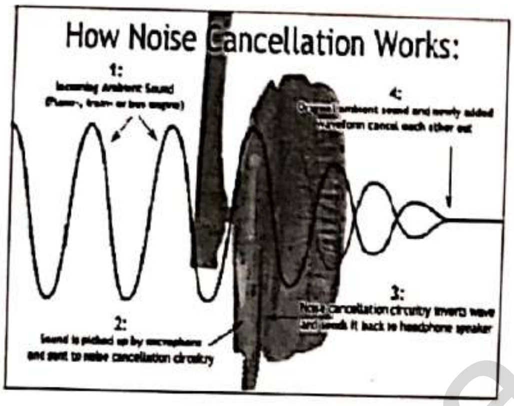
> **Note:** Displacement is a vector, so remember to add the individual displacements taking account of their directions.

Application of the Principle of Superposition

Active Noise Cancellation

The muffling of ambient noise using insulating material in the headphones is called passive noise cancellation.

Active noise cancellation utilizes the principle of superposition to pick up the ambient noise, inverts the wave and generates this sound wave within the headphone. This inverted wave cancels the ambient noise, preserving only the sound waves that the listener wants to hear.



> **Note:** The transverse shown in above figure is for the demo of cancellation of noise only. Remember, sound waves are to be represented in longitudinal form.

Stationary Wave

- A stationary wave is set up by the superposition of two progressive waves of the same type, amplitude and frequency travelling in opposite directions.
- A stationary (or standing) wave is one in which some points are permanently at rest (nodes), others between these nodes are vibrating with varying amplitude, and those points with the maximum amplitude (antinodes) are midway between the nodes.

Uses and application of Melde's experiment

- Melde's experiment teaches us creation of standing waves.
- One can create a great product of neutralising the sounds by creating sounds with same wave length and frequency as the source.
- For example : If we know exactly the frequency of any machine (say an aero plane flying over your building every day during takeoff and landing) and if we can measure the wave length of sounds that machine creates..create a product that can create similar waves in opposite direction, so that they undergo mechanical interference and the machine sound is neutralised.

Characteristics of Stationary Waves

i. There is no sign of any progressive wave in either direction.

ii. Individual particles are oscillating with the same frequency, except at the nodes.

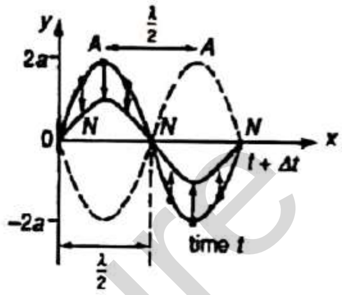
iii. The amplitudes of oscillation of the particles vary from a maximum at the antinodes (A) to zero at the nodes (N).

iv. All particles in the same segment or loop (region between 2 adjacent nodes) are vibrating in phase. Adjacent segments are anti-phase.

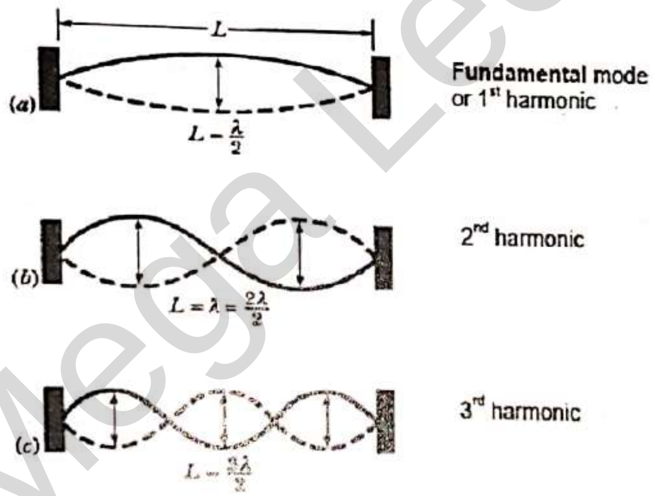
v. Adjacent nodes or adjacent antinodes are half a wavelength apart, i.e. NN = AA = $\frac{\lambda}{2}$

vi. A node and the next antinodes are $\frac{\lambda}{4}$ apart.

vii. Energy is trapped (stored) in stationary waves, since there is no energy is transferring away.



Formation of Stationary Waves in Strings



Let a string be stretched between two clamps separated by a fixed distance L.

When the string is plucked, struck or bowed, it can vibrate in several modes simultaneously.

The simplest possible pattern of the stationary wave consists of one loop (fundamental mode), with the nodes at the 2 ends of the string - diagram (a).

The next simplest pattern has 2 loops, and the next has 3 loops...etc.

In short, just add nodes between the 2 ends, for subsequent modes of vibration.

Formation of Stationary Sound Waves in air in Pipes

1. Stationary sound waves in air can be formed in both closed and open pipes.
2. In a closed pipe, when a sound wave is originated from the open end, the sound wave propagated into the pipe is reflected by the cylindrical wall and from the closed end.

   A stationary wave is then formed.

At resonance,

a) node N is always formed at the closed end of the pipe

   - the air layer at this end is permanently at rest

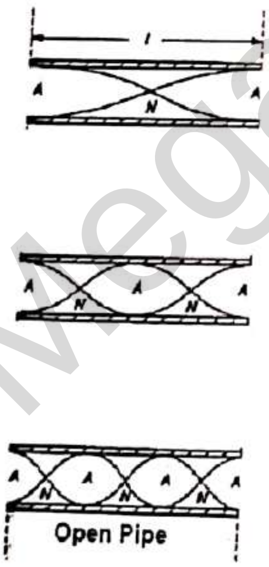
b) antinodes A is formed at the open end of the pipe

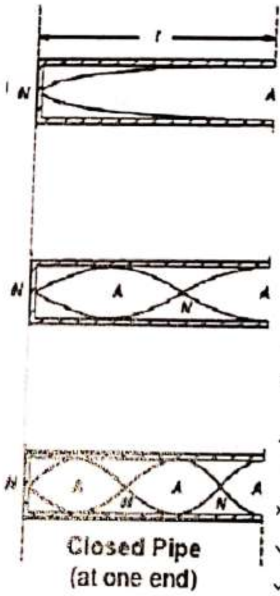
   - the air layer at this end is free to vibrate

3. In an open pipe, when a sound wave is originated from the open end, the sound wave propagated into the pipe to the other open end where it is reflected by the walls and on encountering air at the other open end.

   A stationary wave is set up.

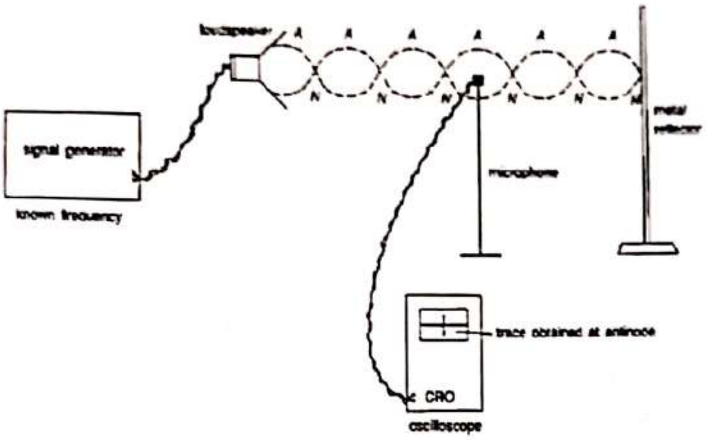
At resonance, since the ends of the pipe are open, both ends are antinodes.





The resonance of sound in pipe may be varied by changing either the frequency of the sound wave, or length of the pipe.

Formation of Stationary Sound Waves in air



Stationary sound waves in air can be demonstrated using the set-up as shown above.

Note: In A level Physics syllabus, this part appears in previous chapter 'waves'.

i. The incident sound wave is generated by the loudspeaker attached to a signal generator.

ii. The incident wave is reflected by the metal reflector (which must be appropriately positioned at a node). The reflected wave and the incident wave superpose to form a stationary wave.

iii. The detection of nodes and antinodes is done using a microphone attached to a CRO.

iv. By moving the microphone slowly forward and backward, the vertical trace (or amplitude) on the CRO screen is seen to vary from minimum to maximum, indicating the positions of nodes and antinodes.

A. To measure the wavelength of the sound wave:

Measure the distance moved by the microphone, d, between 2 successive maxima or minima (e.g. d = 33 cm).

Since this corresponds to $\frac{\lambda}{2}$, the wavelength $\lambda = 2d = 2(33\text{ cm}) = 66\text{ cm}$

B. To measure the frequency of the sound wave:

By measuring the period, T, of the sound wave, the frequency can be determined.

Set the time base of the CRO to a suitable value (e.g. 0.5 ms cm'1). Place the microphone where the CRO shows a sinusoidal trace. The period, 7, is determined by measuring the distance between 2 crests or 2 troughs, (e.g. 4 cm).

the period, $T = 4\text{ cm} \times 0.5\text{ ms cm}^{-1}$

$= 2\text{ ms} = 2 \times 10^{-3}\text{ s}$

Hence the frequency, $f = \frac{1}{T} = \frac{1}{2 \times 10^{-3}} = 500\text{ Hz}$

C. Hence, speed of sound can be calculated from $v = f\lambda = (500)(66 \times 10^{-2}) = 330\text{ ms}^{-1}$

Sample problem 1

A string is stretched under constant tension between fixed points X and Y. The solid line shows a stationary wave at an instant of greatest displacement. The broken line shows the other extreme displacement.

Which one of the following statements is correct?

A The distance between P and Q is one wavelength.

B A short time later, the string at R will be displaced.

C The string at P and the string at Q' will next move in opposite directions to one another.

D At the moment shown; the energy of the standing wave is all in the form of kinetic energy.

E The standing wave shown has the lowest possible frequency for this string stretched between X and Y under this tension.

Solution:

A Incorrect. For a stationary wave, one wavelength contains two complete "loops" (i.e. distance XR). Hence, PQ is only ½ wavelength.

B Incorrect. R is a node, hence it will permanently be at rest.

C Correct! In a stationary wave, particles in adjacent loops will always be moving opposite to each other (i.e. P' will move down, and Q' will move up).

D Incorrect. The energy is alternating between KE and PE, depending on the location of each particle in the wave.

E Incorrect. The lowest possible frequency is the fundamental frequency, in which there will only be one "loop" between XY.

(Ans: C)

Sample problem 2

A boy blows gently across the top of a piece of glass tubing the lower end of which is closed by his finger so that the tube gives its fundamental note of frequency, *f*. While blowing, he removes his finger from the lower end. The note he then hears will have a frequency of approximately

A $f/4$ **B** $f/2$ **C** f **D** $2f$ **E** $4f$

Solution

At resonance, for a closed tube (with one end closed), the stationary wave (at fundamental frequency) formed is shown in (1). When the lower end is removed (2 open ends), the stationary wave (in fundamental mode) formed looks like (2).

In (1): $L = \frac{1}{4}\lambda \rightarrow \lambda = 4L$

Given that the frequency = f

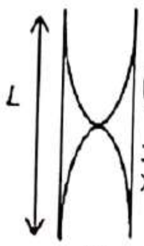
Using $v = f\lambda \rightarrow f = \frac{v}{\lambda} = \frac{v}{4L}$

(1)

In (2): $L = \frac{1}{2}\lambda \rightarrow \lambda = 2L$

If the frequency = f_2

Using $v = f\lambda \rightarrow f_2 = \frac{v}{\lambda} = \frac{v}{2L} = 2f$



(2)

(Ans: D)

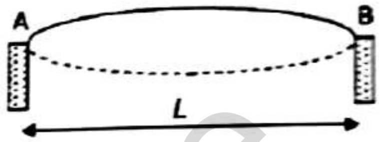
Sample problem 3:

A suspension bridge is to be built across a valley where it is known that the wind can gust at 5 s intervals. It is estimated that the speed of transverse waves along the span of the bridge would be 400 ms^{-1}.

The danger of resonant motions in the bridge at its fundamental frequency would be greatest **if the span had a length of** __________ m.

Solution:

In fundamental mode, the stationary wave has a single "loop" at resonance, with nodes at the 2 ends.



Hence, **if the length of the bridge, *L*,** is equal to $\frac{1}{2}\lambda$, the bridge will resonate with the fundamental frequency.

Given that the wind gusts at 5 s intervals $\rightarrow f_{driver} = \frac{1}{T} = \frac{1}{5} = 0.2$ Hz.

Using $v = f\lambda \rightarrow \lambda = \frac{v}{f} = \frac{400}{0.2} = 2000$ m

Hence, the bridge has the danger of resonating (fundamental mode) if $L = \frac{1}{2}\lambda$ **= 1000 m**

Sample problem 4:

An organ pipe of effective length 0.6 m is closed at one end.

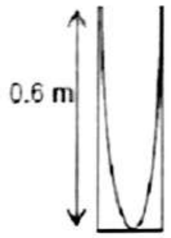
Given that the **speed of sound in air is 300** ms^{-1}, the two lowest resonant frequencies are

Solution:

For fundamental mode:

$\frac{1}{4}\lambda = 0.6$ m $\rightarrow \lambda = 2.4$ m

$f_{fundamental} = \frac{v}{\lambda} = \frac{300}{2.4} = 125$ Hz



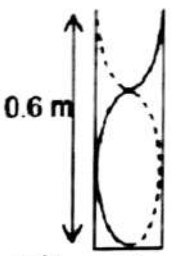
Fundamental Mode
(lowest frequency)

For 2nd lowest frequency:

$\frac{3}{4}\lambda = 0.6$ m $\rightarrow \lambda = 0.8$ m

$f_{2nd lowest} = \frac{v}{\lambda} = \frac{300}{0.8} = 375$ Hz

Hence the two lowest resonant frequencies are **125 Hz & 375 Hz.**



2nd lowest frequency

Sample problem 5:

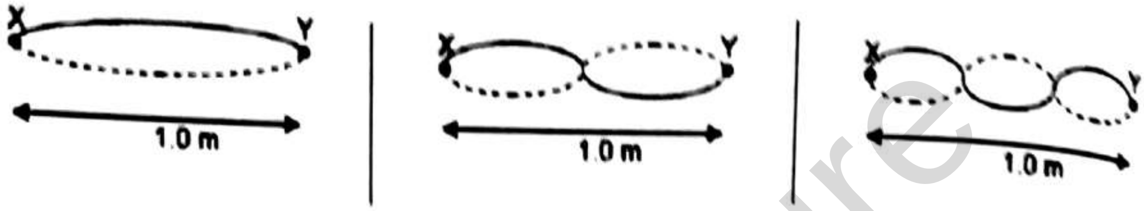
A taut wire is clamped at two points 1.0 m apart. It is plucked near one end.

What are the 3 longest wavelengths present on the vibrating wire?

Solution

Step 1: Draw the 3 modes corresponding to the 3 longest wavelengths (between X & Y).

Step 2: Since the wire is clamped at the 2 points (X & Y), they must be nodes.



Step 3: Relate the length of wire to the corresponding wavelength, λ, in each case

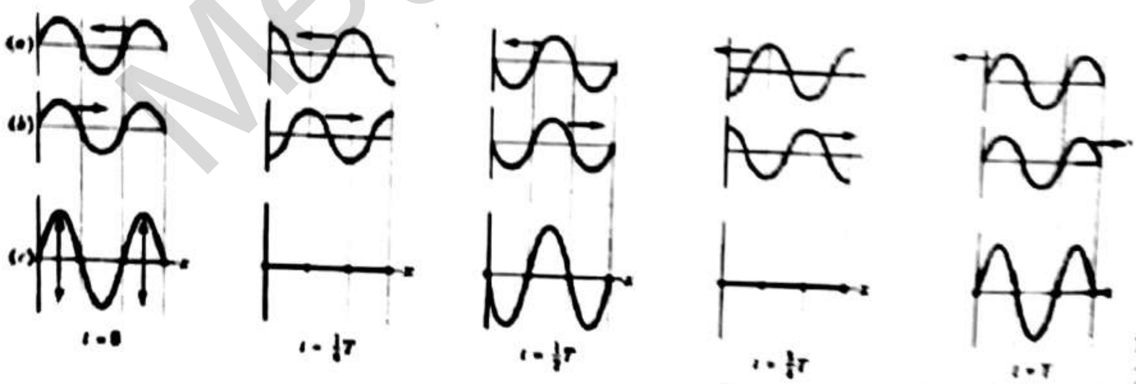
$\frac{1}{2}\lambda = 1.0$ m $\rightarrow \lambda = 2.0$ m	$\lambda = 1.0$ m	$(1.5)\lambda = 1.0$ m $\rightarrow \lambda = 0.67$ m

The formation of a stationary wave using a graphical method

Nodes and Antinodes

Formation of a stationary (standing) wave

A stationary wave is formed when two progressive waves of the same type, wavelength and amplitude travel in opposite directions superpose in the same medium.



In the diagrams above, of the two progressive waves in a string, one is travelling to the left (a), and the other to the right (b).

The resultant wave (c) is a stationary wave, obtained by applying the superposition principle.

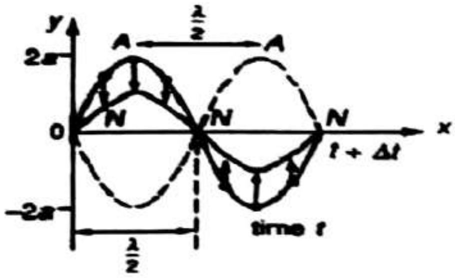
Note:

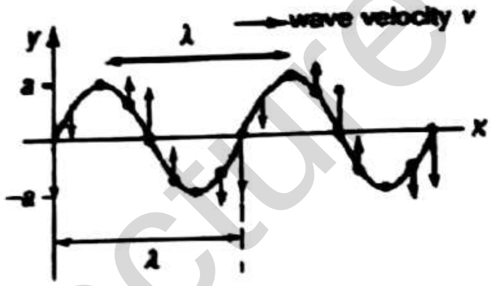
a) There are positions along the string which do not move - called nodes (marked by dots)

b) halfway between successive nodes are antinodes. Where the amplitude of the resultant wave is maximum (double the amplitude of the individual waves).

c) wave patterns shown in diagram (c) are those of a stationary or standing wave because the wave patterns do not move left or right (i.e. the positions of the nodes and antinodes do not change).

Comparison between Stationary and Progressive Wave Motions





	Stationary Wave	Progressive Wave
Amplitude	Varies according to position, from zero at the nodes (permanently at rest) to a maximum of 2a at the antinodes.	Is the same for all particles in the path of the wave (amplitude = a).
Frequency	All particles vibrate in SHM with the same frequency as the wave (except for those at the nodes which are at rest).	All particles vibrate in SHM with the frequency of the wave.
Wavelength	2 x (distance between a pair of adjacent nodes or antinodes) = 2NN = 2AA.	Distance between adjacent particles which have the same phase.
Phase	Phase of all particles between 2 adjacent nodes is the same.	All particles within one wavelength have different phases.
Waveform	Does not advance. (The curved string becomes straight twice in each period.)	Advances with the velocity of the wave.
Energy	No transfer away of energy, but there is energy associated with the wave.	Energy is transferred in the direction of travel of the wave.

Sample problem 6

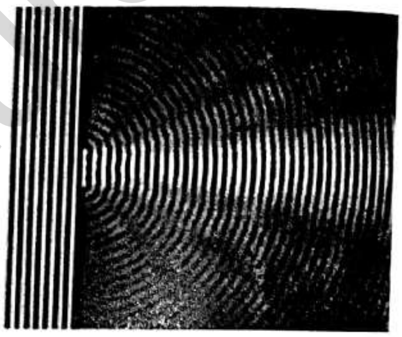
A standing wave is set up on a stretched string XY as shown in the diagram.

At which point(s) will be oscillation be exactly in phase with that at point P?

Solution:

In a stationary wave, all points between 2 successive nodes are in phase. In this case, 1 & 2 are in phase with each other, but are in anti-phase with P. Hence, only 3 are in phase with P.

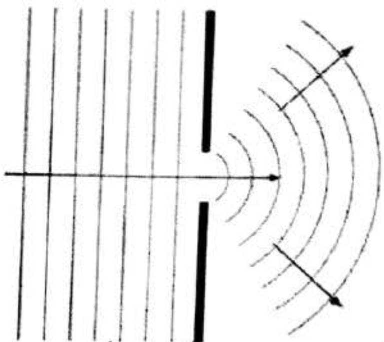
Diffraction



- **Diffraction** is the spreading of waves through an aperture or round an obstacle.
- It is observable when the width of the aperture is of the same order of magnitude as the wavelength of the waves.

Diffraction (Continued)

- The extent of the diffraction effect is dependent on the relative sizes of the aperture to the wavelength of the wave.



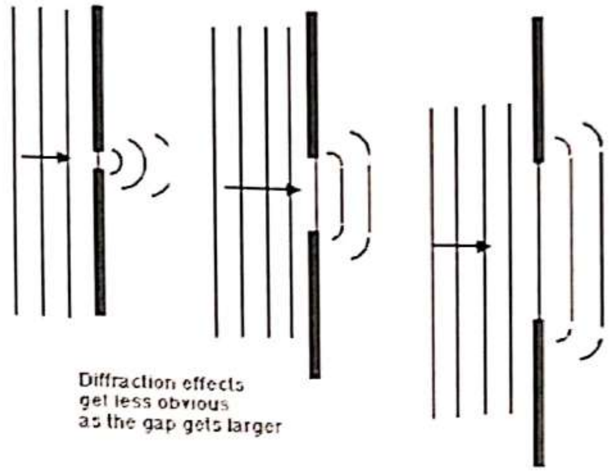
- The smaller the size of the aperture, the greater the spreading of the waves (if the width of the aperture is about the same size as the wavelength, λ, the diffraction effect is very considerable).
- Size of the aperture refers to the width of the slit or gap.

Experiments which demonstrate diffraction including the diffraction of water waves in a ripple tank with both a wide gap and a narrow gap

Note : Huygens' explanation of Diffraction is not mentioned in syllabus.

Generally, the bigger the wavelength in relation to the width of the aperture, the greater is the spreading or diffraction of the waves.

- The diagrams below show the plan view of diffraction of plane water waves through gaps of different width, in a ripple tank. Note that the wavelengths do not change after passing through the gap.

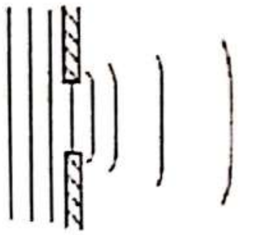


- It is the relative sizes of the aperture to the wavelength that is important.

Application of Diffraction

- The forms of jetties are used for directing currents and they are constructed sometimes of high or low solid projections.

The diagrams below are Incorrect Why?



(c)

(d)

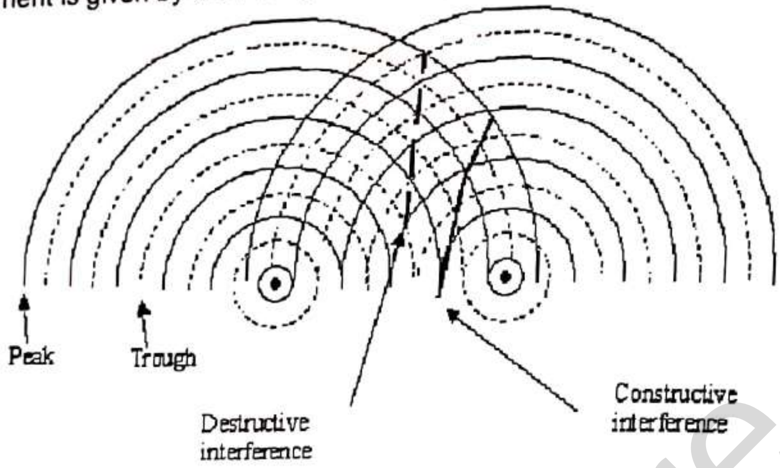
In **(c)** diffraction effect is right, but wavelength increases, which is incorrect.

In **(d)** diffraction effect is too much for the given large slit size and the wavelength should not be increasing.

> **Note:** Huygen's explanation of diffraction is not mentioned in syllabus

Interference

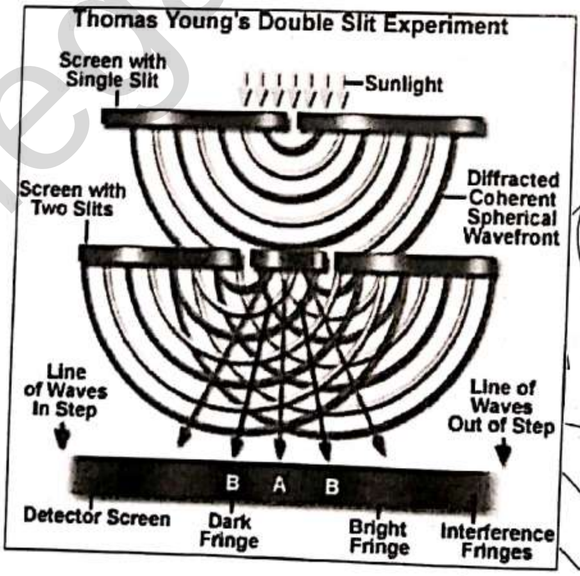
- Interference is the superposing of two or more waves to give a resultant wave whose displacement is given by the Principle of Superposition.

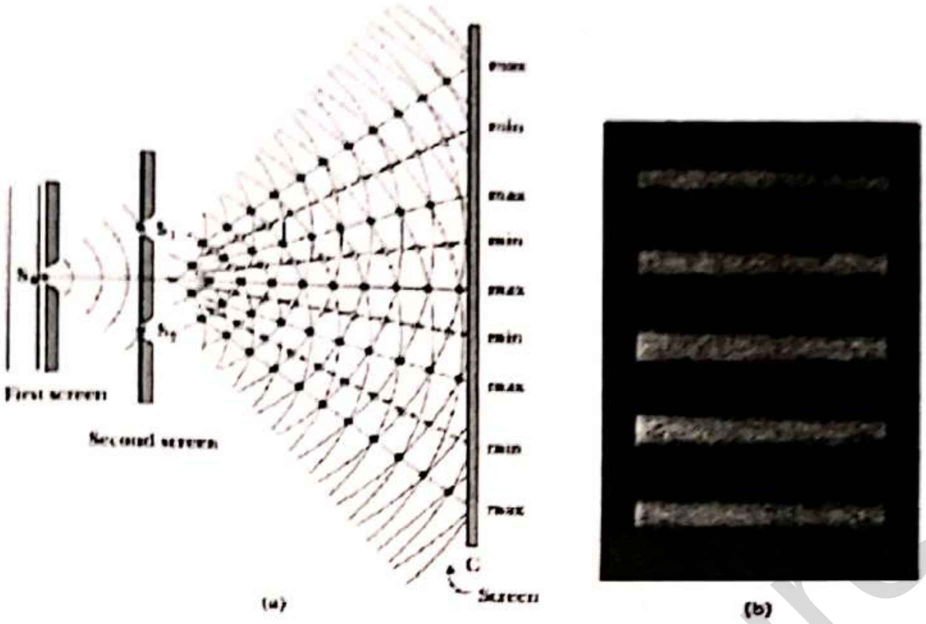


- At regions of maxima, constructive interference occurs (i.e. the waves arrive at these points in phase), resulting in maxima amplitude, hence high intensity.

- At regions of minima, destructive interference occurs (i.e. the waves arrive at these points in anti-phase), resulting in minima or zero amplitude, hence low or zero intensity.

Experiments that demonstrate Two - source Interference

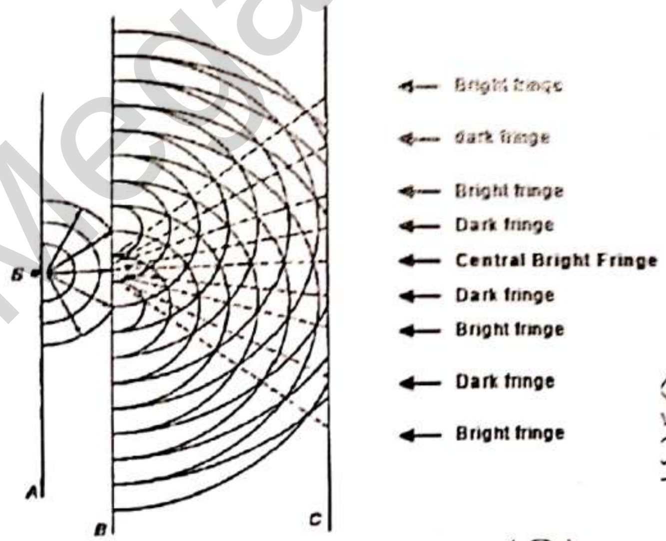




In diagram (a) above, the narrow double slits act as wave sources. Slit S_1 and S_2 behave as coherent sources (waves coming from them are always at a constant phase difference) that produce an interference pattern on screen C.

This interference pattern (fringe pattern) is shown in diagram (b). Separation between successive bright fringes (centre to centre) is the **fringe spacing.**

The bright fringes are formed due to constructive interference (i.e. the waves arrive at these points in phase), while the dark fringes are due to destructive interference (i.e. the waves arrive at these points in anti-phase - hence no resultant amplitude, which then appears dark).

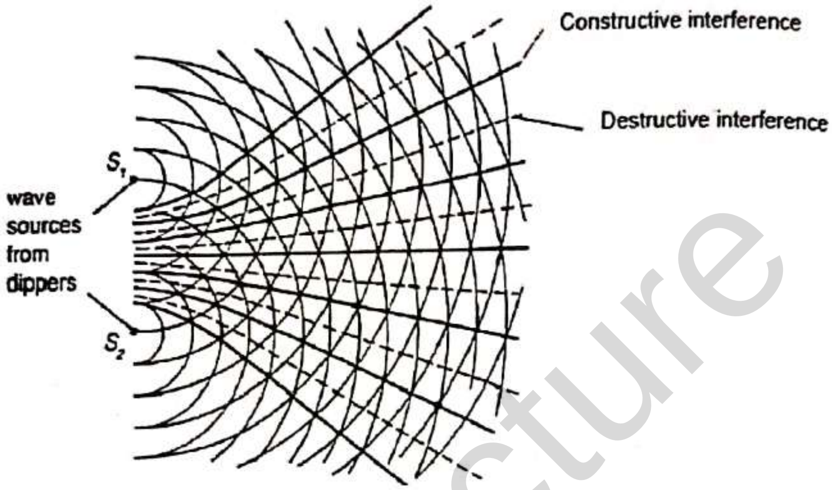


Schematic diagram of Young's double-slit experiment is shown above.

Why is a single source S used (in front of a single slit, instead of using two coherent sources of light?

Two-source interference with water

An interference pattern involving water waves is produced by two vibrating sources at the water surface. The lines represent crests, and the spaces between the lines represent troughs. The regions where the lines intersect (spaces also intersect) have constructive interference. The regions where lines intersecting spaces have destructive interference



Conditions required for two-source interference fringes to be observed

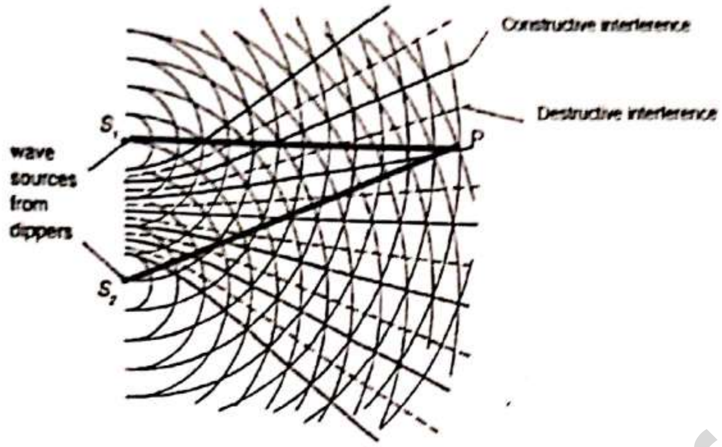
For interference fringes to be observable:

- The sources must be coherent; that is, they must maintain a constant phase difference.
- The sources must have the same frequency (for light waves, this means that they must be monochromatic).
- The principle of superposition must apply (the sources must produce the same type of waves).
- The sources must have (approximately) the same amplitude.
- For transverse waves, the sources must be unpolarised or polarised in the same plane.
- For light waves,
  - ❖ the wavelengths used should be in the visible range (400 nm to 700 nm).
  - ❖ the source (slit) separation (d) is around the order of 10^{-4} m.
  - ❖ the screen-slits distance D is around 1 - 2 m.

What is the meaning of 'a constant phase difference' between two coherent waves'?

- ➢ The primary source of light is transition of electrons. This happens for every source be it the fluorescent tubes or the sun.
- ➢ As an electron jumps to its higher level it reaches an unstable excited state. It stays there for about 10 ns and comes back to the ground state. Thus every 10ns a new stream of light is produced.
- ➢ If we have two sources of light then the phase difference between any two waves would be random. In fact it would change every 10ns or so. This is why we don't find interference in practical life.
- ➢ To have a constant phase difference between two waves (i.e. to be coherent) the waves should be from a common source, so that there is no ab-nitio phase difference to get a constant phase difference and two waves (from the same source) can be made to have some path difference.

Conditions for constructive interference

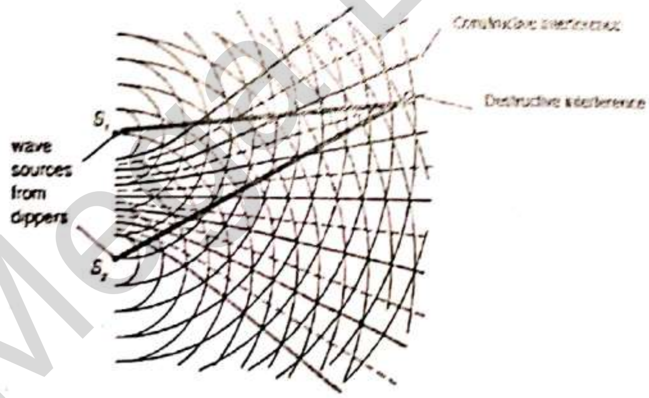


The 2 thick lines intersecting at P represent the paths of water waves from the 2 sources to produce a constructive interference at P.

Length $S_2P = 14\lambda$, length $S_1P = 13\lambda$ → their path difference = $14\lambda - 13\lambda = \lambda$.

For other points with constructive interference, the path difference must be $n\lambda$ where n is an integer. The assumption here is that the sources are in phase.

Conditions for destructive interference



The 2 thick lines intersecting at Q represent the paths of water waves from the 2 sources to produce a destructive interference at Q.

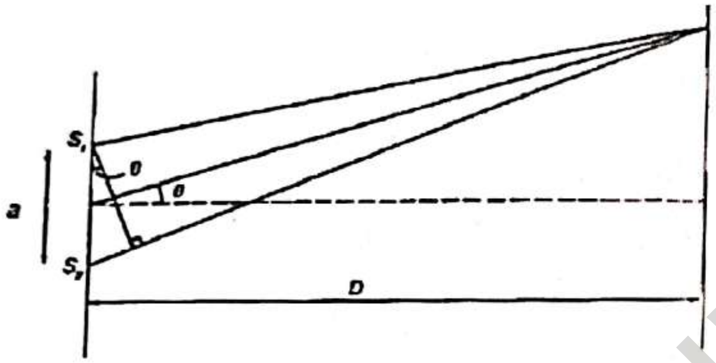
Length $S_2Q = 14\lambda$, length $S_1Q = 12\frac{1}{2}\lambda$ → their path difference = $14\lambda - 12\frac{1}{2}\lambda = 1\frac{1}{2}\lambda$.

For other points with destructive interference, the path difference must be $(n+\frac{1}{2})\lambda$, where n is an integer. The assumption here is that the sources are in phase.

Using the equation $\lambda = \frac{ax}{D}$ for double-slit interference using light

Note: As per syllabus, you need to have an understanding of young's double slit experiment, but you don't have to prove/derive the equation.

Young's Double Slit



In the double slit experiment; bright & dark fringes alternate at **equal separation.**

The double slit interference Is given by the equation

$$\frac{\lambda}{a} = \frac{x}{D}$$

λ	is the wavelength of the light
a	is the separation of the slits
x	is the separation of the fringes on the screen (fringe spacing, separation between centres of bright fringes, or centres of dark fringes)
D	is the separation between the screen and the double-slit

- **Do headlights from a car form interference patterns? Why?**
  - The interference would be 'visible' if the two sources are oscillating in phase or have a constant phase difference. This is why a single light source (as in young's double slit experiment) is split to produce two which are then coherent.
  - In addition the separation of the headlamps is so large that any interference fringes would be too close together to be easily measurable, and the path difference between waves would render them no longer coherent.
  - Note that, because the wavelength of light is so small (of the order of 10^{-7} m) to produce observable fringes 'D' needs to be large and 'a' as small as possible. (This is one of the applications of equation of young's double slit experiment)

Sample problem 7

Which of the following statements must be true about two wave-trains of monochromatic light arriving at a point on a screen if the wave-trains are coherent?

A They are in phase.

B They have a constant phase difference.

C They have both travelled paths of equal length.

D They have approximately equal amplitudes.

E They interfere constructively.

Solution: (Ans: B)

Only **[B] is true** as this is the meaning of coherence.

Sample problem 8

When a two-slit arrangement was set up to produce interference fringes on a screen using a monochromatic source of green light, the fringes were found to be too close together for convenient observation.

In which of the following ways would it be possible to increase the separation of the fringes?

A Decrease the distance between the screen and the slits

B Increase the distance between the source and the slits

C Have a larger distance between the two slits.

D Increase the width of each slit.

E Replace the light source with a monochromatic source of red light

Solution: (Ans: E)

Since it is a double slit setup, using the equation $\frac{\lambda}{a} = \frac{x}{D} \rightarrow x = \frac{\lambda D}{a}$

A decrease $D \rightarrow$ x will decrease

B increase distance between source & slits does not affect the fringe separation

C increase $a \rightarrow$ x will decrease

D increasing the width of the slit will not affect x, but will allow more light through, hence a brighter pattern

E replace green light with red light. $\lambda_{red} > \lambda_{green} \rightarrow$ if λ increases, x will increases.

Sample problem 9

- Calculate the observed fringe width for a young's double slit experiment using light of wavelength 600nm and slits 0.50nm apart. The distance from the slits to the screen is 0.80m.

Solution:

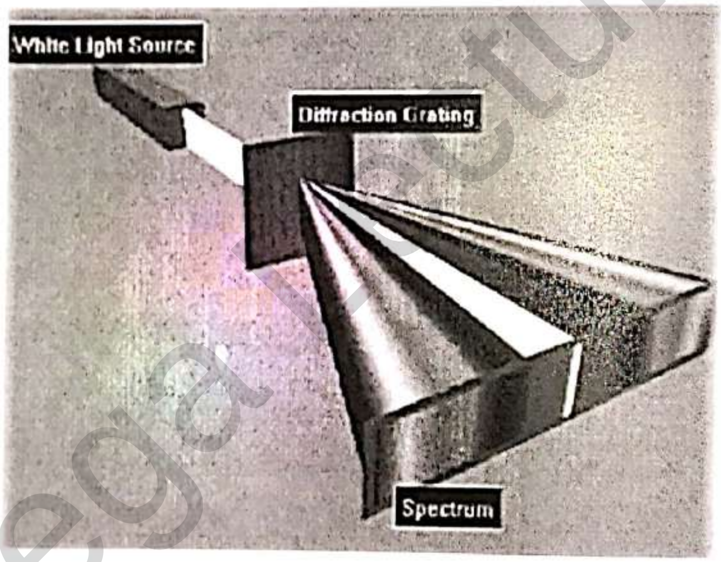
Using $\lambda = \frac{ax}{D}$

$x = 600 \times 10^{-9} \times 0.80 / 0.50 \times 10^{-9}$

$= 960$ m

Use of a diffraction grating to determine the wavelength of light

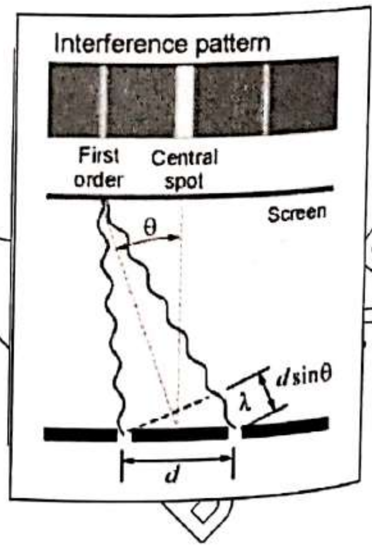
- A diffraction grating is a plate on which there is a very large number of identical, parallel, very closely spaced slits.
- If a monochromatic light is incident on this plate, a pattern of narrow bright fringes is produced.



How a Diffraction Grating Works

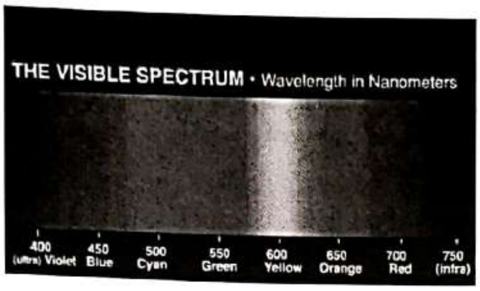
When you look at a diffracted light you see:

- the light straight ahead as if the grating were transparent.
- a "central bright spot".
- the interference of all other light waves from many different grooves produces a scattered pattern called a spectrum.



Application of Diffraction Grating

- A diffraction grating can be used to make a spectrometer and a spectrometer is a device that measures the wavelength of light.

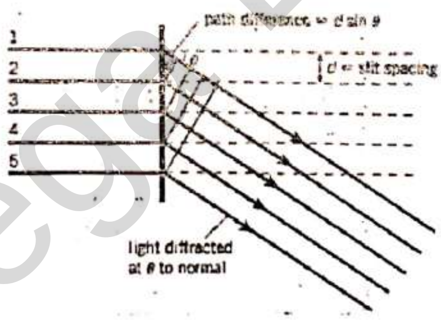


The equation: $d \sin \theta = n\lambda$

Figure 8.54 shows a parallel beam of light incident normally on a diffraction grating in which the spacing between adjacent slits is *d*. Consider first rays 1 and 2 which are incident on adjacent slits. The path difference between these rays when they emerge at an angle θ is $d \sin\theta$, to obtain constructive interference in this direction from these two rays, the condition is that the path difference should be an integral number of wavelengths. The path difference between rays 2 and 3, 3 and 4, and so on, will also be $d \sin\theta$. The condition for constructive interference is the same. Thus, the condition for a maximum of intensity at angle θ is

$$d \sin\theta = n\lambda$$

Where λ is the wavelength of the monochromatic light used, and *n* is a whole number.



When $n = 0$, sin 0 - 0 and θ is also zero; this gives the straight-on direction, or what is called the zero-order maximum. When $n = 1$, we have the first-order diffraction maximum, and so on (Figure 8.55).

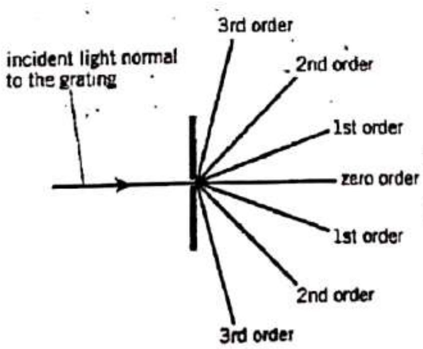


Figure 8.55 Maxima in the diffraction pattern of a diffraction grating

Monochromatic light is incident normally on a grating with 7.00×10^5 lines per meter. A second-order maximum is observed at an angle of diffraction of 40.0°. Calculate the wavelength of the incident light.

The slits on a diffraction grating are created by drawing parallel lines on the surface of the plate. The relationship between the slit spacing d and the number N of lines per meter is = $1/N$. For this grating,

$d = 1/7.00 \times 10^5 = 1.43 \times 10^{-6}$ m. Using $n\lambda = d \sin\theta$,

$\lambda = (d/n) \sin\theta = (1.43 \times 10^{-6}/2) \sin 40.0° =$ **460nm.**

Waves

Introducing Waves

Waves carry energy.

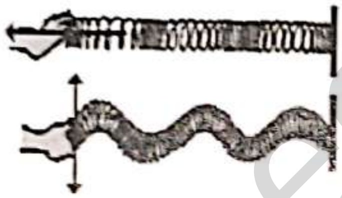
For Example, during an earthquake, the seismic waves produced can cause great damage to buildings and the surroundings.

What is a wave?

Wave is a method of propagation of energy. For example, when we drop a pebble into a pond of still water, a few circular ripples move outwards, on the surface of the water. As these circular ripples spread out, energy is being carried with them.

Sources of Waves

The source of any wave is a vibration or oscillation. For example, the forming of the slinky waves as shown. Wave motion provides a mechanism for the transfer of energy from one point to another without the physical transfer of the medium between the two points.

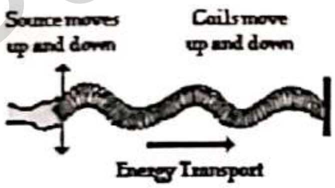


Slinky waves can be made by vibrating the first coil back and forth in either a horizontal or a vertical direction.

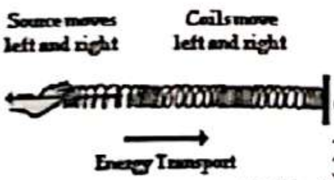
Two Types of Waves

Transverse Wave Rope waves, Water waves, Light waves, Radio waves, Electromagnetic waves.
Longitudinal Wave Sound waves and waves produced in a vertical oscillating spring under tension.

Transverse Wave



Longitudinal wave



Waves

Introducing Waves

Waves carry energy.

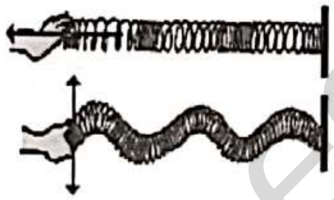
For Example, during an earthquake, the seismic waves produced can cause great damage to buildings and the surroundings.

What is a wave?

Wave is a method of propagation of energy. For example, when we drop a pebble into a pond of still water, a few circular ripples move outwards, on the surface of the water. As these circular ripples spread out, energy is being carried with them.

Sources of Waves

The source of any wave is a vibration or oscillation. For example, the forming of the slinky waves as shown. Wave motion provides a mechanism for the transfer of energy from one point to another without the physical transfer of the medium between the two points.

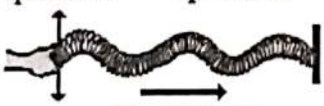


Slinky waves can be made by vibrating the first coil back and forth in either a horizontal or a vertical direction.

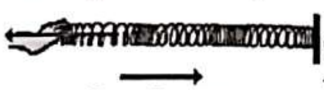
Two Types of Waves

Transverse Wave Rope waves, Water waves, Light waves, Radio waves, Electromagnetic waves. Longitudinal Wave Sound waves and waves produced in a vertical oscillating spring under tension.

Transverse Wave

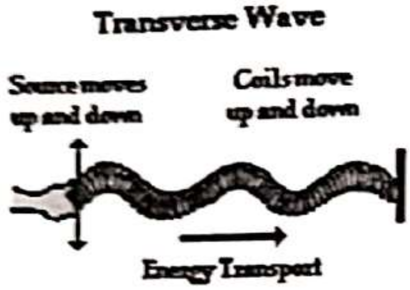


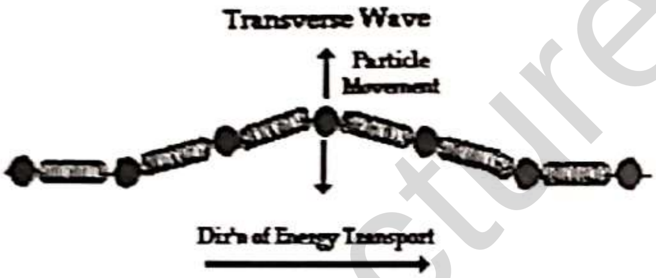
Longitudinal wave



Transverse Waves

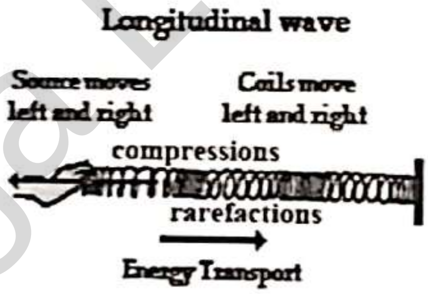
Transverse waves propagate in a direction perpendicular to the direction of vibration.

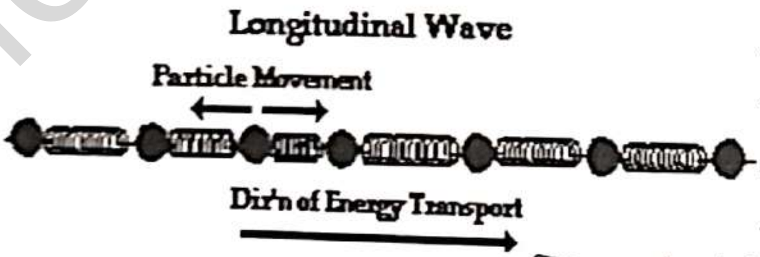




Longitudinal Waves

Longitudinal waves propagate in a direction parallel to the direction of vibration.





Reference link for

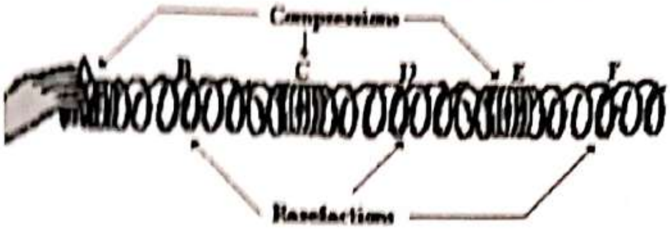
Demonstration of waves

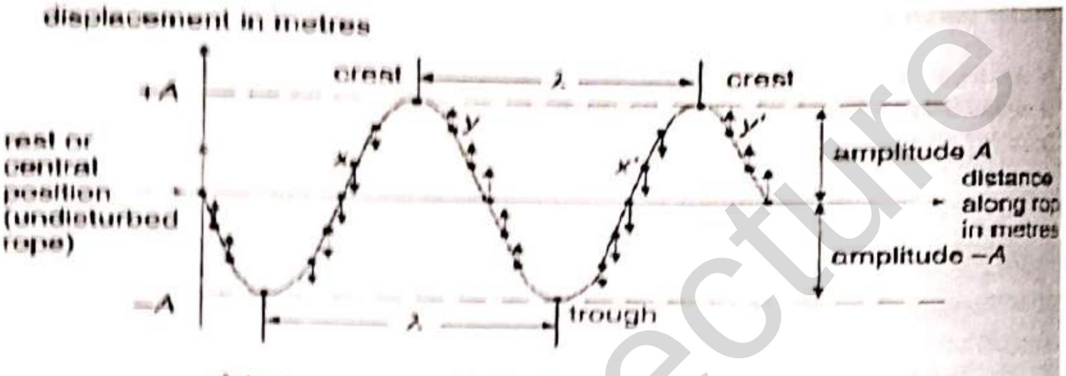
http://www.acs.psu.edu/drussell/demos/waves/wavemotion.html

Describing Waves

Crests and troughs

High points and low points that characterise transverse waves only. For longitudinal waves, compressions and rarefactions are used. Amplitude, A, SI Unit: metre (m)

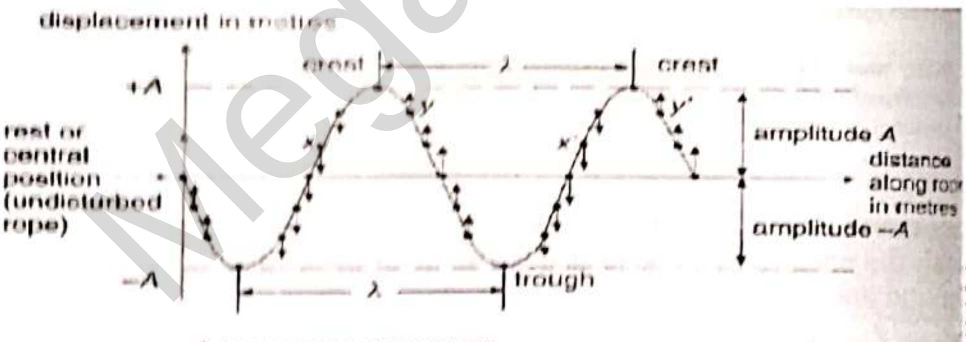




A transverse rope wave

Wavelength,λ, SI Unit: metre (m)

The shortest distance between any two points on a wave that are in phase. The two easiest points to choose for a distance of one wavelength are two successive crests or troughs.



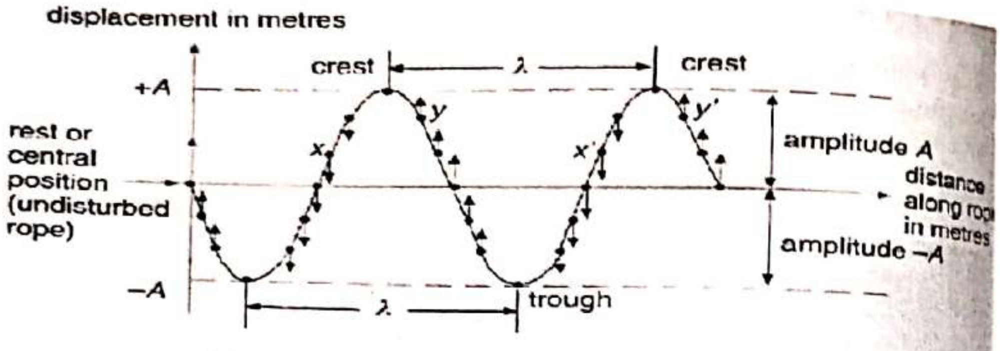
A transverse rope wave

Frequency,/ SI Unit: hertz (Hz)

The number of complete waves produced per second. The figure shows two complete waves and if they are produced in one second, then the frequency of this wave is two waves per second or 2 hertz.

Period, T, SI Unit: second (s)

The time taken to produce one complete wave. T= /f



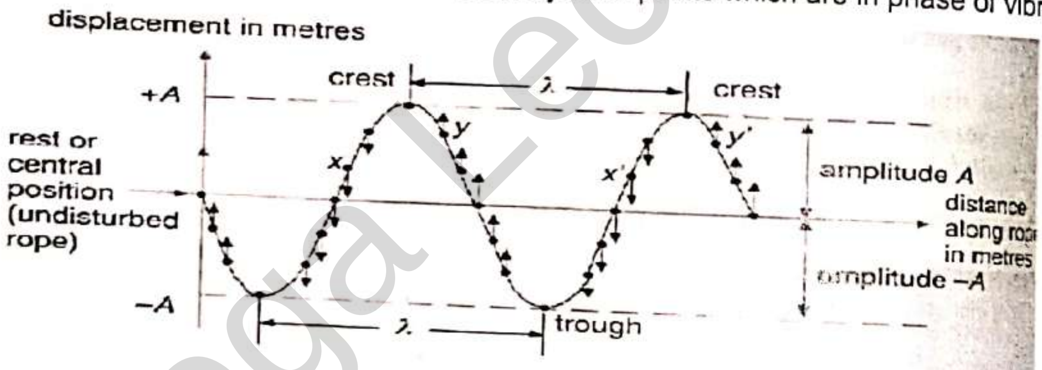
A transverse rope wave

Wave Speed, v, SI Unit: metre per s (m/s)

The distance travelled by a wave in one second.

Wave Front

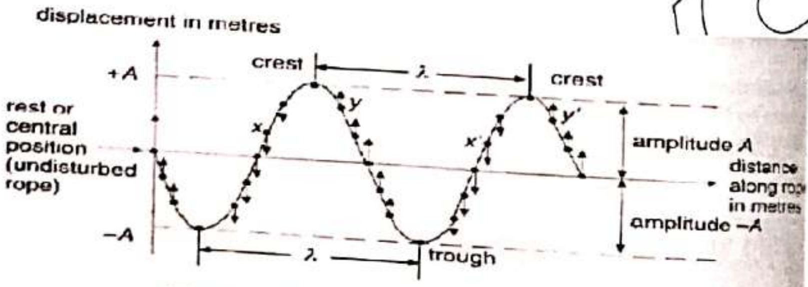
An imaginary line on a wave phase of vibration that join all points which are in phase of vibration.



A transverse rope wave

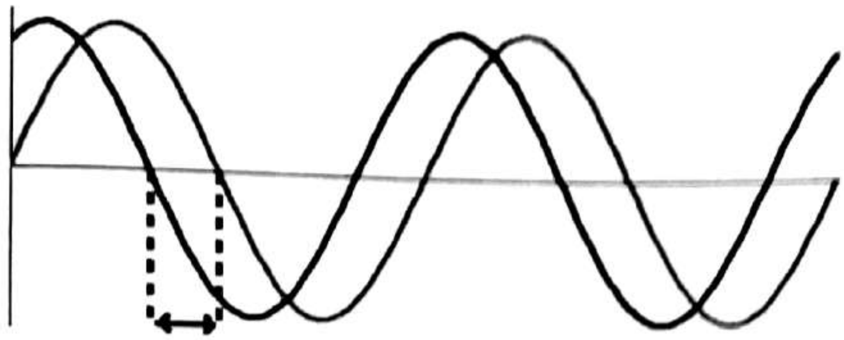
Phase

Two points (such as x &x', and y & y') are said to be in phase because that are moving in the same direction with the same speed and having the same displacement from the rest position. Any two crests or trough are in phases.

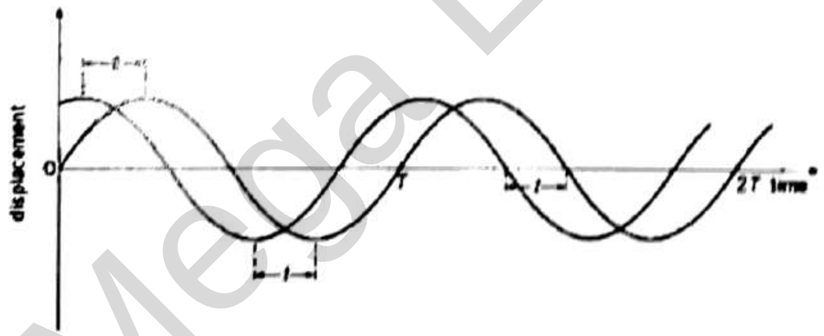


A transverse rope wave

Describing Waves – Phase difference



A term used to describe the relative positions of the crests or troughs of two waves of the same frequency is phase When the crests and troughs of the two waves are aligned, the waves are said to he in phase When a crest is aligned with a trough, the waves are out of phase When used as a quantitative measure, phase has the unit of angle (radians or degrees) Thus, when waves are out of phase, or the wave is half a cycle behind the other Since one cycle is equivalent to 2π radians or 360°, the phase difference between waves that are exactly out of phase is π radians or 180° Consider Figure in which there are two waves of the same frequency, but with a phase difference between them. The period T corresponds to a phase angle of 2π rad or 360°. The two waves are out of step by a time t. Thus, phase difference is equal to 2π (t/T) rad = 360(t/T)G. A similar argument may be used for waves of wavelength A which are out of step by a distances. In this case the phase difference is $2\pi(x/\lambda)$ rad = $360(x/\lambda)°$.



The wave equation and principle

Speed = distance/time

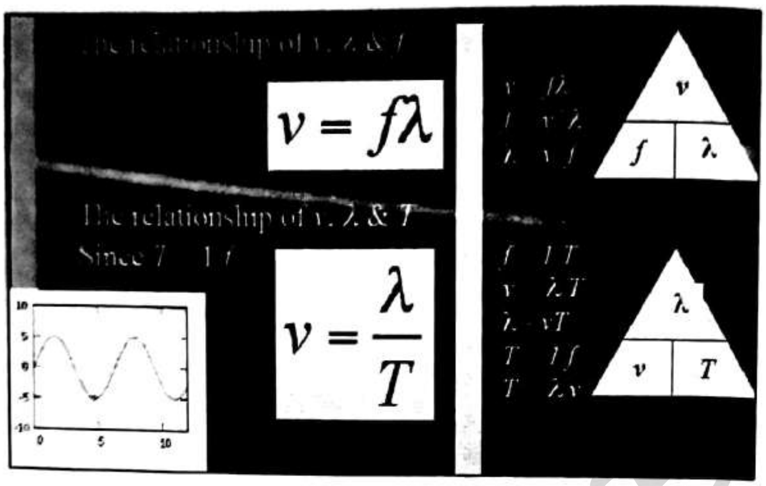
Wavelength is the distance moved by the wave in one cycle I.e distance

Time = period = 1/frequency

So speed = wavelength/period

Speed = wavelength x frequency, i.ev = λ f

The Wave Equation



Example 1

Visible light has wavelengths between 400 nm and 700 nm, and its speed in a vacuum is 3.0×10^8 m s^{-1}.

What is the maximum frequency of visible light?

Solution:

From v = fλ, the frequency $f = \frac{v}{\lambda}$, i.e f is inversely proportional to λ.

For maximum frequency, minimum wavelength should be used.

$$\text{Hence, } f_{max} = \frac{v}{\lambda_{min}} = \frac{3 \times 10^8 \text{ m}}{400 \times 10^{-9}} = 7.5 \times 10^{14} \text{ Hz}$$

Example 2

A sound wave of frequency 400 Hz is travelling in a gas at a speed of 320 m s^{-1}. What is the phase difference between two points 0.2 m apart in the direction of travel?

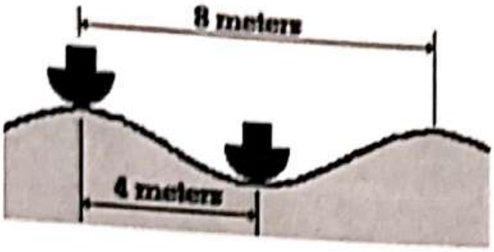
Solution:

$$\text{Wavelength}, \lambda = \frac{v}{f} = \frac{320 \text{ ms}^{-1}}{400 \text{ Hz}} = 0.80 \text{ m}$$

$$\frac{\phi}{2\pi} = \frac{x}{\lambda} = \frac{0.2}{0.8} = \frac{1}{4} \quad \rightarrow \quad \phi = \frac{\pi}{2} \text{rad}$$

Example 4

Two boats are anchored 4 metres apart. They bob up and down every 3 seconds, but when one is up the other is down. There are never any wave crests between the boats. Calculate the speed of the waves.



Solution:

Period, T = (3 x 2)s = 6s

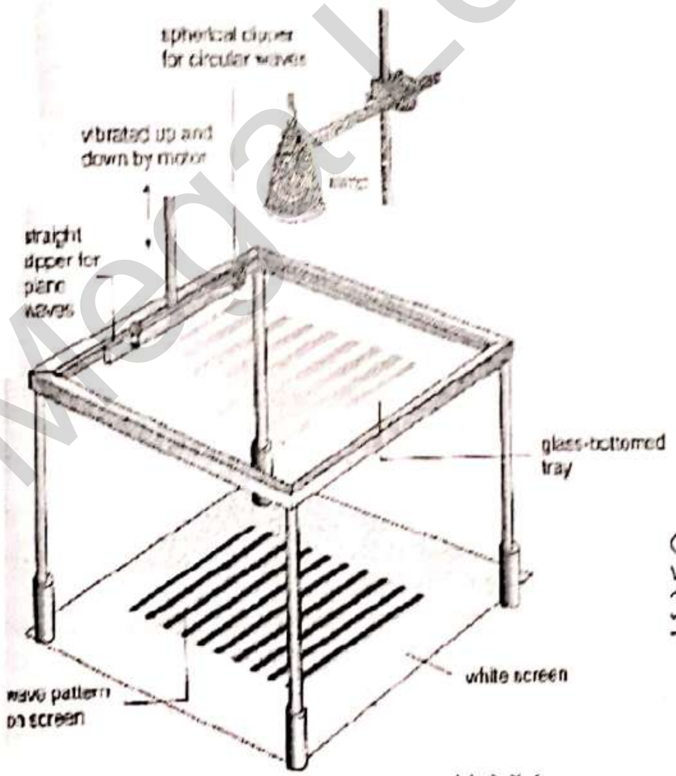
Wavelength, λ= 8 m

Speed, v = λ/T = (8/6) m/s = 1.33 m/s

Ripple Tank (Wave production)

The Structure

A shallow glass-bottomed tray; A light source directly above the tray; and a white screen beneath the tray used to capture the shadows formed when water waves traverse the tray. Production of waves Plane waves by using the straight dipper Circular waves by spherical dipper



Energy is transferred by a progressive wave

Wave Motion

There are also two other ways to classify waves – by their motion. A wave in which energy is transferred from one place to another as a result of its motion is called a progressive wave. For Example, An ultraviolet light wave, which transfers energy from the sun to the skin of people lying on the beach, for instance, is a progressive wave. In general, waves that move from one point to another transfer some kind of energy. In a progressive wave, the shape of the wave itself, is what is transferred, not the actual components of the medium.

Look at this animated example

http://library.thinkquest.org/15433/unit5/5-3.html

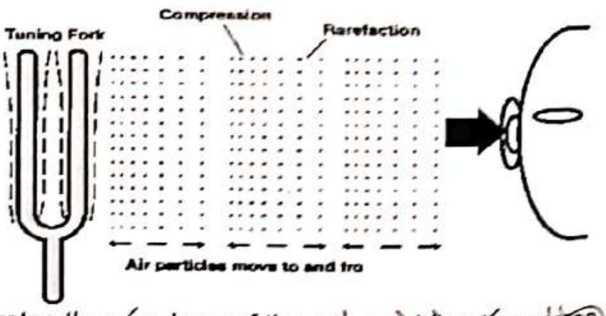
This animation of a dog on a leash shows a progressive wave transferring energy from the boy to the dog, which end up getting flipped through the air.

Show an understanding that energy is transferred due to a progressive wave.

Oscillation (or oscillatory motion) refers to the to-and-fro motion of a particle about an equilibrium position. The oscillatory motion of the particle is a continuous exchange of potential and kinetic energy of the particle. Wave refers to the combined motion of a series of linked-particles: each of which is originally at rest at its respective equilibrium position. Starting from the oscillation of the first particle about its equilibrium position, the energy of the oscillation is passed to the second panicle, which in turn is passed to the third particle and subsequent particles in the series of linked-particles. So wave motion is the motion of energy passed from one particle to the next in a series, through oscillatory motion of these particles, in sequence.

Examples:

(1) Soundwave:



When a sound wave is propagated from a tuning fork to an ear of a person some distance away, the vibration of the fork sets the air layer next to it into vibration. The second layer of air is then set into vibration by the transfer of energy from the first layer.

This transfer of energy continues for subsequent layers until the layer of air next to the ear is also set into vibration, which in turn vibrates the ear-drum of the ear, enabling the person to hear the sound originated from the tuning fork.

There is no net transfer of air particles from the tuning fork to the ear. The ear-drum in the ear can vibrate because energy has been transferred to it from the tuning fork through the sequential vibration of the layers of air between the tuning fork and the ear. (Diagram above) This sequential vibration of the layers of air forms regions of compression (where air layers are closer to each other) and regions of rarefaction (where air layers are further apart). The one-way movement of such regions from the tuning fork to the ear signifies the propagation of sound wave energy.

(2) Wave in a rope:

The wave travelling in a rope may originate from the vibration of the first particle at one end of the rope. The energy of the vibrating first particle is transferred to the second particle, setting it into vibration. This transfer of energy continues to subsequent particles in the rope until it reaches the other end of the rope.

(3) Water wave:

The energy of the vibrating water molecules is transferred to subsequent molecules along the surface of water, causing these molecules further from the vibrating source to be set into up-down motion The examples (1), (2) and (3) are examples of progressive waves, where energy is transferred from one region to another region through sequential vibration of a series of linked-particles. The energy of a first vibrating particle is propagated along a series of linked-particles to another region Sound energy is propagated from the tuning fork to the ear, energy from one end of a rope is propagated to the other end, and energy from one region of wafer surface next to a vibrating source is propagated to another region in the ripple tank.

Intensity of the Wave

One of the characteristies of a progressive wave is that it carries energy The amount of energy passing through unit area per unit time is called the intensity of the wave. The intensity is proportional to the square of the amplitude of a wave. Thus, doubling the amplitude of a wave increases the intensity of the wave by a factor of four. The intensity also depends on the frequency: intensity is proportional to the square of the frequency. or a wave of amplitude A and frequency f , the intensity f is proportional to A^2f^2.

If the waves from a point source spread out equally in all directions, we have what is called a spherical wave. As the wave travels further from the source, the energy it carries passes through an increasingly large area. Since the surface area of a sphere is $4\pi r^2$, the intensity is $W/4\pi^2$, where W is the power of the source. The intensity of the wave thus decreases with Increasing distance from the source. The intensity I is proportional to $1/r^2$ where r is the distance from the source.

This relationship assumes that there is no absorotion of wave energy.

Recall and use the relationship, intensity ∝ (amplitude)^2.

Intensity t is the rate of incidence of energy per unit area normal to the direction of incidence.

The rate of incidence of energy can be regarded as power. The plane of the area, which the wave energy is incident onto, has to be normal (perpendicular) to the direction of the incidence of the wave energy. The unit of intensity is W m^{-2}. Intensity on an area A can be expressed as

$$I = \frac{P}{A}$$

where P is the power incident on the area normally.

$$\text{intensity} \propto (\text{amplitude})^2$$

A sound wave of amplitude 0.20 mm has an intensity of 3.0 W m^{-2}. What will be the intensity of a sound wave of the same frequency which has an amplitude of 0.40 mm?

Solution:

The relation $I \propto (\text{amplitude})^2$

Can be expressed as $I = A(\text{amplitude})^2$

Where k is the constant of proportionality.

Substituting,

$$3.0Wm^{-2} = k(0.20mm)^2 ----(1)$$

$$\text{New intensity, } I = k(0.40mm)^2 ---(2)$$

$$\frac{(2)}{(1)} : \quad \frac{I}{3.0Wm^{-2}} = 4$$

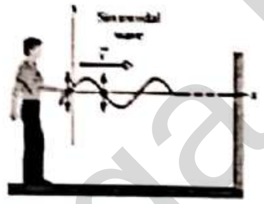
For sound waves, intensity is a measure of loudness.

For light waves, intensity is a measure of brightness.

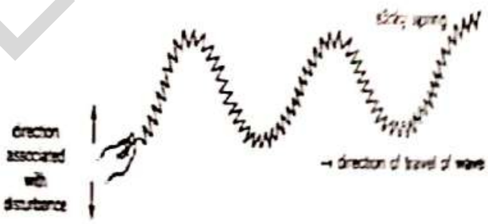
Analyse and interpret graphical representations of transverse and longitudinal waves.

In a wave, there are two directions of motions: direction of propagation of energy (which is the direction of motion of the wave) direction of oscillation of the particles in the wave.

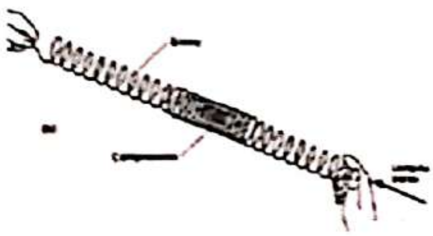
A transverse wave is one in which the direction of propagation of energy is perpendicular to the direction of oscillation of the particles in the wave.



The string element's motion is perpendicular to the wave's direction of travel. This is a transverse wave.



In the example of a wave travelling along a string (or a wave travelling along a slinky diagrams above, the wave is started from one end of the string by the oscillation of the first element in the direction perpendicular to the string, then this wave travelling along the string is an example of a transverse wave. the direction of propagation of the wave is along the string. If A longitudinal wave is one in which the direction of propagation of energy is parallel to the direction of oscillation of the particles in the wave.



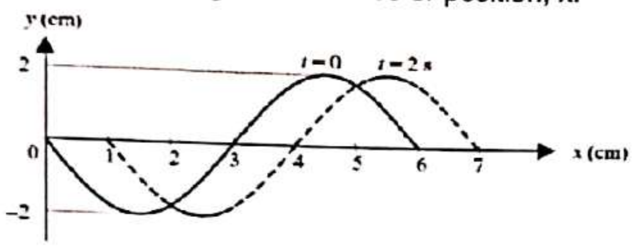
A visual demonstration of a longitudinal wave.

When a sound wave set up by the vibrating piston propagates along the pipe of air, the direction of propagation of sound energy is along the pipe to the right. The direction of oscillation of the air layers is back and forth, parallel to this direction. Hence sound wave is an example of a longitudinal wave.

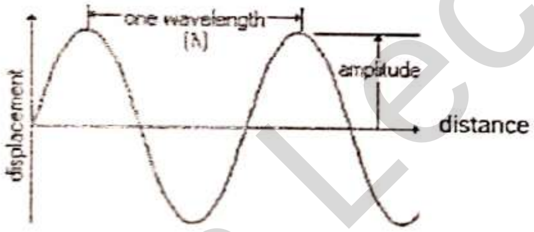
Graphs representing waves

Graph 1: Displacement vs. Position graphs

These are plotted with displacement, y, against distance or position, x.

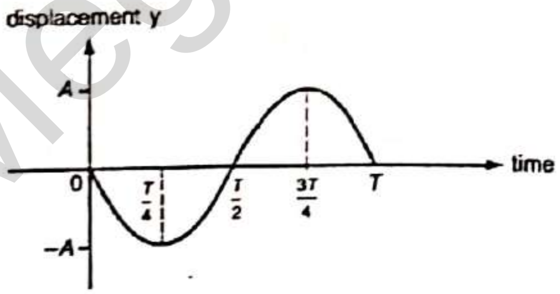


For a transverse wave moving from left to right along the x-axis, displacement of the particles in the wave, y, may be given a +ve sign for displacement upwards, and a –ve sign for displacement downwards. For a longitudinal wave moving from left to right along the x-axis, displacement of the particles in the wave, y, may be given a +ve sign for displacement to the right and a –ve sign for displacement to the left

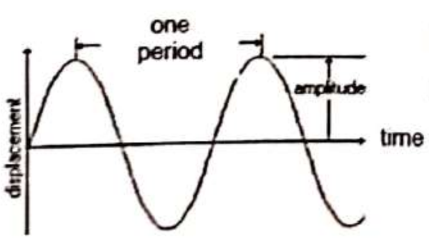


Graph 2 : Displacement vs. Time graphs

In contrast, graphs used to represent an oscillation of a particle are plotted with displacement, y, against time, f.



In the graph above, we are tracking the displacement of one particle only as time goes by. This does NOT represent the wave



In Displacement vs. Time graphs, The graph represents the oscillation of one particle on the wave with time. the "distance" between consecutive crests or consecutive troughs is one period The maximum height of the vertical axis = amplitude of oscillation.

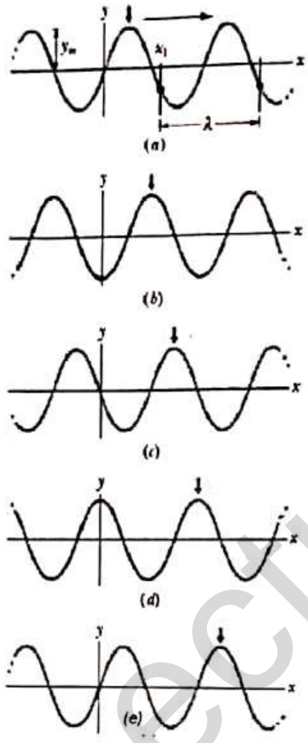
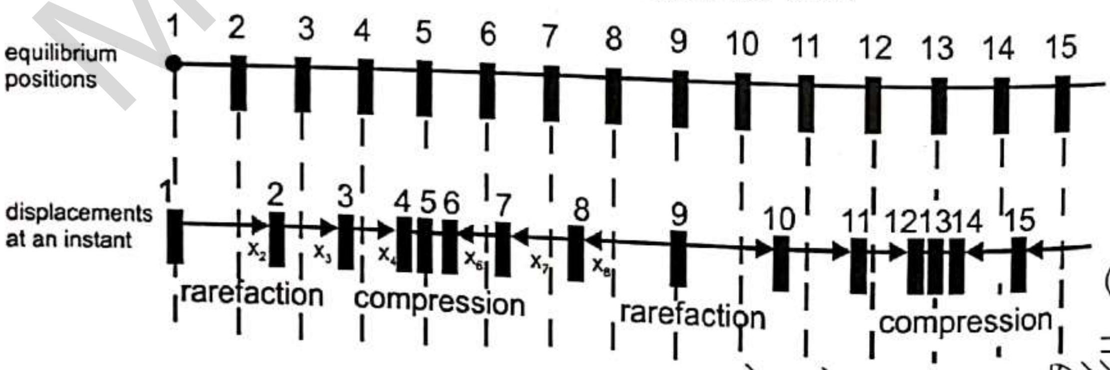


Fig.2

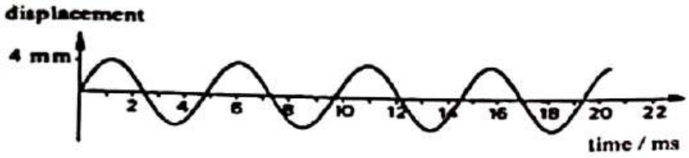
Fig.2 shows 5 snapshots' of a transverse wave in a string, travelling in the +ve direction of an x-axis (left to right). The movement of the wave is indicated by the right-ward progress of the short down-pointing arrow, pointing at the middle crest' of the wave in snapshot (a). From snapshots (a) to (e), the short arrow moves to the right with the wave, but each particle in the string moves parallel to the y-axis (up and down). An example of such a particle is along the y-axis (shown darkened). Each snapshot is taken at an interval of % period. One full oscillation takes place from (a) to (e).

Actual positions of layers within the longitudinal wave



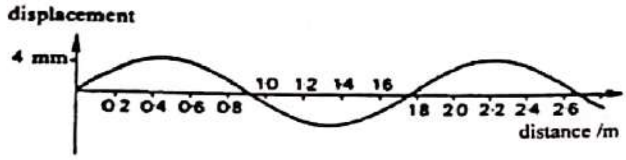
Summary For Part (f):

(1) Displacement-time graph is for the oscillation of a particle in the wave



The graph above shows an element oscillating with an amplitude of 4 mm Its period of oscillation is about 5 ms.

(2) Displacement-distance graph is for a snapshot of a wave motion at an instant



The graph above shows an instant of a wave with an amplitude of 4 mm. Its wavelength is about 1.8 m.

Example 7

The diagram below shows an instantaneous position of a string as a transverse progressive wave travels along it from left to right.

Which one of the following correctly shows the directions of the velocities of the points 2 and 3 on the string?

	1	2	3
A	→	→	→
B	→	←	→
C	↓	↓	↓
D	↓	↑	↓
E	↑	↓	↑

Solution

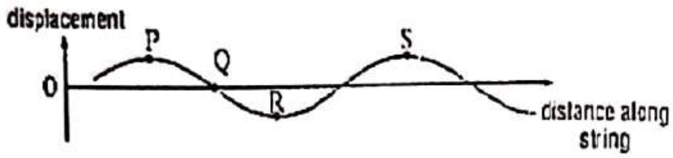
Knowing that the wave is traveling from LEFT to RIGHT, sketch how the wave would look like just an instant after:

Then look at the points concerned. Since it is a TRANSVERSE wave, the particles only oscillates perpendicular to the wave direction. This eliminates Answers A & B.

Ans: D

Example 8

The graph shows the shape at a particular instant of part of a transverse wave travelling along a string



Which statement about the motion of elements of the string is correct?

A The speed of the element at P is a maximum

B The displacement of the element at Q is always zero

C The energy of the element at R is entirely kinetic

D The acceleration of the element at S is a maximum

Solution:

Although the graph represents the whole wave at an instant in time, the question requires you to analyse the motion of the individual particles within the wave at this instant.

Element P: At extreme end of oscillation → stationary
Element Q: At equilibrium position → moving fastest
Element R: At extreme end of oscillation → stationary, no kinetic energy
Element S: At extreme end of oscillation → max displacement, max acceleration

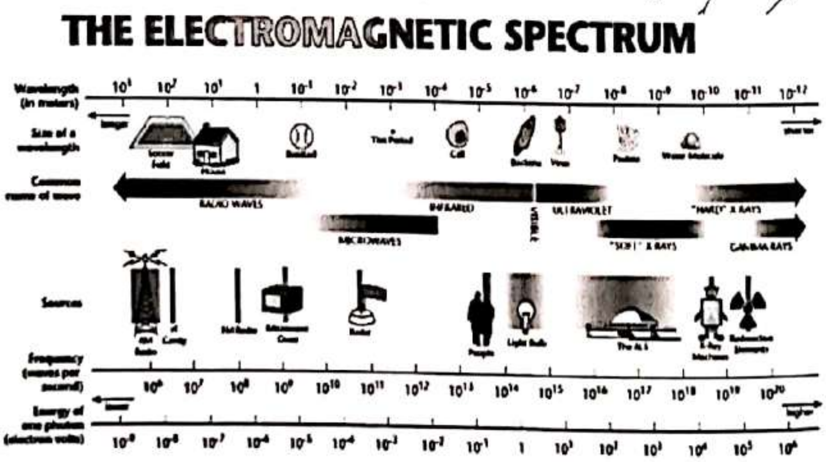
Ans: D

The Electromagnetic Spectrum

Electromagnetic Waves

James Clerk Maxwell s (1831 - 1879) crowning achievement was to show that a beam of light is a travelling wave of electric and magnetic field, an e/ectro-magnetic wave. In Maxwell s time, the visibleÿ infrared and ultraviolet form of light were the only electromagnetic waves known. Heinrich Hertz then discovered what we now call radio waves and verified that they move through the laboratory at the same speed as visible light.

We now know a wide spectrum of electromagnetic waves The Sun, being the dominant source of these waves, continually bathes us with electromagnetic waves throughout this spectrum.



Type of EM wave	Typical Wavelengths λ and its corresponding frequency, f.	Orders of magnitude for wavelength, λ / m
Gamma (γ) rays	λ = 1 pm = 10^{-12} m f = 3×10^{20} Hz	10^{-12}
x-rays	λ = 100 pm = 10^{-10} m f = 3×10^{18} Hz	10^{-10}
UV ultraviolet	λ = 10 nm = 10^{-8} m f = 3×10^{16} Hz	10^{-8}
Visible light	λ_{red} = 700 nm λ_{green} = 600 nm = 0.6 μm λ_{violet} = 400 nm f_{green} = 5×10^{14} Hz	10^{-6}
IR (infra-red)	λ = 100 μm = 10^{-4} m f = 3×10^{12} Hz	10^{-4}
Radio wave (*includes microwaves, UHF, VHF etc*)	λ = 3 m f = 10^{8} Hz	$10^{0} \sim 10^{-2}$

Properties of Electromagnetic Waves

1) EM waves have the same speed, c, in vacuum ($c \approx 3 \times 108$ m s^{-1}).

2) EM waves consist of oscillating electric and magnetic fields that are perpendicular to each other.

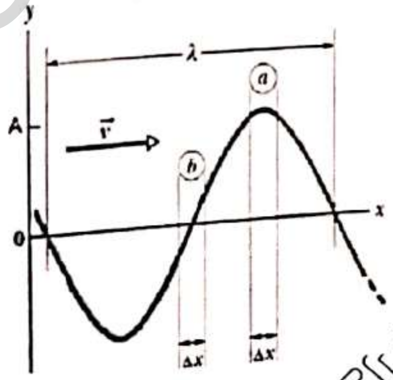
3) EM waves are all transverse waves

Energy (E) and Intensity (I) of a Progressive Wave

When we set up a wave on a stretched string, we provide energy for the motion of the string. As the wave moves away from us, it transports that energy as both kinetic energy and elastic potential energy.

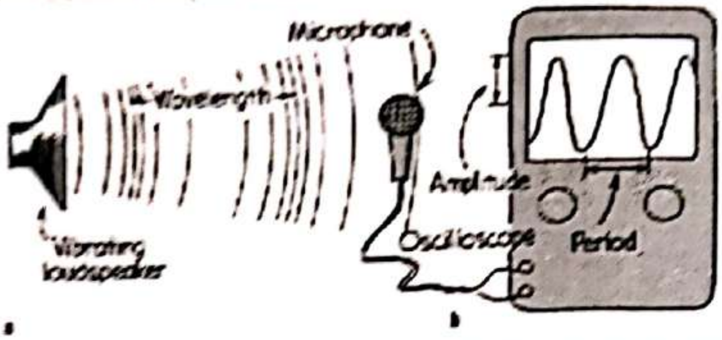
Kinetic Energy

An element of the string of mass Δm, oscillating transversely in simple harmonic motion as the wave passes through it, has KE associated with its transverse velocity u. When the element is rushing through its y- 0 position (element b in the diagram), its transverse velocity- and thus its KE is a maximum. When the element is at its extreme position y - A (element a), its transverse velocity- and thus its KE- is zero.



The frequency of sound using a calibrated CRO

(This topic was done in Second chapter : Measurement & Techniques)



A calibrated c.r.o. (cathode-ray oscilloscope) implies that the time-base is set such that the period, T, of oscillations of the air layers detected by the microphone may be read. Using the relation

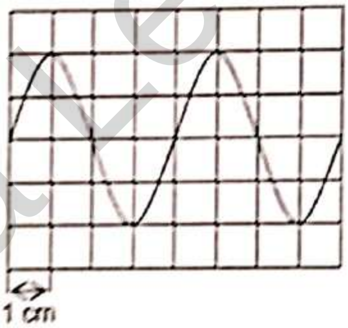
$$f = \frac{1}{T}$$

the frequency, f of sound produced by the vibrating loudspeaker may be determined

Sample problem

(This topic was done in Second chapter : Measurement & Techniques)

The trace shown appeared on an oscilloscope screen with the time-base set to 2.0 ms cm^{-1}.



What is the frequency of the signal?

A 40 Hz

B 125 Hz

C 250 Hz

D 500 Hz

Solution

Period, T = 2.0 ms cm^{-1} x 4 cm = 8.0 ms

Frequency, $f = \frac{1}{T} = \frac{1}{8 \times 10^{-3} s} = 125$ Hz

Ans: B

The wavelength of sound using stationary waves

This topic would be studied in detail in next chapter 'Superposition'. Please refer to notes on Stationary Waves in the topic Superposition.

Polarization

Electromagnetic Wave : Electric Field & Magnetic Field

A light wave is an electromagnetic wave that travels through the vacuum of outer space. Electromagnetic wave is a transverse wave that has both an electric and a magnetic component.

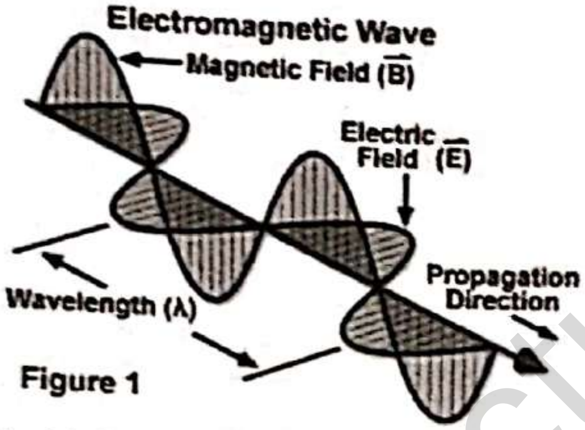
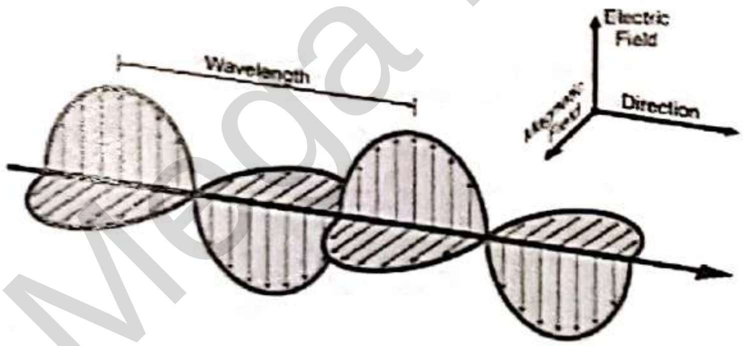


Figure 1

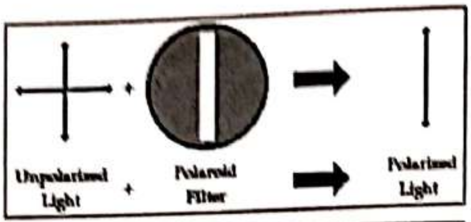
Electromagnetic Wave : Electric Field & Magnetic Field

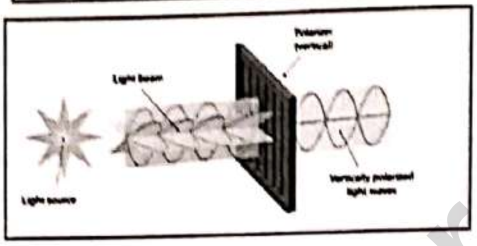
A light wave that is vibrating in more than one plane is referred to as unpolarized light. Light emitted by the sun, by a lamp in the classroom or by a candle flame are examples of unpolarized light. Such light waves are created by electric charges and vibrate in a variety of directions.



Polarization is a phenomenon associated with transverse waves

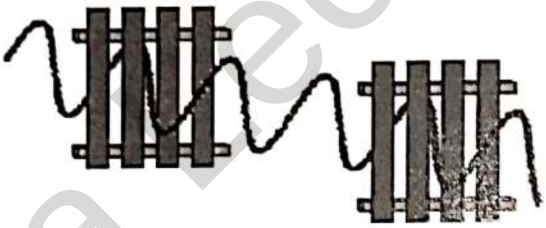
Process by which a wave's oscillations are made to occur in one plane only. Associated with transverse waves only.



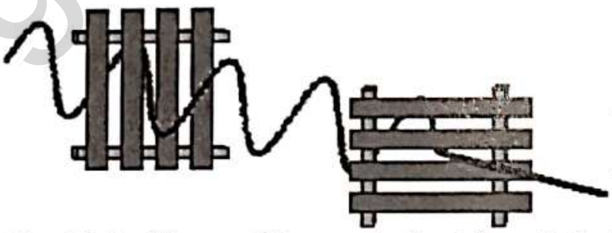


Note : Here, Polarization of light is analogous to that shown in the diagrams.

The Picket Fence Analogy



When the pickets of both fences are aligned in the vertical direction, a vertical vibration can make it through both fences.



When the pickets of the second fence are horizontal, vertical vibrations which make it through the first fence will be blocked.

Show an understanding that Polarisation is a phenomenon associated with transverse waves

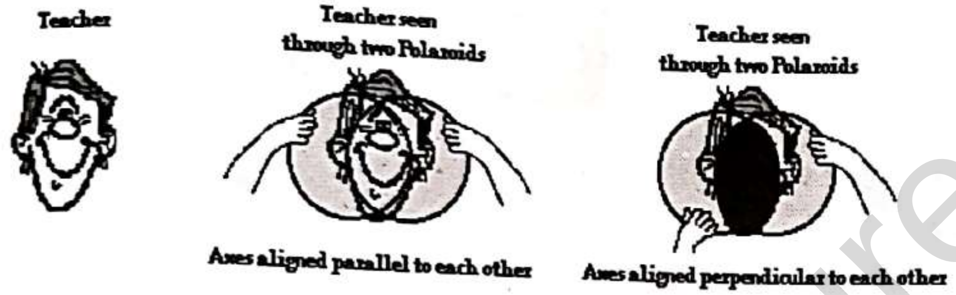
Reference link :

http://www.youtube.com/watch?v=e8aYoLj2rO8

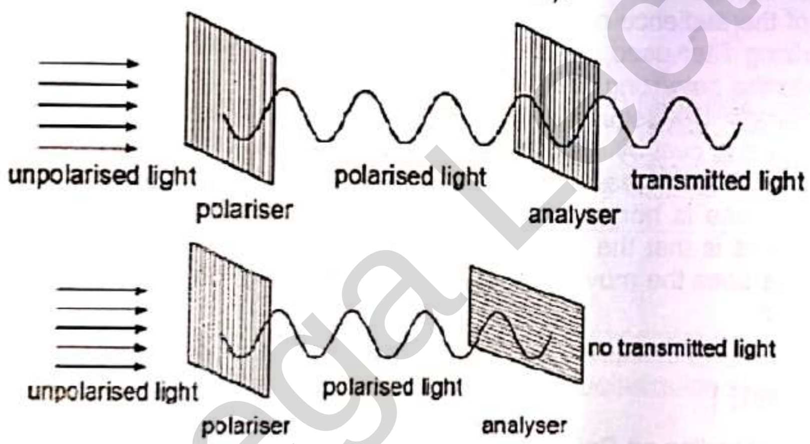
Polarization by Use of a Polaroid Filter

The most common method of polarization involves the use of a Polaroid filter. Polaroid filters are made of a special material that is capable of blocking one of the two planes of vibration of an electromagnetic wave.

In this sense, a Polaroid serves as a device that filters out one-half of the vibrations upon transmission of the light through the filter. When unpolarized light is transmitted through a Polaroid filter, it emerges with one-half the intensity and with vibrations in a single plane; it emerges as polarized light.



Light travelling parallel to polariser the transmitted light has (almost) the same intensity as the polarised light (i.e. the amplitude of the light wave is identical).



When the 2nd polariser, or the Analyser is perpendicular to polariser, no transmitted light is observed. Hence, intensity is zero. (i.e. the amplitude of the light wave is zero).

A longitudinal waves cannot be polarised. Why?

A longitudinal waves cannot be polarised because the particles in the wave oscillate parallel to the wave direction and cannot be restricted to vibrate in any plane.

Applications of Polarizations

1) Polaroid sunglasses

The glare from reflecting surfaces can be diminished with the use of Polaroid sunglasses. The polarization axes of the lens are vertical, as most glare reflects from horizontal surfaces.

Applications of Polarizations

2) Polarization is also used in the entertainment industry to produce and show 3-D movies.

Reference link : http://www.youtube.com/watch?v=qIKzPgo2rNw

HOW 3D WORKS (not in syllabus, just for your information only) Three-dimensional movies are actually two movies being shown at the same time through two projectors. The two movies are filmed from two slightly different camera locations. Each individual movie is then projected from different sides of the audience onto a metal screen. The movies are projected through a polarizing filter. The polarizing filter used for the projector on the left may have its polarization axis aligned horizontally while the polarizing filter used for the projector on the right would have its polarization axis aligned vertically. Consequently, there are two slightly different movies being projected onto a screen. Each movie is cast by light that is polarized with an orientation perpendicular to the other movie. The audience then wears glasses that have two Polaroid filters. Each filter has a different polarization axis - one is horizontal and the other is vertical. The result of this arrangement of projectors and filters is that the left eye sees the movie that is projected from the right projector while the right eye sees the movie that is projected from the left projector. This gives the viewer a perception of depth.

QUESTION TIME !

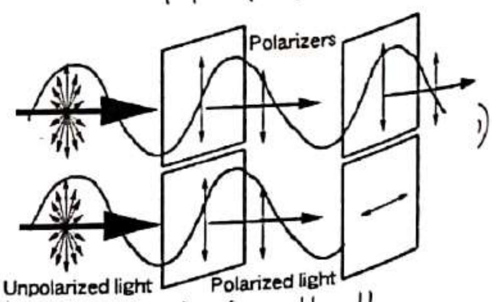
Check your understanding on Polarization

Question No.1

1. Suppose that light passes through two Polaroid filters whose polarization axes are parallel to each other. What would be the result?

Answer - Question No.1

The first filter will polarize the light, blocking one-half of its vibrations. The second filter will have no affect on the light. Being aligned parallel to the first filter, the second filter will let the same light waves through.



Question No.2

2. Which of the following cannot be polarised?

A-infrared waves

B-microwaves

C-sound waves

D- ultraviolet waves

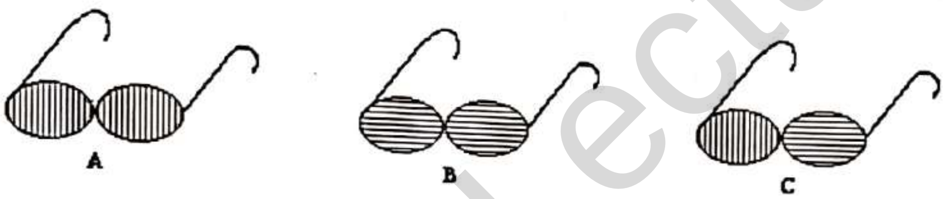
Answer - Question No.2

Answer: C – Sound waves

Question No.3

3. Consider the three pairs of sunglasses below. Identify the pair of glasses which is capable of eliminating the glare resulting from sunlight reflecting off the calm waters of a lake? _________ Explain.

(The polarization axes are shown by the lines.)



Answer - Question No.3

Answer: A

The glare is the result of a large concentration of light aligned parallel to the water surface. To block such plane-polarized light, a filter with a vertically aligned polarization axis must be used.

The Doppler effect

You may have noticed a change in pitch of the note heard when an emergency vehicle passes you while sounding its siren. The pitch is higher as it approaches you and lower as it recedes into the distance. This is an example of the Doppler effect: you can hear the same thing if a train passes at speed while sounding its whistle. Figure 13.11 shows why this change in frequency is observed. It shows a source ofsound emitting waves with a constant frequency f, together with two observers A and B. If the source is stationary (Figure 13.11a), waves arrive at A and B at the same rate, and so both observers hear sounds of the same frequency f. If the source is moving towards A and away from B (Figure 13.11b), the situation is different. From the diagram you can see that the waves are squashed together in the direction of A and spread apart in the direction of B. Observer A will observe waves whose wavelength is shortened. More waves per second arrive at A, and so A observes a sound of higher frequency than I. Similarly, the waves arriving at B have been stretched out and B will observe a frequency lower than f.

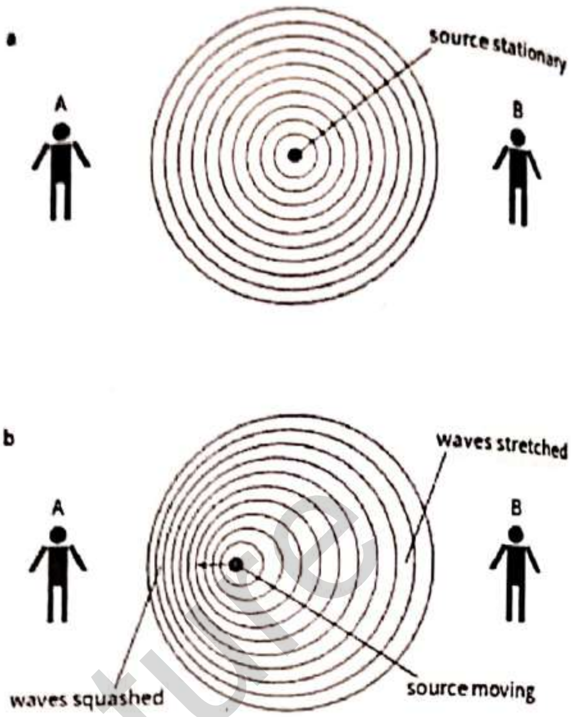


Figure 13.11 Sound waves, represented by wavefronts, emitted at constant frequency by a a stationary source, and b a source moving with speed v_s.

An equation for observed frequency

There are two different speeds involved in this situation. The source is moving with speed vt. The sound waves travel through the air with speed v, which is unaffected by the speed of the source. (Remember, the speed of a wave depends only on the medium it is travelling through.) The frequency and wavelength observed by an observer will change according to the speed v, at which the source is moving. Figure 13.12 shows how we can calculate the observed wavelength A„ and the observed frequency f_o. The wave trains shown in Figure 13.12 represent the waves emitted by the source in 1 s. Provided the source is stationary (Figure 13.12a), the length of this train is equal to the wave speed v since this is the distance the first wave travels away from the source in 1 s. The wavelength observed by the observer is simply $\lambda_o = \frac{v}{f_s}$ The situation is different when the source is moving away from the observer (Figure 13.12b). In 1 s, the source moves a distance v_s. Now the train off waves will have a length equal to v + v_s

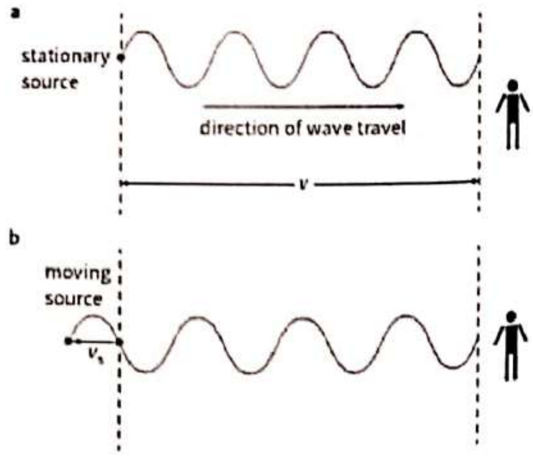


Figure 13.12 Sound waves, emitted at constant frequency by a a stationary source, and b a source moving with speed v_s away from the observer.

Light waves show the Doppler effect in the same way that sound waves do. So, for example, if an astronomer looks at the light from a distant star which is receding from Earth at speed v_s, its wavelength will be increased and its frequency will be decreased. The change in wavelength $\Delta\lambda$ is simply given by $\Delta\lambda/\lambda = v_s/c$.

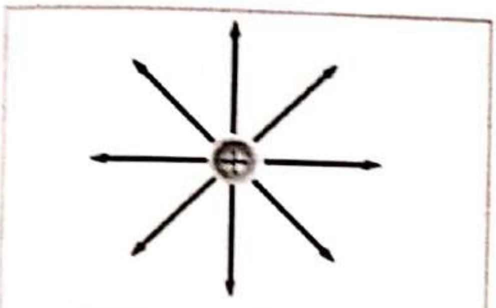
Electric Fields

Electric Fields

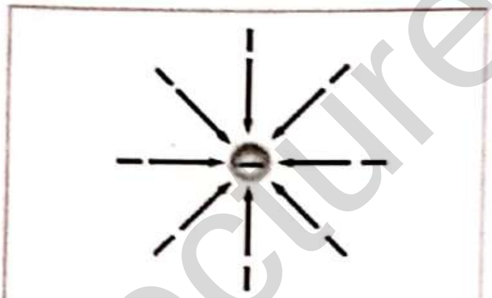
Electric charges exert forces on each other when they are a distance apart. The word 'Electric field' is used to explain this action at a distance. An Electric field is defined as the region of space where a stationary charge experiences force.

The direction of Electric Fields

The direction of electric field is defined as the direction in which a positive charge would move if it were free to do so. So the lines of force can be drawn with arrows that go from positive to negative. Electric field lines are also called force lines. The field lines are originated from the positive charge and they end up at the negative charge.



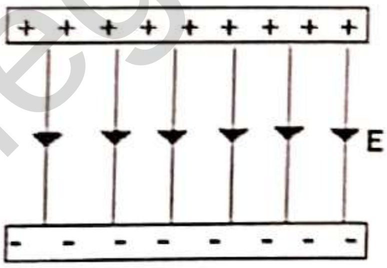
Positive Charge Electric Field
(animated demo)



Negative Charge Electric Field
(animated demo)

Remember, for any ELECTRIC FIELD.....

The lines of force starts on a positive charge and end on a negative charge. The lines of force never touch or cross. The strength of the electric field is indicated by the closeness of the lines; means the closer they are, the stronger the field.



Electric Field Strength

Electric field strength at a point is defined as the force per unit charge acting on a small positive charge placed at that point. If a force experienced by a positive charge +Q placed in the field is F, then the field strength, E is given by $E = \frac{F}{Q}$

Note:
Remember, the symbol E is also used for 'energy'.

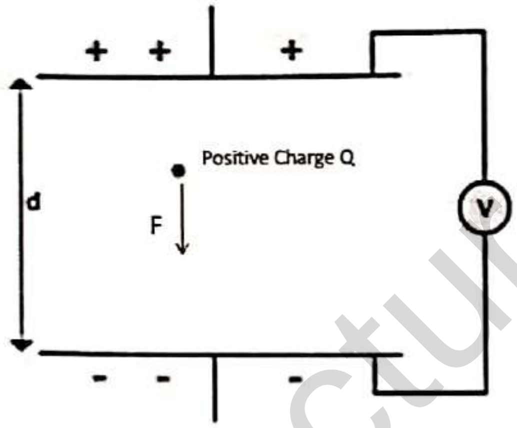
Unit of Electric Field Strength

The unit of Electric field strength for the equation $E = \frac{F}{Q}$ is given by $N\ C^{-1}$

where force is measured in Newtons and charge in Coulombs.

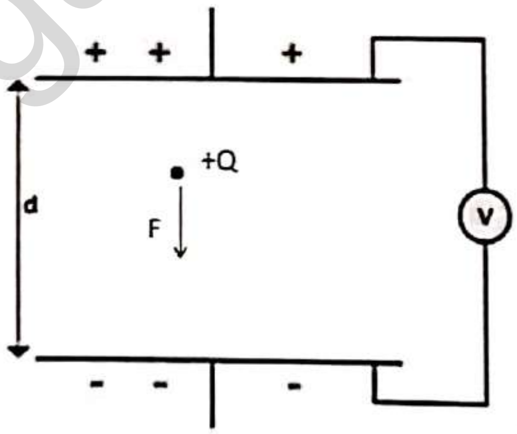
The field strength (E) of the uniform field between charged parallel plates in terms of potential difference (V) and separation (d)

Note:
Remember, later we shall see that there is another common SI unit for electric field strength Vm^{-1} . However the 2 units are equivalent.



The field strength of the uniform field between charged parallel plates in terms of potential difference and separation.

The figure illustrates parallel plates at a distance d apart with a potential difference V between them. A charge +Q in the uniform field between the plates has a force F acting on it. To move the charge towards the positive plate would require work to be done on the charge.



Work done is given by the product of force and distance. To move the charge from one plate to other requires work W and is given by W = Fd, where F is force and d is the distance. Now lets see what is potential difference.

So what is potential difference?

If the electric field is NOT UNIFORM, it is not so simple to calculate the energy change due to moving a charge in the field. It is therefore useful to define a quantity which describes the work done in moving unit charge from one point in the field to another point. We call this quantity the POTENTIAL DIFFERENCE between the two points and is given by $V = \frac{W}{Q}$ V is the symbol for potential difference, which has units of JOULES PER COULOMB, (JC^{-1}). As this is an important quantity, it is given its own unit, the VOLT, (V). "One volt is the potential difference between two points in an electric field such that one joule of work is done in moving one coulomb of charge from one point to another."

By rearranging equation on potential difference, work done W = VQ Thus W = Fd = VQ $\frac{F}{Q} = \frac{V}{d}$

But is the force per unit charge and this is the definition of electric field strength. Thus, for a uniform field, the field strength E given by E = $\frac{V}{d}$

For parallel plates separated by a distance d, with a potential difference ΔV, the uniform electric field within the plates has strength:

$$E = \frac{\Delta V}{d}$$

We sometimes use an alternate unit for E.

$$E = \frac{\text{Voltage}}{\text{distance}}$$

$$= \frac{\text{Volts}}{\text{metre}}$$

$$= Vm^{-1}$$

Calculate the forces on charges in uniform electric fields.

$$\frac{F}{Q} = \frac{V}{d}$$

$$E = \frac{V}{d}, E = \frac{\Delta V}{d}$$

Sample problem 1: Calculate E

Two parallel plates separated by **0.1m** have a potential difference **ΔV = 100V**. What is the Electric Field strength between the plates?

$$E = \frac{\Delta V}{d}$$

$$= \frac{100V}{0.1m}$$

$$= 1000 Vm^{-1}$$

Sample problem 2: Calculate E and F

Two metal plates 5.0cm apart have a potential difference of 1000 V between them. Calculate:

(a) The strength of the electric field between plates.

(b) The force on a charge of 5.0 nC between the plates.

Solution :

(a) $E = \frac{V}{d}, E = \frac{1000}{0.05} = 2.0 \times 10^4 Vm^{-1}$

(b) $F = EQ$, $F = 2.0 \times 10^4 \times 5.0 \times 10^{-9} = 1.0 \times 10^{-4} N$

The effect of a uniform electric field on the motion of charged particles

Energy Changes in Electric Fields

Consider the movement of a charge in a uniform electric field;

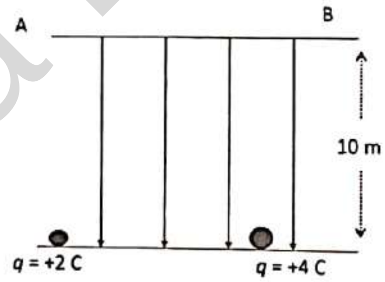
To lift a charge towards the top (positive) plate we exert an external force; Therefore, Work Done by external Force is:

$$W = F_{ext} \times d$$

$$= EQ.d \quad (\text{since } E = \frac{V}{d})$$

$$= \frac{V}{d} \times Q \times d \quad (\text{since } E = \frac{V}{d})$$

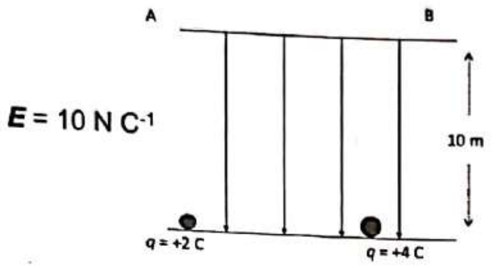
$$W = QV$$



$E = 10\ N\ C^{-1}$

Sample problem 3:

Calculate the Work done The work done on each charges are :



w = QEd

= 2 x 10 x 10

= 200J

w = QEd

= 4 x 10 x 10

= 200J

Sample problem 3 : Calculate V

We define the Work done (in moving charge from one position to another) per unit charge as the change in potential or potential difference, V.

$$V = \frac{W}{q}$$

Taking the data of W from previous sample problem, calculate V.

+2 C Charge,

$$V = \frac{200J}{2C}$$

= 100 JC^{-1}

+4C Charge,

$$V = \frac{400J}{4C}$$

= 100 JC^{-1}

Electron Volt

Work done when a charge of one electron moves through a potential difference of 1 V is one electron volt (e.V).The equivalent energy is:

Since W = QV

Q = 1.6 x 10^{-19}C,

and 1V = 1J C^{-1}

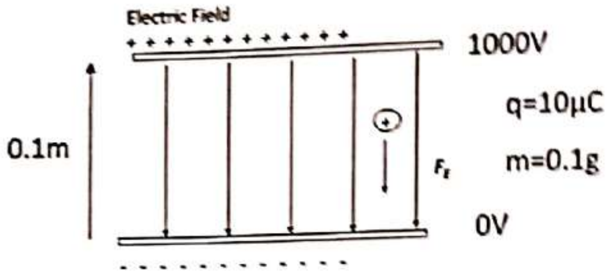
hence 1eV

= 1.6 x 10^{-19} C x 1J C^{-1}

1 eV = 1.6 x 10^{-19}

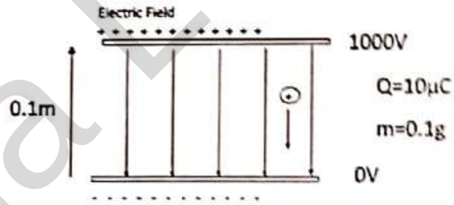
Motion in an Electric Field Find the velocity using Equations of Motion (with sample problem)

Consider a positive charge placed in a uniform electric field, as shown in the diagram below.



Find the velocity of the charge after it has travelled a distance of 5 cm. Use the following information:

$$E = \frac{V}{d}$$
$$= \frac{1000}{0.1} = 1\times10^4 Vm^{-1}$$
$$= 1\times10^4 NC^{-1}$$
$$F = QE$$
$$= 10\times10^{-6}\times1\times10^4$$
$$= 10^{-1} N$$



$$a = \frac{F}{m}$$
$$= \frac{10^{-1}}{10^{-4}} = 10^3 ms^{-2}$$

Can use the equations of motion to determine the speed of particle after travelling for 5cm.

$v_1 = 0ms^{-1}$ $d = 0.05m$ $a = 10^3 ms^{-2}$ $v_2 = ?$

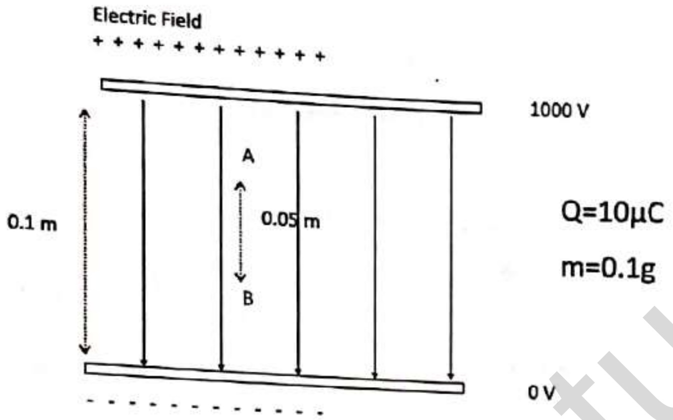
$$v_2^2 - v_1^2 = 2as$$
$$v_2^2 = 2as\left(v_1 = 0ms^{-1}\right)$$
$$v_2 = \sqrt{2as}$$
$$v_2 = \sqrt{2\times10^3\times0.05}$$
$$v_2 = 10ms^{-1} \text{ towards the } -\text{'ve plate}$$

Motion in an Electric Field Find the velocity using Change in K.E (with sample problem)

Can also determine the velocity by using the change in kinetic energy of the particle.

$$E = \frac{\Delta V}{d}$$

$$= 10000 Vm^{-1}$$



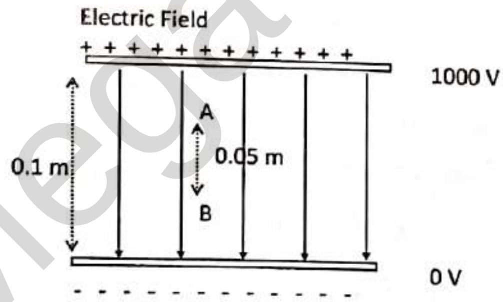
To find the potential difference between A and B, rearrange the equation,

$$E = \frac{\Delta V}{\Delta s}$$

$$\therefore \Delta V = E\Delta s$$

$$\therefore \Delta V = 10000 Vm^{-1} \times 0.05 m$$

$$\therefore \Delta V = 500 V$$



Q=10μC

m=0.1g

Now calculate the kinetic energy at point B. If the charge is released at rest,

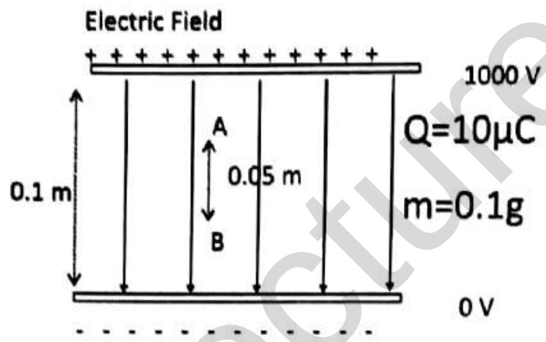
K.E at B (Gain in K.E) = P.E lost

$$\frac{1}{2}mv^2 = q\Delta V$$

$$\therefore v = \sqrt{\frac{2q\Delta V}{m}}$$

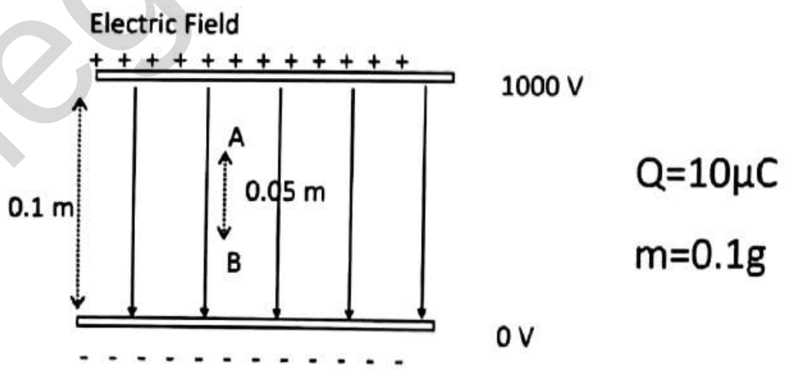
$$= \sqrt{\frac{2\times(10\times10^{-6})\times500}{10^{-4}}}$$

$10ms^{-1}$ towards the −'ve plate

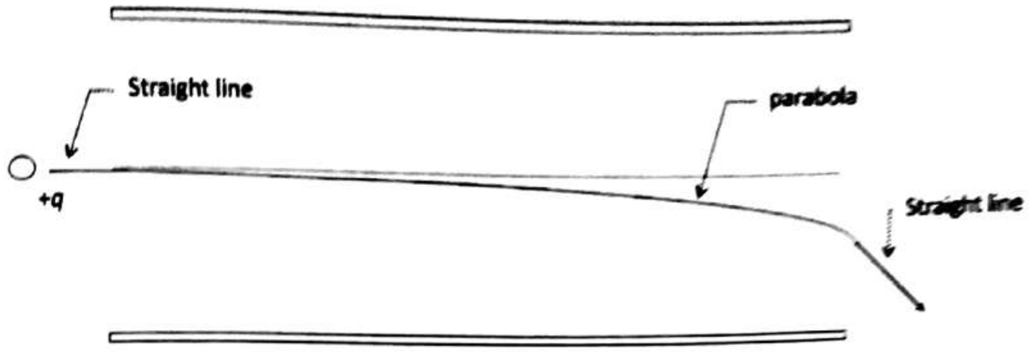


The work done by the field on the charge can be calculated easily because it is equal to the gain in kinetic energy by the charge.

$$\Delta E_k = W = q\Delta V$$
$$= 10^{-5}\times500$$
$$= 5\times10^{-3}$$
$$= 5mJ$$



For a charge that enters the Electric Field...



Horizontal Component of the velocity (H component)

$v_h = v_{1h} = v_{2h}$ horizontal velocity is constant

$v_h = \frac{L}{\Delta t}$ so $\Delta t = \frac{L}{v_h}$

$a = 0$ as $\Delta v = 0$

Vertical Component of the velocity (v component)

As it is initially travelling horizontally,

$v_{y1} = 0$ m/s

Where v_{y1} is initial vertical velocity and v_{y2} is final vertical velocity

$$\text{Now } a_v = \frac{F}{m} = \frac{QE}{m}$$

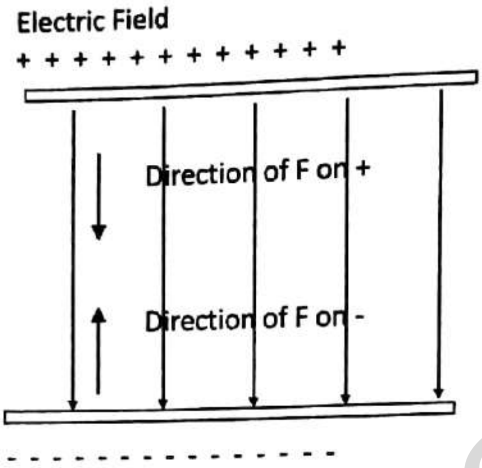
$$\text{And, } v_{y2} = a\Delta t$$

$$= \frac{QE}{m}\frac{L}{v_x}$$

$$\text{So, } \Delta s_v = \frac{1}{2}a_v\left(\frac{L}{v_x}\right)^2$$

$$\therefore \Delta s_v = \frac{1}{2}a_v\frac{L^2}{v_x^2}$$

The direction of the force in an electric field



The direction of the force depends on the charge on the particle.

Assumptions (just for your info only)

- Ignore fringe effects (i.e. assume that the field is completely uniform).
- Ignore gravity (the acceleration due to gravity is insignificant compared with the acceleration caused by the electric field).
- For a charge that enters the field
- Before entering electric field, the charge follows a straight line path (no net force).
- As soon as it enters the field, the charge begins to follow a parabolic path (constant force always in the same direction).
- As soon as it leaves the field, the charge follows a straight line path (no net force).

Current Electricity

Recap……

Types of electricity

Current Electricity: Net flow of charges in a certain direction

Static Electricity: No net flow of charges in a certain direction

Matter can be classified into 3 types according to their electrical properties:

Conductors – Materials which have mobile charge carriers, mainly electrons and ions which will drift to constitute an electric current under the effect of an applied electric field. Hence they can conduct electricity.

Examples include metals and electrolyte solutions.

Insulators – Materials which have no mobile charge carriers that can drift under the effect of an applied electric field. Hence they cannot conduct electricity. Examples include rubber, wood and plastic.

Semiconductors – Materials which have intermediate electrical conductivity which vary substantially with temperature. Examples include Germanium, Silicon.

Show an understanding that electric current is the rate of flow of charged particles.

All matter is made up of tiny particles called atoms, each consisting of a positively charged nucleus with negatively charged electrons moving around it. Charge is measured in units called coulombs (C). The charge on an electron is -1.6×10^{-19} C. Normally atoms have equal number of positive and negative charges, so that their overall charge is zero. For some atoms, it is relatively easy to remove an electron, leaving an atom with an unbalanced number of positive charges. This is called positive ion.

Atoms in metals have one or more electrons which are not held tightly to the nucleus. These free (or mobile) electrons wander at random throughout the metal. But when a battery (or source) is connected across the ends of the metal, the free electrons drift towards the positive terminal of the battery (or source) producing an electric current.

The size of the electric current is given by the rate of flow of charge and is measured in units called amperes with symbol A. A current of 3 amperes means that 3 coulombs pass a point in the circuit every second. In 5 seconds, a total charge of 15 coulombs will have passed the point.

Charge is quantised

Because electric charge is carried by particles, it must come in amounts which are multiples of e. So, for example, 3.2×10^{-19}C is possible, because this is +2e, but 2.5×10^{-19} C is impossible, because this is not an integer multiple of e. We say that charge is 'quantised'; this means that it can only come in amounts which are integers multiples of the elementary charge. If you are studying chemistry, you will know that ions have charges of ±e, ±2e, etc. The only exception is in the case of the fundamental particles called quarks, which are the building blocks from which particles such as protons and neutrons are made. These have charges of or ±e. However, quarks always appear in twos or threes in such a way that their combined chargeis zero or a multiple of e.

An equation for current

Copper, silver and gold are good conductors of electric current. There are large numbers of conduction electrons in a copper wire- as many conduction electrons as there are atoms. The number of conduction electrons per unit volume (e.g. in 1 m^3 of the metal) is called the number density and has the symbol n. For copper, the value of n is about $10^{29} m^{-3}$.

Figure 9.9 shows a length of wire, with cross-sectional area A, along which there is a current *I*. How fast do the electrons have to travel? The following equation allows us to answer this question:

$$I = nAvq$$

Here, v is called the mean drift velocity of the electrons and q is the charge of each particle carrying the current. Since these arc usually electrons, we can replace q by e, where e is the elementary charge. The equation then becomes:

$$I = nAve$$

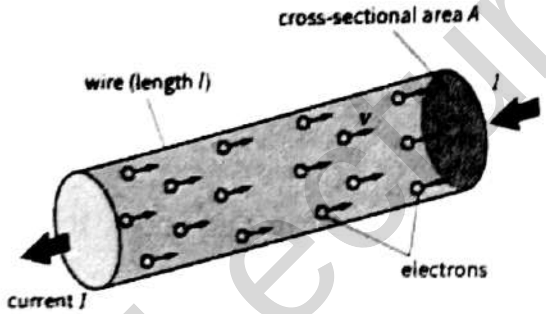


Figure 9.9 A current *I* in a wire of cross-sectional area *A*. The charge carriers are mobile conduction electrons with mean drift velocity *v*.

Deriving *I* = nAve

Look at the wire shown in Figure 9.9. Its length is l. We imagine that all of the electrons shown travel at the same speed v along the wire.

Now imagine that you are timing the electrons to determine their speed. You start timing when the first electron emerges from the right-hand end of the wire. You stop timing when the last of the electrons shown in the diagram emerges. (This is the electron shown at the left hand end of the wire in the diagram.) Your timer shows that this electron has taken time f to travel the distance *l*.

In the time t, all of the electrons in the length *l* of wire have emerged from the wire. We can calculate how many electrons this is, and hence the charge that has flowed in time t:

number of electrons = number density x volume of wire

= n x A x l

Charge of electrons = number x electron charge

= n x A x l x e

We can find the current I because we know that we can find the current I because we know that this is the charge that flows in time t, and current = charge/time:

$$I = n \times A \times l \times e/t$$

Substituting v for l / t gives

$$I = nAve$$

The moving charge carriers that make up a current are not always electrons. They might, for example, be ions (positive or negative) whose charge q is a multiple of e.

Hence we can write a more general version of the equation as

$$I = nAvq$$

Worked example 3 shows how to use this equation to calculate a typical value of v.

WORKED EXAMPLE

3 Calculate the mean drift velocity of the electrons in a copper wire of cross-sectional area $5.0 \times 10^{26}\ m^{-3}$ carrying a current of 1.0 A. The electron number density for copper is $8.5 \times 10^{28}\ m^{-3}$.

Step1 Rearrange the equation I = nAve to make v the subject:

$$v = \frac{I}{nAe}$$

Step 2 Substitute values and calculate v:

$$v = \frac{1.0}{8.5 \times 10^{28} \times 5.0 \times 10^{-6} \times 1.6 \times 10^{-19}}$$

$$= 1.47 \times 10^{-5}\ ms^{-1}$$

$$= 0.015\ mms^{-1}$$

Slow flow

It may surprise you to find that, as suggested by the result of Worked example 3, electrons in a copper wire drift at a fraction of a millimetre per second. To understand this result fully, we need to closely examine how electrons behave in a metal. The conduction electrons are free to move around inside the metal. When the wire is connected to a battery or an external power supply, each electron within the metal experiences an electrical force that causes it to move towards the positive end of the battery. The electrons randomly collide with the fixed but vibrating metal ions. Their journey along the metal is very haphazard. The actual velocity of an electron between collisions is of the order of magnitude $10^5\ ms^{-1}$ but its haphazard journey causes it to have a drift velocity towards the positive end of the battery. Since there are billions of electrons, we use the term mean drift velocity v of the electrons.

Figure 9.10 shows how the mean drift velocity of electrons varies in different situations. We can understand this using the equation:

$$v = \frac{I}{nAe}$$

If the current increases, the drift velocity v must increase. That is:

$$v \propto I$$

If the wire is thinner, the electrons move more quickly for a given current. That is:

$$v \propto \frac{1}{A}$$

There are fewer electrons in a thinner piece of wire, so an individual electron must travel more quickly. In a material with a lower density of electrons (smaller n), the mean drift velocity must be greater for a given current.

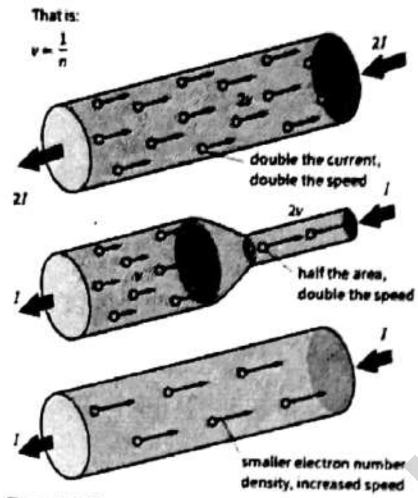


Figure 9.10 The mean drift velocity of electrons depends on the current, the cross-sectional area and the electron density of the material.

It may help you to picture how the drift velocity of electrons changes by thinking about the flow of water in a river. For a high rate of flow, the water moves fast – this corresponds to a greater current I. If the course of the river narrows, it speeds up - this corresponds to a smaller cross sectional area A. Metals have a high electron number density – typically of the order of 10^{28} or $10^{29}m^{-3}$ Semiconductors, such as silicon and germanium, have much lower values of n perhaps 1023m \ In a semiconductor, electron mean drift velocities are typically a million times greater than those in metals for the same current. Electrical insulators, such as rubber and plastic, have very few conduction electrons per unit volume to act as charge carriers.

Electric current

Electric current is the rate of flow of electric charge. Mathematically, $I = \frac{Q}{t}$ where I is the electric current (unit: ampere, symbol: A); Q is the electric charge (unit: coulomb, symbol: C); t is the time taken (unit: second, symbol: s)

Charge & Coulomb

From the definition of electric current $I = \frac{Q}{t}$ we obtain, Q = It. Electric charge flowing through a section of a circuit is the product of the electric current and the time that it flows.

Q = It, substituting in units we obtain the following :

1 C = (1 A) (1 s) = 1 A s

One coulomb is the quantity of electric charge that passes through a section of a circuit when a steady current of one ampere flows for one second.

Solve problems using the equation Q = It

Example 1

Given that the electric current flowing through a circuit is 0.76 mA, calculate the electric charge which passes each section of the circuit over a time of 60 s.

Solution:

$[Q = It]$

$Q = (0.76 \times 10^{-3})(60) = 0.0456 = 4.56 \times 10^{-2} C$

Solve problems using the equation Q = It

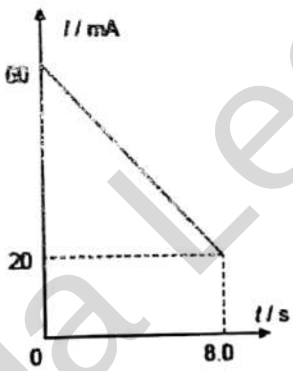
Example 2

Over a time of 8.0 s, the electric current flowing through a circuit component is reduced uniformly from 60 mA to 20 mA. Calculate tlhe charge that flows during this time.

Solution

Charge = area under current – time graph

$$= \frac{1}{2}(8.0)(60 + 20)(10^{-3}) = 0.32 \text{ C}$$



Resistance and Ohm

Ohm's Law states that the current through the conductor is directly proportional to the potential difference between its ends provided its temperature and other physical conditions remain constant.

Mathematically

$I \propto V \Rightarrow V = RI \Rightarrow R = \frac{V}{I}$

The proportionality constant R in the equation is the electrical resistance of the device It is constant for a metallic conductor under steady physical conditions. Materials which obey Ohm s law are called ohmic conductors. Resistance of a conductor is defined as the ratio of the potential difference across it to the current flowing through it.

From $R = \frac{V}{I}$, $1\ \Omega = 1\ V\ A^{-1}$ defines the ohm.

The ohm is the resistance of a conductor if a current of one ampere flows through when there is a potential difference of one volt across it.

Solve problems using P = VI, P = I²R, V= IR

Example 5

A 12 V 24 W bulb is connected in series with a variable resistor and a 18 V battery of negligible internal resistance. The variable resistor is adjusted until the bulb operates at its normal rating.

Determine

(i) the current in the bulb

(ii) the resistance of the bulb

(iii) the p.d. across the variable resistor:

(iv) the power dissipation in the variable resistor.

Solution:

(i)
P = VI
24 = (12)I
I = 2.0 A

(ii)
V = IR
12 = (2.0)R
R = 6.0Ω

(iii) P.d across variable resistor = 18 – 12 = 6.0 V

(iv) P = VI = (6.0)(2.0) = 12 W

Resistance & Resistivity

The resistance R of a sample is directly proportional to its length l and inversely proportional to its cross-sectional area A.

$$R \propto \frac{l}{A}$$

The relationship could be expressed as an algebraic equation by introducing a constant of proportionality as follows:

$$R = \frac{\rho l}{A}$$

The constant ρ is now recognised as a property of the material and is called its resistivity Hence

$$\rho = \frac{RA}{l}$$

where ρ is the resistivity of the material, in Ω m

R is the resistance of the sample, in ohms (Ω)

A is the cross-section area of the sample, in m^2

l is the length of the sample, in metres (m)

Resistivity is useful when comparing various materials on their ability to conduct electricity A high resistivity means a sample of the material is a poor conductor. A low resistivity means a sample of the material is a good conductor.

Resistivity

Resistivity is defined as the electrical property of a material that determines the resistance of a piece of given dimensions. It is equal to $\rho = \frac{RA}{l}$ where R is the resistance, A the cross-sectional area, and l the length, and is the reciprocal of conductivity. It is measured in ohm metres. It is denoted by the symbol ρ.

Solve problems using $R = \frac{\rho L}{A}$

Example 6

The resistivity of a material is 3.1 x 10-5 Ω m. Determine the resistance of a sample of the material given that its length is 20 cm and its cross-section area is 2.0 mm^2.

Solution:

$$R = \frac{\rho l}{A} = \frac{(3.1 \times 10^{-5})(0.20)}{(2.0)(0.001)^2} = 3.1\Omega$$

Potential difference and Volt

Defining p.d in terms of energy: The potential difference between two points in a circuit is defined as the electrical energy converted to other forms of energy per unit charge passing between the two points. Alternatively, defining p.d in terms of power The p.d. between two points in a circuit is defined as the rate of conversion of electrical energy to other forms of energy per unit current flowing between the two points.

In terms of energy:

$$\text{potentail difference (p.d)} = \frac{\text{energy converted}}{\text{charge}}$$

$$\text{hence } V = \frac{W}{Q} \text{ or } W = QV$$

In terms of power:

$$\text{Potential difference (p.d.)} = \frac{\text{power converted}}{\text{current}}$$

$$\text{hence } V = \frac{P}{I} \text{ or } P = VI$$

Where V is the p.d, in volts (V)
W is the energy converted, in joules (J)
Q is the electric charge moved, in coloumbs (C)
P is the power converted, in watts (W)
I is the electric current flowing, in amperes (A)
Since V = IR from learning outcome (h), $P = I^2R$.

From $V = \frac{W}{Q}$, $1V = 1 J C^{-1}$ defines the volts (in terms of energy)

The volt is the potential difference between two points in a circuit if one joule of electrical energy is converted to other forms of energy when one coulomb of charge passes between the two points.

Alternatively, from P = VI, 1 V = 1 W A^{-1} defines the volt (in terms of power).

The volt is the potential difference between two points in a circuit if one watt of electrical power is converted to other forms of power when one ampere of current passes between the two points.

Note:

Since the unit for p.d. is volt, p.d. is frequently called voltage.

The p.d. can only be used if the two points are stated clearly. For a single circuit component, the two points are usually the two ends of the component hence the p.d. across the component.

Sometimes the term "potential at a point" in a circuit is used. This has meaning only if there is a defined reference point for zero potential e.g. the electrical earth has zero potential.

Just for your info: The real Earth is electrically neutral. This means that it has the same number of electrons and protons, so their charges cancel out overall. Scientifically, we describe this by saying that the Earth has an Electric Potential of zero.

Solve problems using $V = \frac{W}{Q}$

Example 4

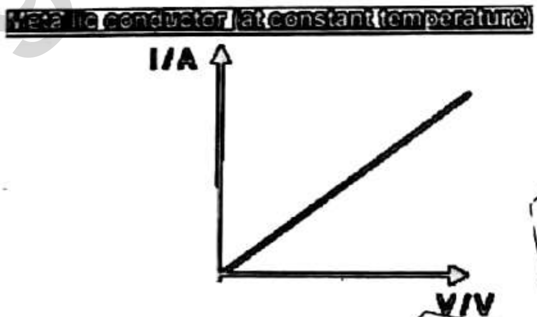
An immersion heater is rated at 3000 W and is switched on for 2000 s. During this time a charge of 25 kC is supplied to the heater. Determine the potential difference across the heater.

Solution:

$$V = \frac{W}{Q} = \frac{(3000)(2000)}{25000} = 240\ V$$

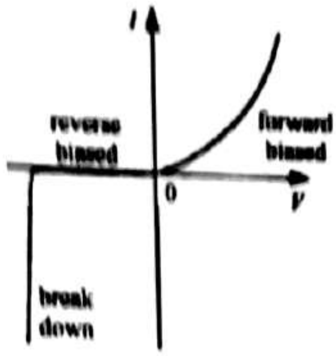
Sketch and explain the I-V characteristics of a metallic conductor at constant temperature, a semiconductor diode and a filament lamp.

1) Metallic conductor at constant temperature



The I-V characteristic of a metallic conductor at constant temperature is a straight line through the origin. This implies constant I-V ratio, i.e. constant resistance Therefore a metallic conductor at constant temperature is an ohmic conductor. In terms of the movement of charge carriers, resistance in metallic conductors arises from the reduction in the drift velocity of free electrons due to collision with lattice ions. If the temperature of the conductor is kept constant, the lattice ion vibrations will remain the same hence its resistance will remain the constant. In short, the resistance of a metallic conductor is constant at constant temperature (ohmic conductor).

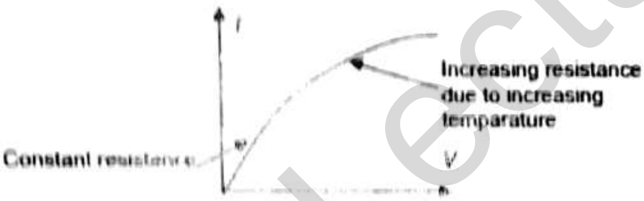
2) Semiconductor diode



A diode is a device that has a low resistance in one direction (forward-biased direction) and a very high resistance in the other direction (reverse-biased direction). The I - V characteristic of a forward-biased semiconductor diode is similar to that of a thermistor, i.e. resistance decreases as p.d. increases

The I - V characteristic of a reverse-biased semiconductor diode is nearly zero if reverse-biased p.d. is too high, the diode will break down and conduct electricity

3) Filament lamp



A filament lamp contains a long thin wire made of metal with high melting point (eg. tungsten). With low p.d. across the filament lamp, low current flowing through it and the heating effect is insignificant hence the resistance is fairly constant. As the p.d. across a filament lamp increases, current increases. Heating effect is significant resulting in temperature increase. The resistance of metals increases with temperature. Hence, decreasing I-V gradient. In terms of the movement of charge carriers, the lattice ion vibrations will be more at higher temperature. There will be more reduction in the drift velocity of electrons due to collision with lattice ions hence current will be lower and resistance will be higher.

In short, the resistance of a filament lamp increases as the p.d applied across it increases.

E.M.F in terms of the energy transferred by a source in driving unit charge round a complete circuit

Movement of charge carriers is possible only if they possess energy and are allowed to dissipate their energy. Sources like batteries and generators provide the energy to the charge carriers. Available path(s) for charge carriers to dissipate their energy cause their movement. Defining in terms of energy: The electromotive force (e.m.f.) of a source is defined as the non-electrical energy convened to electrical energy per unit charge driven through the source. Defining in terms of power:

The electromotive force (e.m.f.) of a source is defined as the non electrical power converted to electrical power per unit current delivered by the source. The SI unit of e.m.f. is same as that of potential difference, i.e. the volt. (Recall that 1 V = 1 J C1 or 1 W A⁻¹)

Mathematically $E = \frac{W}{Q}$ or $E = \frac{P}{I}$

where E is the e.m.f. of the source, in volts (V)

W is the energy converted, in joules (J)

Q is the electric charge moved, in coulombs (C)

P is the power converted, in watts (W)

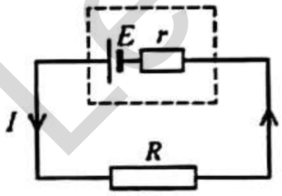
I is the electric current delivered, in amperes {A)

Examples include:

In a battery, chemical energy converted to electrical energy through chemical reactions. In a generator, mechanical energy {in the form of rotational kinetic energy) is converted to electrical energy

Distinguish between e.m.f. and p.d. in terms of energy considerations

The electromotive force (e.m.f.) of a source is defined using the non-electrical energy converted to electrical energy while the potential difference (p.d.) between two points is defined using electrical energy converted to non-electrical energy. The effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power In practice, no energy souce (battery or generator) perfect. Some of the electrical energy delivered by a source is always dissipated within itself. The source is said to have internal resistance. When the external load is large, the internal resistance has negligible effect. When the external load is not large, the internal resistance can be depicted as a series resistor within the source as shown in the diagram in next slide.



The energy delivered by the source is then shared between its internal resistance and external load,

i.e. energy supplied = energy dissipated (external + internal)

$EIt = I^2Rt + I^2rt$

$E = IR + Ir$

$E = I(R + r)$

The terminal p.d. is the potential difference across the source. It is equivalent to the potential difference across the external circuit. Hence terminal p.d. is V- IR - E - Ir

where V\s the terminal p.d., in volts (V) E is the e.m f. of the source, in volts (V) I is the electric current delivered, in amperes (A) R is the resistance of the external circuit in ohms (Q) r is the internal resistance of the source, in ohms (Q)

It can be deduced that when the source is connected to an external circuit, the terminal p.d. of the source is reduced by the amount Ir. When the current I through the source is zero (such as when the external circuit is open) then terminal p.d. 1/ will be equal to the e.m.f E

Alternatively, viewing in terms of power, the power delivered by the source is shared between its internal resistance and external load, i.e power supplied = power dissipated (external + internal).

$$P_E = P_R + P_r$$

$$EI = I^2R + I^2r$$

The power dissipated internally ($Pr = I^2r$) is wasted in heating up the energy source Only the power that is dissipated externally ($PR = I^2R$) is available to the external circuit so the efficiency of the source is always below 100%

Show an understanding of the effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power.

Example 7

A battery of e.m.f. 12 V and internal resistance 0.014 Ω delivers a 2.0 A current when first connected to a motor. Calculate the resistance of the motor.

Solution:

$$E = I(R + r) = 12 = 2.0(R + 0.014) = R = 5.99\ \Omega$$

D.C Circuits

Types of electricity

Current Electricity: Net flow of charges in a certain direction

Types of electric current

Direct Current (D.C.):

Flow of charges in the circuit is in the same direction all the time, from a higher potential to a lower potential (e g. current from battery)

Alternating Current:

Flow of charges in the circuit reverses direction at regular intervals (e.g. current from household mains) Electric circuits consist of circuit components (e g batteries, resistors, and switches) connected by conductors (e.g. copper cables). For electric current to flow, the circuit components and conductors must form closed loops. There must also be sources of electrical energy (e.g. batteries) and sinks of electrical energy among the circuit components (e.g. resistors and lamps).

> **Note :** This chapter includes only D.C. In AS syllabus A.C is not included.

Electrical Circuit Symbols

Circuit symbols:

Electrical circuits use a lot of components and when circuits are drawn their symbols are used the following are the standered symbols used in circuits:-

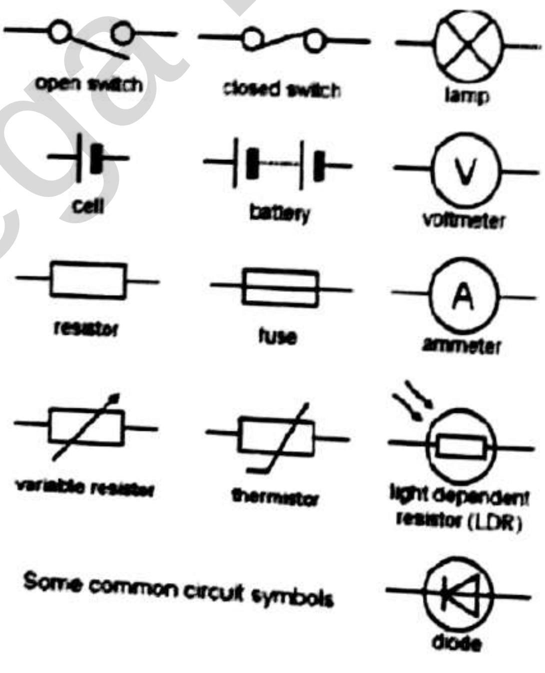
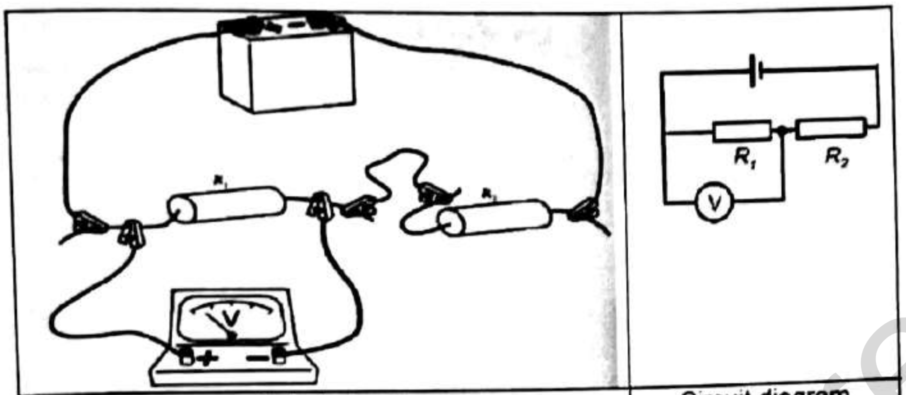


Figure : Symbols of common circuit elements

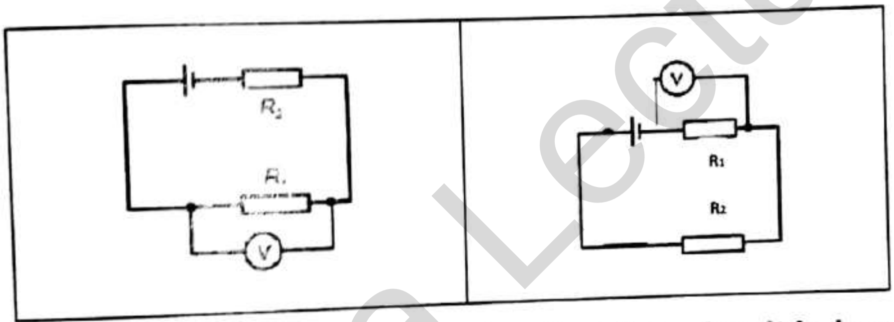
Draw and interpret circuit diagrams containing sources, switches, resistors, ammeters, voltmeters, and/or any other type of component

Note that, for a certain electric circuit, there are different ways of drawing its circuit diagram

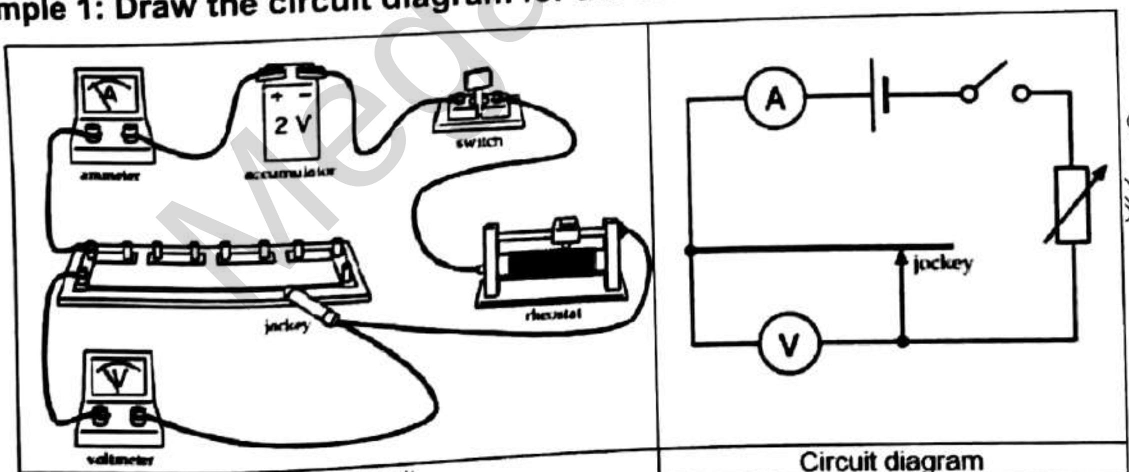


Actual circuit | Circuit diagram

Two other possible circuit diagrams for the above electric circuit are as follows:



Example 1: Draw the circuit diagram for the electrical circuit below



Actual circuit | Circuit diagram

COMBINATION OF RESISTORS- RESISTANCE IN SERIES AND PARALLEL

Resistors connected in Series

The figure below shows 3 resistors connected in series to an Ideal battery (no internal resistance) Connection in series means the resistors are wired one after the other and the potential difference V is applied across the ends of the whole series.

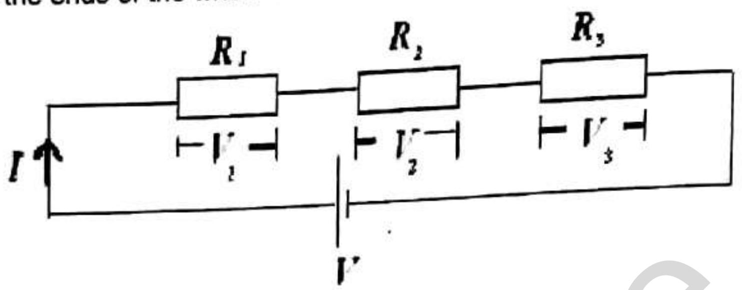


Figure Resistors in series-Note the current through ah the resistors is the same but voltage is not When a potential difference V is applied across the series the current through all the resistors is the same, but the potential difference across each resistor is different and the sum of these individual

Potential Difference is equal to the applied potential difference V

$$V_1 = IR_1$$

$$V_2 = IR_2$$

$$V_3 = IR_3$$

$$V = V_1 + V_2 + V_3$$

$$V = IR_1 + IR_2 + IR_3$$

$$V = I(R_1 + R_2 + R_3)$$

$$\frac{V}{I} = R_{eq} = R_1 + R_2 + R_3$$

Hence the equivalent resistance of a series combination is given by:

$R_{eq} = R_1 + R_2 + R_3$

In general if there are n resistors connected in series then

$R_{eq} = R_1 + R_2 + R_3 ..... R_n$

IN SERIES

The resistors connected in series can be replaced by an equivalent resistor R_{eq}

R_{eq} has the same currentl as the individual resistors

Two resistors are said to be connected series if current can flow from one resistor to another without branching

Resistors connected in Parallel

The figure below shows 3 resistors connected in parallel to all Ideal battery (no internal resistance) Connection in parallel means the resistors are wired directly together on one side and directly together on the other side and a potential V applied across the connected sides. When resistors are connected in parallel all resistors have the same potential difference V as that of the source, but the current branches out into the P.D, is same but current is not). The total current in the circuit is the sum of the individual currents hence

$$I = I_1 + I_2 + I_3$$

$$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{V}{R_{eq}} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

Cancelling V we get

$$\frac{1}{R_{eq}} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

In general if there are n resistors connected in parallel then:

$$\frac{1}{R_{eq}} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots \frac{1}{R_n}\right)$$

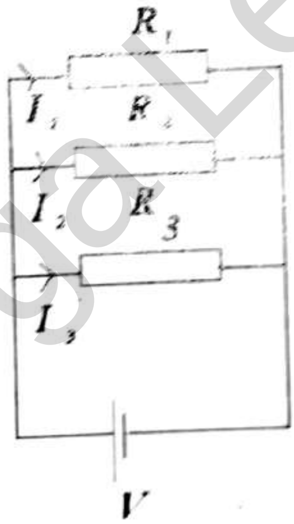


Figure Resistance in Parellel-Note that the current branches out but voltage is the same for all 3 resistors

IN PARALLEL

The resistors connected in Parallel can be replaced by an equivalent resistor R_{eq}. R_{eq} has the same current V as the individual resistors For resistors connected Parallel current in each of them is different but the voltage is the same.

Solve problems using the formula for the combined resistance of two or more resistors in series.

Example 4

Calculate the effective resistance of a 4 Ω and two 3 Ω resistors connected in series

Solution:

$R_{eff} = 4 + (2)(3) = 10\Omega$

Solve problems using the formula for the combined resistance of two or more resistors in parallel.

Example 5

Calculate the effective resistance of a 2 Ω, a 3 Ω and a 4 Ω resistor connected in parallel.

Solution:

$$\frac{1}{R_{eff}} = \frac{1}{2} + \frac{1}{3} + \frac{1}{4} = \frac{6+4+3}{12} = \frac{13}{12}$$

$R_{eff} = 0.903\Omega$

Why the current is the same in all series resistances? And why the voltage is the same in all parallel resistors?

1) In a series circuit of resistors, the same current flows through all the resistors, however potential gets divided according to individual resistance values. Because according to Ohm's law V = I R, and here since I is same, and V is directly proportional to R. Hence the potential will be different across different resistors.

Note

Theoretically, for resistors that have equal resistance, they have same V

2) In the case of parallel combination of resistors, the same potential will exist across every resistor, but now current gets divided in the inverse ratio of resistance values.

(I = V / R) this is also in accordance with Ohm's law.

Conservation of charge:

The net charge of an isolated system remains constant. Charge cannot be created and destroyed, but only in positive-negative pairs. It is not possible to destroy or create charge. * You can cancel out the effect of a charge for neutralize the charge on the body) on a body by

adding an equal and opposite charge to it, but you can't destroy the charge itself.

The following example makes this clear

If a glass rod is rubbed with a silk cloth, due to friction the glass gets charged positively and the silk

Negatively The charging is basically due to the transfer of negative charge(electrons) from the glass to the silk. This experiment suggests that

- Charge is transferred but not created or destroyed.
- The total charge on the Glass silk cloth system remains the same he zero before rubbing and after rubbing.

Gustav Kirchhoff's Junction Rule & Loop Rule The Junction rule And The Loop rule

Kirchhoff's First Law

Kirchhoff's First Law: At any junction in a circuit, the sum of the currents arriving at the junction is equal to the sum of the currents leaving the junction. This is also known as 'junction rule'.

Conservation of Charge and the Kirchhoff's First Law

Kirchhoff's first rule is a statement of conservation of electric charge.

All charges that enter a given point in a circuit must leave that point because charge cannot build up (accumulate) at a point. If this does not happen then charges are getting accumulated at a point or charges are created from nowhere both of which don't happen, In other words - charge is conserved.

The sum of currents meeting at a Junction

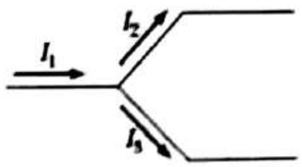


Figure : Current I_1 splits into I_2 and I_3

If we apply this rule to the junction shown in Figure below , we obtain

$$I_1 = I_2 + I_3$$

The law can also be stated as:-The algebraic sum of currents meeting at a junction is zero.

SIGN CONVENTION USED: Currents entering a Junction are taken as positive and currents leaving a junction is taken as negative.

Example- Consider a junction O in an electrical circuit as show below:- Here the currents I₁ and:

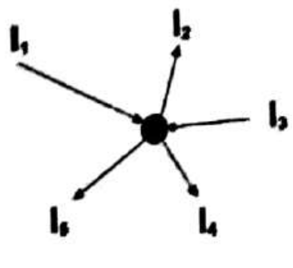


Figure: Currents entering a Junction are taken as positive and currents leaving a junction is taken as negative. is are entering the junction O whereas I_2,I_4 and I_5 leave the junction hence I_1 I_3 are positive and 1%. I_4 and I_5 are negative as the are leaving the junction. Applying the sign convention we get

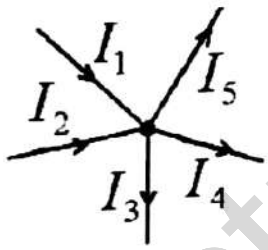
$$I_1 + I_3 - I_2 - I_4 - I_5 = 0$$

Or

$$I_1 + I_3 = I_2 + I_4 + I_5$$

Conservation of charge (must know in order to solve circuit problems)

Given that we are dealing with steady currents (i.e. no accumulation of charge at circuit junctions), the sum of currents entering a circuit junction is equal to the sum of currents leaving it.



$$I_1 + I_2 = I_3 + I_4 + I_5$$

Taking currents entering circuit junction as positive and currents leaving circuit junction as negative, we have:

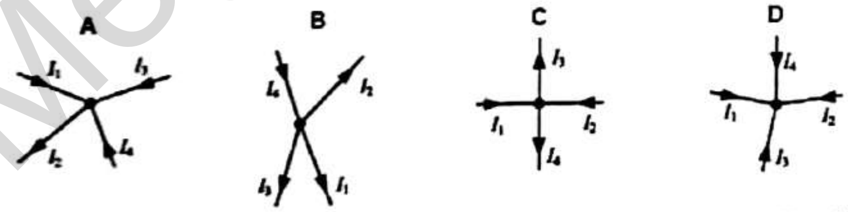
$$I_1 + I_2 - I_3 - I_4 - I_5 = 0$$

Taking currents leaving circuit junction as positive and currents entering circuit junction as negative, we have:

$$I_3 + I_4 + I_5 - I_1 - I_2 = 0$$

Sample problem 1

The given diagrams show wires carrying currents I_1 I_2 1_3, and I_4, meeting at a junction. Which of the following diagrams represents the equation $I_1 + I_2 = I_3 + I_4$?



A: $I_1 + I_3 + I_4 + = I_2$

B: $I_1 + I_2 + I_3 = I_4$

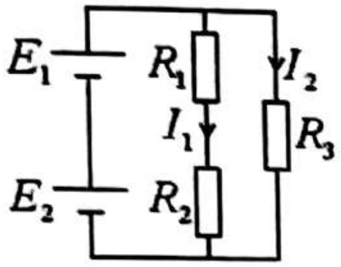
C: $I_1 + I_2 = I_3 + I_4$ (**correct answer**)

D: Impossible, all currents are entering and no current leaving.

Conservation of energy (must know in order to solve circuit problems)

The algebraic sum of e.m.f. (i.e. sources of electrical energy) is equal to the algebraic sum of p.d. (i.e. sinks of energy) for any closed loop within the circuit.

Sample problem 2



Find I_1 and I_2 in terms of E_1, E_2, R_1, R_2 and R_3

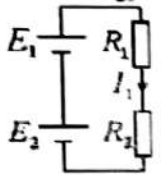
Given that

$E_1 = 3.0$ V
$E_2 = 1.5$ V
$R_1 = R_2 = R_3 = 10\ \Omega$

find the values of I_1 and I_2.

Solution:

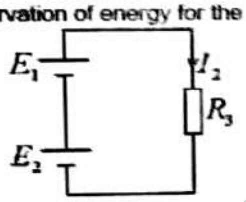
Conservation of energy for the loop.



$$E_1 + E_2 = I_1R_1 + I_1R_2 = I_1(R_1 + R_2)$$

$$I_1 = \frac{E_1 + E_2}{R_1 + R_2}$$

Conservation of energy for the loop.



$$E_1 + E_2 = I_2R_3$$

$$I_2 = \frac{E_1 + E_2}{R_3}$$

Substituting $E_1 = 3.0$ V, $E_2 = 1.5$ V and $R_1 = R_2 = R_3 = 10\ \Omega$,
$I_1 = 0.23$ A and $I_2 = 0.45$ A.

Kirchhoff's Second Law

The algebraic sum of e.m.f is equal to the algebraic sum p.d for any closed loop within the circuit. This is also known as 'Loop rule'.

Conservation of Energy and the Kirchhoff's Second Law

Let us imagine moving a charge around a closed loop of a circuit. When the charge returns to the starting point, the charge circuit system must have the same total energy as it had before the charge was moved. The sum of the increases in energy as the charge passes through some circuit elements must equal the sum of the decreases in energy as it passes through other elements. The potential energy decreases whenever the charge moves through a potential drop -IR across a resistor or whenever it moves in the reverse direction through a source of emf. The potential energy increases whenever the charge passes through a battery from the negative terminal to the positive terminal.

Rules for applying Kirchhoff's Laws for solving problems

Currents are labeled with the assumed sense of direction. The solution is carried out with the assumed sense of direction and if the actual direction of a particular current is opposite to the assumed direction the value of current will emerge with a negative sign.

Choose any closed loop in the given network and designate a direction (clockwise or anticlockwise) to traverse the loop for applying the Kirchhoff's II law.

Go around the loop in the designated direction algebraically adding the potential differences across the resistors (IR Terms) and the source (cells) emfs.

SIGNS:

If a resistor is traversed positive first (the end at which the current enters a resistor is positive) then the IR term is taken as negative, similarly for an emf source (say battery) if the positive is encountered first then the emf is taken as negative. In order to solve a particular circuit problem, the number of independent equations you need to obtain from the two rules equals the number of the number of unknown currents.

Sample problem 3

Find the currents I_1, I_2, and I_3 in the circuit shown in Figure 4 below.

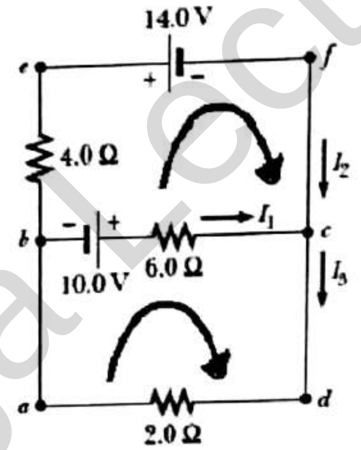


Figure 4: *Example Problem*

Arbitrarily choose the directions of the currents as labeled in Figure 4 Applying Kirchhoff's junction rule to junction c gives

We now have one equation with three unknowns, I_1, I_2. and 1_3. There are three loops in the circuit abcda, befcb, and aefda. Applying Kirchhoff's loop rule to loops abcda and befcjb and traversing these Loops clockwise (shown by curved arrows), we obtain the expressions for the closed loop abcda

$$10.0\ V - (6.0\Omega)\ I_1 - (2.0\Omega)I_3 = 0$$

For the closed loop befcb

$$-14.0\ V + (6.0\Omega)\ I_1 - 10.0\ V - (4.0\Omega)I_2 = 0$$

Which gives

$$(6.0\Omega)\ I_1 - (4.0\Omega)I_2 = 24.0\ V$$

Substituting into Equation $I_1 + I_2 = I_3$ in the equation (2) we get

$$10.0\ V - (6.0\Omega)\ I_1 - (2.0\Omega)\ (I_1 + I_2) = 0$$

solving equations (3) and (4) we get

$$I_1 = 2.0\ A$$

$$I_2 = -3.0\ A$$

$$I_3 = -1.0\ A$$

To finalize the problem, note that /3 and I3 are both negative. This indicates only that the currents are opposite the direction we chose for them. However, the numerical values are correct .

The potential divider circuit (fig.) is one of the most useful circuits. The potential divider arrangement can be used to divide the input voltage(V_S) in the ratio that we want. The circuit diagram for a potential divider arrangement is shown below:

For a potential divider the current through each resistor is the same (why?they are in series, hence).

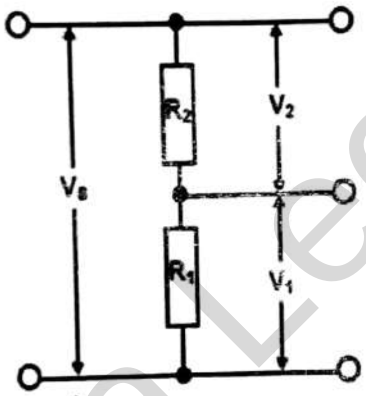


Figure: A potential Divider circuit

The current in the circuit can be found by using the Ohms law and remembering that the total resistance in the circuit is $R_1 + R_2$ we ge

$$I = \frac{V_s}{R_1 + R_2}$$

The voltage across the resistot R_1 is given by:

$$V_1 = IR_1$$

using (9) we get

$$V_1 = IR_1 = \frac{V_sR_1}{R_1 + R_2}$$

Similarly, the voltage across the resistor R_2 is given by:

$$V_2 = IR_2$$

using (9) we get

$$V_2 = IR_2 = \frac{V_sR_2}{R_1 + R_2}$$

The ratio V_1 to V_2 can be found as:

$$\frac{V_1}{V_2} = \frac{R_1}{R_2}$$

Application of Potential Divider Circuits:

Temperature Sensor

A common example of a sensing system is a temperature sensor in a thermostat, which uses a thermistor (A thermistor is a kind of resistor whose resistance decreases as the temperature increases-it is generally made of semiconductors). The thermistor is then used in a potential divider, as in the diagram in fig.8. In this diagram, the potential difference is divided between the resistor and the thermistor. As the temperature rises, the resestance of the thermistor decreases, so the potential difference across it decreases. This means that potential difference across the resistor increases as temperature increases. This is why the voltage is measured across the resistor, not the thermistor. As the source voltage and R are known using the graph below fig.9 the temperature can be found.

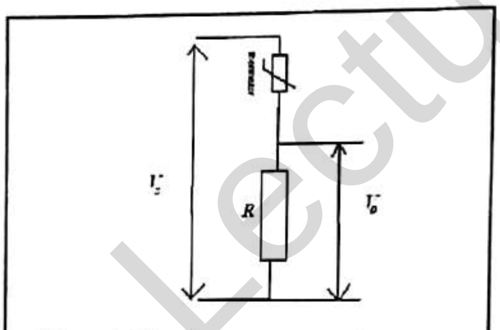


Figure 8: *Thermistor as a temperature sensor*

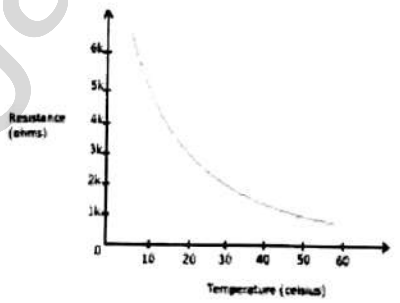


Figure 9: *Temperature Vs resistance for a thermistor*

Light Dependent Resistors: Light-dependent resistors [LDRs] have a resistance which changes in response to changes in light levels, as detected by a photo-sensitive plate on the resistor. Most LDRs have a negative light coefficient - meaning that their resistance falls as the amount of light falling on them increases. LDRs are used in light-detection circuits as shown in the figure below using the same technique as in the measurement of temperature the intensity of light can be measured with the circuit shown below.

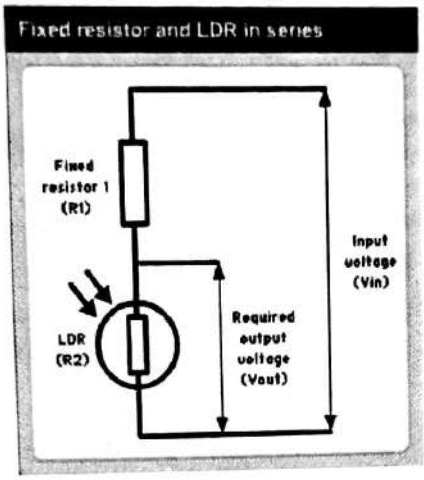


Figure 10: LDR used in a potential divider

Potentiometer

A variable voltage-divider (potentiometer): A variable voltage divider is another form of the potential divider arrangement it is also called the potentiometer. Consider a long piece of high resistance wire AB connected to a battery as shown below:-

Between A and J a voltmeter is connected. The point J is a movable contact as the point j is moved

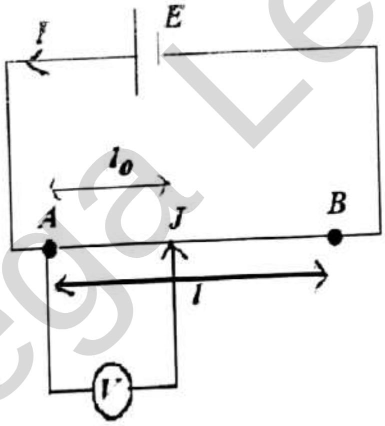


Figure 11: A variable voltage potential divider the potential drop increases.hence by varying the length of AJ the potential can bo varied. Let be the resistivity of the wire AB and let E be Emf of the battery,let l_0 be the length of wire AB and let l be the length AJ then

$$E = IR = I\frac{\rho l}{A}$$

The drop V across the length AJ whose resistance is R_0 is given by

$$V = IR_0 = I\frac{\rho l_0}{A}$$

Dividing the above two equation we get

$$\frac{V}{E} = \frac{l_0}{l}$$

Principle of Potentiometer

POTENTIOMETER:

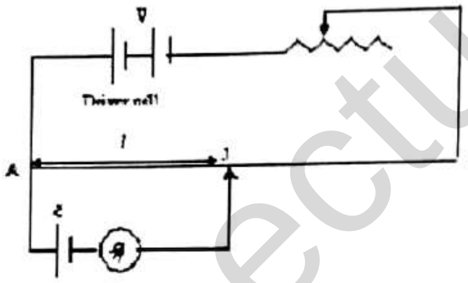
Construction: The potentiometer consists of a long uniform wire usually made of manganin or constantan (high Resistivity low temp coeff of resistance) .The ends of the wire are connected to binding screws A and B. A meter scale is fixed on the board .The potentiometer has jockey J with the help of which contact can be made with the potentiometer wire.

Principle: The fall of potential across any portion of the wire is directly proportional to the length of that portion, if the area of cross section is uniform and the current constant. If I is the constant current through the potentiometer wire and if R is the resistance between the wire between A and J Then:

$$V = IR$$

$$V = I\frac{\rho}{A}l$$

Note :
This equation is going to be used for next application.



$$V = \phi l$$

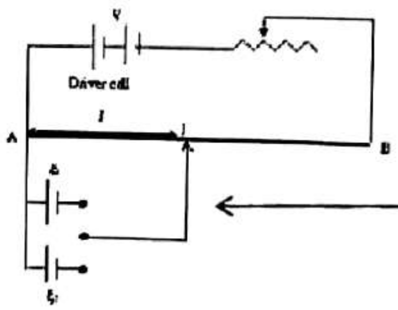
Where $\phi = I\frac{\rho}{A}$, and ϕ is called the potential gradient.

Hence the potential drop across the length of the potentiometer wire is directly pro-portional to the length. This is the principle of the potentiometer.

Note :
The above equation is used for next application.

Potentiometer and its application

Comparison of EMF: The potentiometer can used to compare the emf of two cells with the help of the circuit diagram shown below. Let the emF's of the cells to be compared be ϵ_2 and to let the driver cell potential be V. The cells are connected to the potentiometer through a two way key. First the key



Note :
Galvanometer is connected along with Jockey

put in the two way key such that the cell with emf £i is connected to the circuit.The jockey(movable contact) is moved along the wire till at a point there is no delection in the galvanometer , at a distance l_1 from A.

The EMF of the cell is proportional to the balancing length

$$\epsilon_1 = \phi l_1$$

similarly when the second cell is connected

$$\epsilon_2 = \phi l_2$$

dividing the equations

$$\frac{\epsilon_1}{\epsilon_2} = \frac{l_1}{l_2}$$

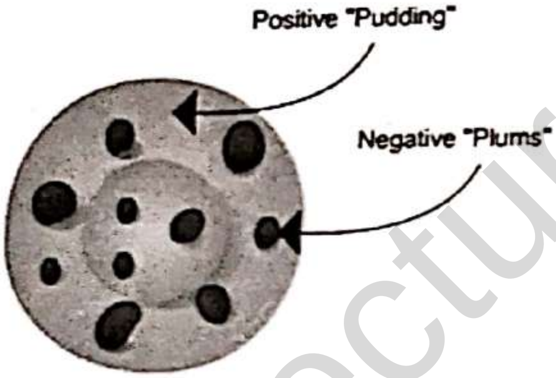
Note:
(i) The Driver cell potential should always be greater than the potential of the cells whose Emf's are compared.
(ii) If one cells emf is accurately known the other cells emf can be determined.

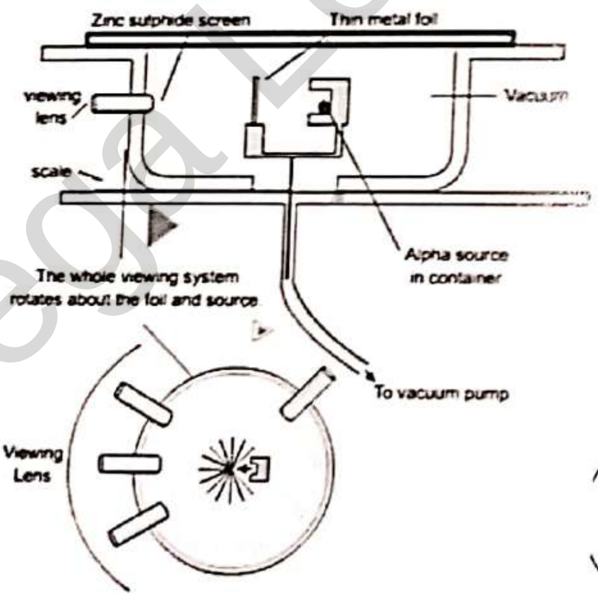
Particle and Nuclear Physics

The results of the α-particle scattering experiment & the existence and small size of the nucleus

Rutherford Alpha Particle Scattering Experiment

Rutherford's alpha particle scattering experiment changed the way we think of atoms. Before the experiment the best model of the atom was known as the Thomson or "plum pudding" model. The atom was believed to consist of a positive material "pudding" with negative "plums" distributed throughout.





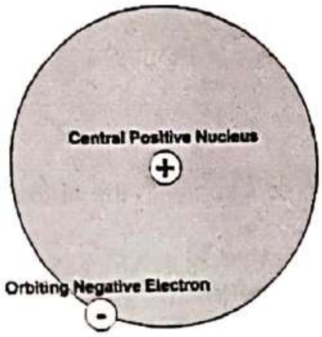
Rutherford directed beams of alpha particles (which are the nuclei of helium atoms and hence positively charged) at thin gold foil to test this model and noted how the alpha particles scattered from the foil.

Note: Diagram is only for your reference, its not in syllabus

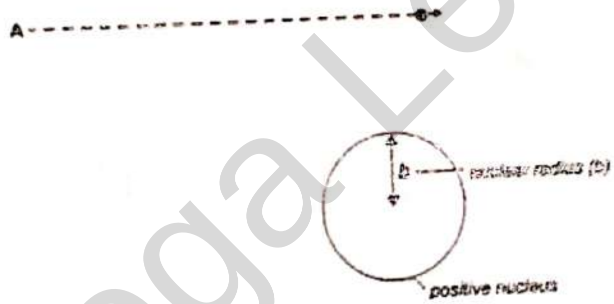
Rutherford made 3 observations:

Most of the fast, highly charged alpha particles went whizzing straight through un-deflected. This was the expected result for all of the particles if the plum pudding model was correct. Some of the alpha particles were deflected back through large angles. This was not expected. A very small number of alpha particles were deflected backwards! This was definitely not as expected.

To explain these results a new model of the atom was needed.

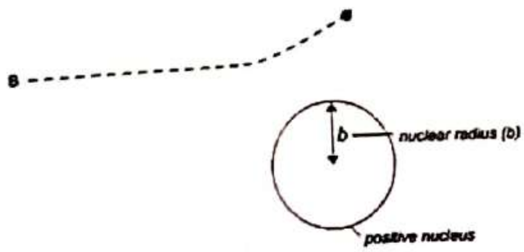


In this model the positive material is concentrated in a small but massive (lot of mass - not size) region called the nucleus. The negative particles (electrons) must be around the outside preventing the atom from trespassing on its neighbours space to complete this model. The diagram in next slide will help you to understand the results of the experiment.

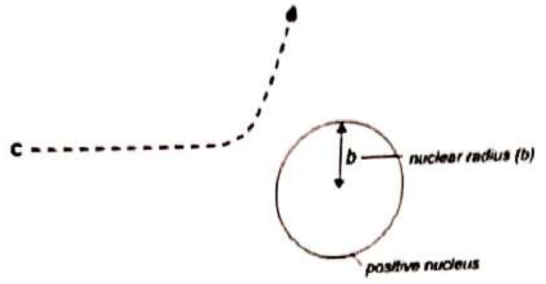


A) Alpha particles this far from the nucleus experience little or no deflection as they are not close enough to the small positive nucleus

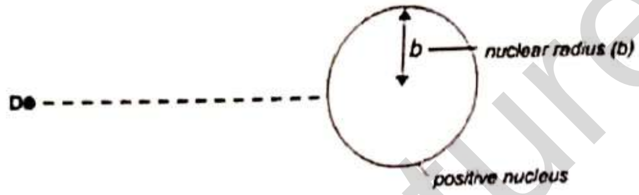
B) Here alpha particle will be slightly deflected as they are closer to the nucleus, so you will see some scattering



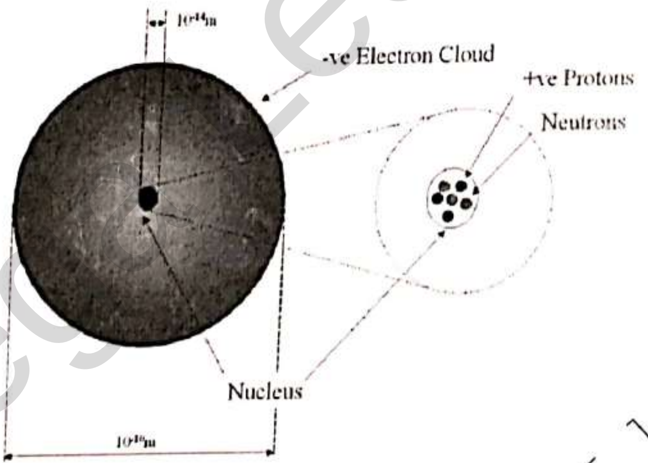
C) This close to the nucleus, the alpha experiences a large deflection, so they are scattered through large angles.



D) The alpha particle has a head on collision with the nucleus so it bounces straight back.



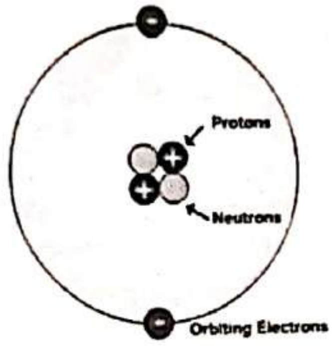
describe a simple model for the nuclear atom to include protons, neutrons and orbital electrons



	Protons	Neutrons	Electrons
Relative Mass	1	1	Negligible
Charge	+1	Neutral	-1

Particles in the Atom

Atoms contain 3 types of particles: protons, neutrons and electrons.



It is important to understand that the picture above is model of the atom. It conveys an impression of what the atom is like, but is not a completely true representation.

As an example of this consider the relative sizes of the nucleus and whole atom. It can be found that a typical nuclear diameter is 1 x 10 $^{-14}$ m while the typical atomic diameter is 1 x 10 $^{-10}$ m. Thus the nucleus is around 10, 000 times smaller than the entire atom. You could build a model of an atom by placing a pea on the center spot of a football stadium (to represent the nucleus) and then placing the electrons somewhere out in the stands. The picture above certainly does not reflect this fact accurately! Molecules are simply combination of 1 or more atoms so are slightly larger than atoms themselves.

Each of these particles has a mass and a charge.

Table of masses and charges

	Mass / Kg	Charge/ Coulombs
Proton	1.660 x 10 $^{-27}$	1.602 x 10 $^{-19}$
Neutron	1.660 x 10 $^{-27}$	0
Electron	9.110 x 10^{-31}	1.602 x 10^{-19}

It is possible to simplify this information by looking for patterns in the numbers.

Firstly, notice that the electron and proton have equal and opposite charges. A new unit of charge called the **elementary charge** (e = 1.602 x 10^{-19} kg). Using this new unit we can approximate the masses of proton, neutron and electron to be 1u, 1u and 0 u respectively. The relative atomic masses of the three particles can therefore simply be stated as 1, 1, 0.

Table of Relative masses and charges

	Relative Mass	Relative Charge
Proton	1	+1
Neutron	1	
Electron	0	

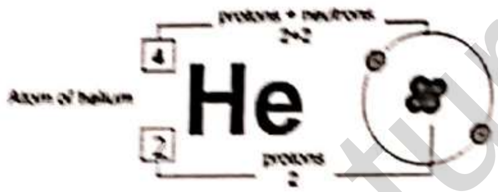
Many different atoms can be built using the 3 particles described above. 91 different atoms occur naturally (the chemical element) and many more can be found in situations where energy levels are high. It is useful to have a concise way of descending these atoms.

To describe the number of particles in a given atom, we use this notation:

The top number (A) is called the nucleon number (as it is the number of things in the nucleus of the atom) or the mass number (as it is the mass of the atom.)

The bottom number (Z) is called the proton number (as it is the number of protons) or the atomic number (as it is number that tells you which element the atoms belongs to).

The letters give you a clue as to the name of the element. For example here is an atom of helium:



How do we know about the protons and neutrons in the nucleus?

It is an established scientific fact that the atom has a central nucleus containing protons and neutrons. But how did physicists gather evidence to support this view?

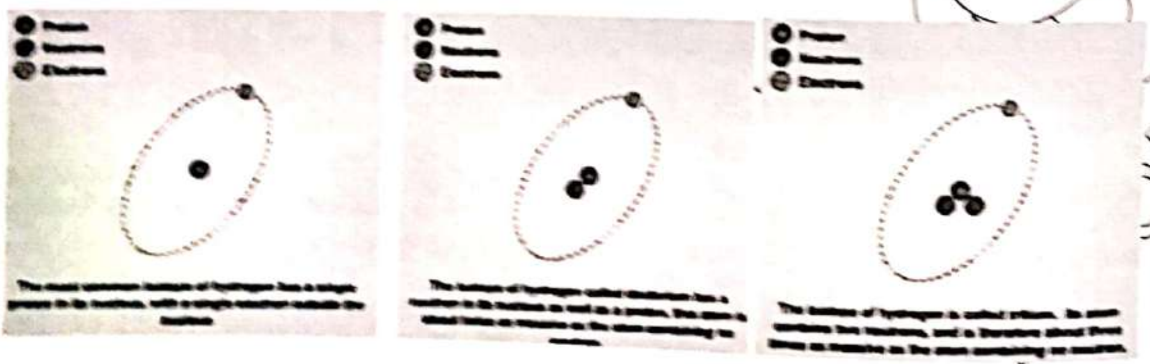
The Rutherford scattering experiment proved that the nucleus was small and positive but it took a different experiment to prove the existence of the protons and neutrons within. Very high – energy electrons have energy to actually penetrate into the nucleus itself.

Isotopes

The number of protons in an atom is crucial. It gives you the charge of the nucleus and therefore it gives you the number of electrons needed for a neutral atom. And the number of electrons governs how an atom behaves and reacts chemically with other atoms. In other words, it gives you its properties. So the number of protons makes the atom belong to a particular element. Change the number of protons and you change the element.

The number of neutrons in the nucleus is less crucial. You can change the number of neutrons without changing the chemical properties of the atom. So it behaves in the same way. Atoms with the same proton number but different numbers of neutrons are called isotopes.

Here are 3 Isotopes of Hydrogen



Recap...

Distinguish between nucleon number and proton number

Nucleon number A: The number of nucleons (Protons and Neutrons)

Proton number Z: The number of protons in the nucleus.

Neutron number N: The number of neutrons in the nucleus

Show an understanding that an element can exist in various isotopic forms, each with a different number of neutrons

Nuclide: An atom with a particular number of protons and neutrons

Isotope: Isotopes are nuclides that contain the same number of protons, but different number of neutron

Nucleon: Component of the nucleus = Protons and Neutrons

Decay equations

To show what happens before and after a nuclear reaction (reaction involving the nucleus of an atom) we use equations that show both the proton (Z) and nucleon number (A). To balance a nuclear equation (left side and right side) you have to make sure that the sum of the nucleon (top) numbers on the left hand side equals the sum of the nucleon numbers on the right hand side AND the sum of the proton numbers on both sides also balance.

For Example:

$${}^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{17}_{8}O + {}^{1}_{1}H$$

Top row = 18 on the left and right hand sides.

Bottom row = 9 on the both left and right sides.

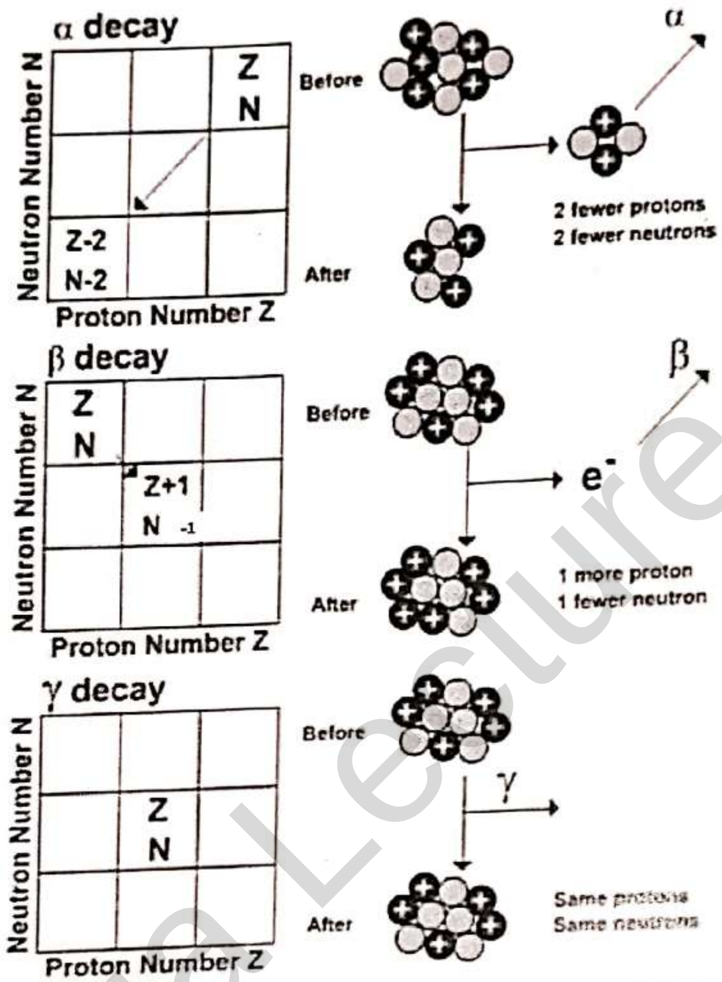
This is a balanced equation.

Nuclear equations such as these are useful for explaining what happens in radioactive decay processes.

Unstable nuclei emit alpha, beta or gamma radiation in order to become more stable.

As a result of emitting this radiation the character of the nucleus remaining is changed. This is radioactive decay.

The diagram below shows what happens when a nucleus emits alpha, beta or gamma radiations.



In alpha decay 2 protons and 2 neutrons are emitted. Notice that this reduces the nucleon number by 4 and the proton number by 2. A new element is thus formed. In beta decay a neutron changes into a proton (which remains in the nucleus) and an electron (which is emitted as beta radiation). The net effect is an increase in proton number by 1, while the nucleon number stays the same. Again a new element is formed.

When a nucleus has undergone alpha or beta decay it is often left in a high energy (excited) state. This energy can be lost in the form of an emitted a gamma ray. Because the composition of the nucleus is unchanged no new element is formed.

Recap...

Represents simple nuclear reactions by nuclear equations of the form

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$$

Alpha decay...

$$^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}\alpha$$

Beta decay

$$^{A}_{Z}X \rightarrow ^{A}_{Z+1}Y + ^{0}_{-1}\beta + \bar{\nu}$$

Gamma decay

$$^{A}_{Z}X \rightarrow ^{A}_{Z}X + ^{0}_{0}\gamma$$

Example...

$$^{241}_{95}Am \rightarrow ^{237}_{93}Np + ^{4}_{2}\alpha$$

$$^{90}_{38}Sr \rightarrow ^{90}_{39}Y + ^{0}_{-1}\beta + \bar{\nu}$$

In any nuclear reaction the following must always be true:

- The total atomic number before the reaction must be the same as the total atomic number after the reaction.
- The total atomic mass before the reaction must be the same as the total atomic mass after the reaction.

The first requirement above is the statement of the conservation of charge in nuclear reactions. The second requirement is the statement of the conservation of nucleon number.

Why are some atoms radioactive?

Instability

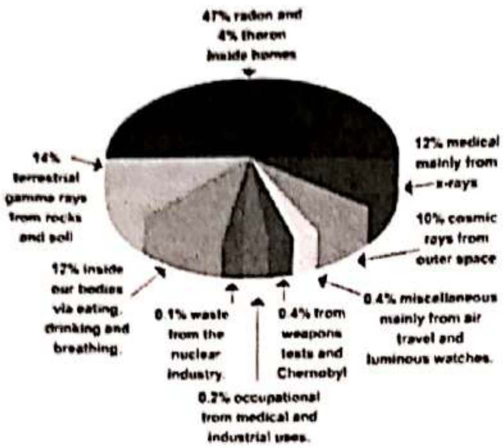
Some atoms are unstable. They have too much energy or the wrong mix of particles in the nucleus. So to make themselves more stable, they breakdown (or decay) and get rid of some matter and/ or some energy. This is called radioactive decay and isotopes of atoms that do this are called radioisotopes.

The process is spontaneous and random. You can't do anything to speed it up or slow it down and you can't predict when it will happen. The only reason we can do any calculations on radioisotopes is because there are huge numbers of atoms in most samples so we can use statistics to accurately predict what's most likely to happen.

Background Radiation

A Geiger counter set up anywhere on Earth will always register a count. This is due to tiny fragments of radioactive elements presents in all rocks and soil, the atmosphere and even living material. The Earth is also continuously bombarded by high – speed particles from outer space and the Sun called cosmic rays. In addition the nuclear and health industries produce small amounts of radiation each year. Collectively this radiation around us from natural and unnatural sources is called background radiation.

The chart shows the main sources of background radiation.



When carrying out practical work involving count – rates from radioactive sources, allowance should be made for this background radiation. This can usually be done effectively by measuring the background count in the laboratory for several minutes, and subtracting the appropriate amount from subsequent readings taken with the source.

What is ionizing radiation?

Alpha, beta and gamma

Ionising radiation comes in three varieties:

α (alpha) particles

β (beta) particles

γ (gamma) particles

All of these forms of radiations are energetic enough to pull electrons away from atoms. The atoms that have had electrons removed in this way are now charged particles, or ions, and hence the name ionizing radiation.

The fact that these radiations are ionizing allows them to be detected and discriminated from other forms of radiation (such as infra – red or radiowaves). Detectors such as ionization chambers, Geiger – Muller tubes and cloud chambers all rely on the ionizing properties of these radiations to produce measurable effects.

Properties of alpha, beta and gamma radiation

Alpha particles

Alpha particles are strongly ionizing but can be stopped by paper or skin. They have strong positive charge (+2) and a mass of 4 (i.e. 4 times the mass of a proton)

An alpha particle is in fact the same as a helium nucleus – 2 protons and 2 neutrons.

Beta particles

Beta particles are electrons – but they are called beta particles to identify that they came from the nucleus of the atom.

How do you get an electron from the nucleus? A neutron splits up and becomes a proton and an electron. The proton remains behind in the nucleus, the electron is emitted.

Beta particles are also strongly ionizing (perhaps 1 beta particle will cause 100 ionisations).

Gamma Rays

Gamma rays are very poor at ionizing (about 1 to 1) but they are very difficult to stop (they are very penetrating). As they are not good ionisers, they are less dangerous to life.

They are in fact pure energy (at the shortest wavelength end of the E –M spectrum) and gamma emission accompanies most emissions of beta or alpha particles.

Recap...

Show an understanding of the nature and properties of α-, β- and γ - radiations (β+ is not included: β- radiation will be taken to refer to β-)

Property	Alpha	Beta	Gamma
Description	Helium Nuclei	Electron from the nucleus	Electromagnetic radiation
– Ionising power	High	Medium	Low
Penetration (absorbed by)	Low (paper)	Medium (5mm Al)	High (Thick lead)
Charge	+ ve	- ve	None

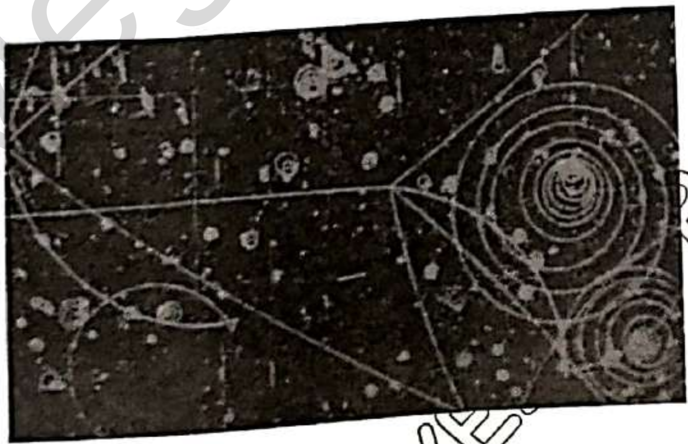
Fundamental Particles?

Chemistry is very complicated because there are literally billions of different molecules that can exist. The discovery of the Periodic Table simplified things because it suggested that there were roughly 92 different elements whose atoms could be arranged to make these various molecules. The idea that atoms are made up of just three types of particle (protons, neutrons and electrons) seemed to simplify things still more, and scientists were very happy with it because it seemed to provide a very simple explanation of a complex world. Protons, neutrons and electrons were thought of as fundamental particles, which could not be subdivided further.

However in the middle decades of the 20th century, physicists discovered many other particles that did not fit this pattern. They gave them names such as pions, kaons, muons, etc. using up most of the letters of the Greek alphabet.

These new particles were formed in two ways:

- By looking at cosmic rays, which are particles that arrive at the Earth from outer space.
- By looking at the particles produced by high – energy collisions in particle accelerators (Figure 16.9).



The discovery of new particles with masses different from those of protons, neutrons and electrons suggested that these were not fundamental particles. Various attempts were made to tidy up this very confusing picture.

In principle, we can never know for certain whether a particle such as the electron is truly fundamental; the possibility will always remain that a physicist will discover some deeper underlying structure.

Families of particles

Today, sub-atomic particles are divided into two families:

- Hadrons such as protons and neutrons. These are all particles that are affected by the strong nuclear force.
- Leptons such as electrons. These are particles that are unaffected by the strong nuclear force.

The word 'hadron' comes from a Greek word meaning 'bulky', while 'lepton' means 'light' (in mass). It is certainly true that protons and neutrons arc bulky compared to electrons. At the Large Hadron Collider (Figure 16.10) at the CF.RN laboratory in Geneva, physicists are experimenting with hadrons in the hope of finding answers to some

Figure 16.10 Particle accelerators have become bigger and bigger as scientists have sought to look further and further into the fundamental nature of matter. This is one of the particle detectors of the Large Hadron Collider (LHC), as it was about to be installed. The entire collider is 27 km in circumference.

fundamental questions about this family of particles. In 2013, they announced the discovery of the Higgs boson, a particle which was predicted 50 years earlier and which is required to explain why matter has mass.

Inside hadrons

To sort out the complicated picture of the hadron family of particles, Murray Gell-Mann in 1964 proposed a new model. He suggested that they were made up of just a few different particles, which he called quarks.

Figure 16.1 1 shows icons used to represent three quarks, together with the corresponding antiquarks, 'these are called the up (u), down (d) and strange (s) quarks. Gell-Manns idea was that there arc two types of hadron: baryons, made up of three quarks, and mesons, made up of two quarks. In either case, the quarks are held together by the strong nuclear force. For example:

A proton is made up of two up quarks and a down quark; proton = (uud).

A neutron is made up of one up quark and two down quarks; neutron = (udd).

A pi4 meson is made up of an up quark and a down antiquark; pi4 meson = (ud).

A phi meson is made up of a strange quark and an antistrange quark; phi meson = (ss).

Antiquarks are shown with a 'bar' on top of the letter for the quark. Antiquarks are needed to account for the existence of antimatter. This is matter that is made of antiparticles; when a particle meets its antiparticle, they annihilate each other, leaving only photons of energy.

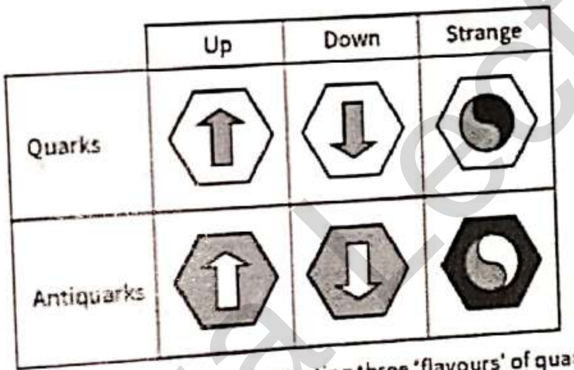


Figure 16.11 Icons representing three 'flavours' of quark, up, down and strange, and their antiquarks.

Discovering radioactivity

The French physicist Henri Becquerel (Figure 16.12) is credited with the discovery of radioactivity in 1896. He had been looking at the properties of uranium compounds when he noticed that they affected photographic film – he realised that they were giving out radiation all the time and he performed several ingenious experiments to shed light on the phenomenon.

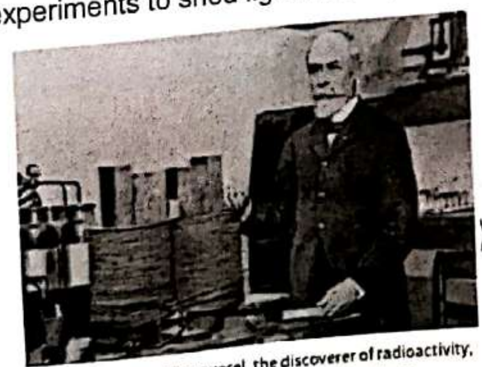


Figure 16.12 Henri Becquerel, the discoverer of radioactivity, in his laboratory. His father and grandfather had been professors of physics in Paris before him.

Radiation from radioactive substances

There are three types of radiation which are emitted by radioactive substances: alpha (α), beta (β) and gamma (γ) radiations come from the unstable nuclei of atoms. Nuclei consist of protons and neutrons, and if the balance between these two types of particles is too far to one side, the nucleus may emit a- or (Eradiation as a way of achieving greater stability. Gamma radiation is usually emitted after α or β decay, to release excess energy from the nuclei.

In fact, there are two types of β-radiation. The more familiar is beta-minus (β^-) radiation, which is simply an electron, with negative charge of-e. However, there are also many unstable nuclei that emit beta-plus (β^+) radiation. This radiation is in the form of positrons, similar to electrons in terms of mass but with positive charge of +e. Positrons arc a form of antimatter. When a positron collides with an electron, they annihilate each other. Their mass is converted into electromagnetic energy in the form of two gamma photons (Figure 16.13).

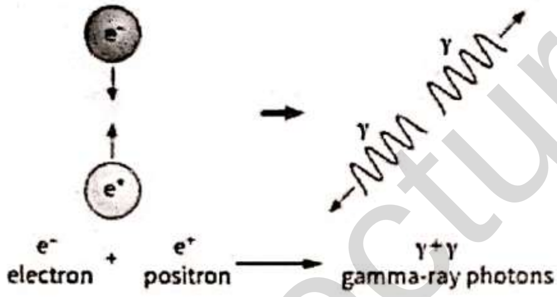


Figure 16.13 Energy is released in the annihilation of matter and antimatter.

Table 16.4 shows the basic characteristics of the different types of radiation. The masses arc given relative to the mass of a proton; charge is measured in units of e, the elementary charge.

Radiation	Symbol	Mass (relative to proton)	Charge	Typical speed
α-particle	α, ${}^{4}_{2}He$	4	+2e	'slow' (10^6 m s^{-1})
β^--particle	β, β^-, e, ${}^{0}_{-1}e$	$\frac{1}{1840}$	−e	'fast' (10^8 m s^{-1})
β^+-particle	β, β^+, e+, ${}^{0}_{+1}e$	$\frac{1}{1840}$	+e	'fast' (10^8 m s^{-1})
γ-ray	γ	0	0	speed of light (3×10^8 m s^{-1})

Table 16.4 The basic characteristics of ionising radiations.

Note the following points:

Is a-α and photon of electromagnetic are particles radiation of matter. similar A y-ray to an X-ray. (X-rays are produced when electrons are decelerated; y-rays are produced in nuclear reactions.)

An a-particle consists of two protons and two neutrons; it is a nucleus ofhelium-4. A (T-particle is simply an electron and a β^+-particle is a positron. The mass of an a-particle is nearly 10000 times that of an electron and it travels at roughly one-hundredth of the speed of an electron.

Discovering neutrinos

There is a further type of particle which we need to consider. These are the neutrinos. When β decay was first studied, it was realised that β-particles were electrons coming from the nucleus of an atom. There are no electrons in the nucleus (they "orbit' outside the nucleus), so the process was pictured as the decay of a neutron to give a proton and an electron. It was noticed that β-particles were emitted with a range of speeds- some travelled more slowly than others, It was deduced that some other particle must be carrying off some of the energy and momentum released in the decay. This particle is now known as the antineutrino (or, more correctly, the electron antineutrino), with symbol v. The decay equation for (3 decay is written as:

$$\text{beta - minus } (\beta^-) \text{ decay: } {}^1_0n \rightarrow {}^1_1p + {}^0_{-1}e + \bar{v}$$

Neutrinos are bizarre particles. They have very little mass (much less than an electron) and no electric charge, which makes them very difficult to detect. The Austrian physicist Wolfgang Pauli predicted their existence in 1930, long before they were first detected in 1956. In β^+ decay, a proton decays to become a neutron and an electron neutrino (symbol v) is released:

$$\text{beta - plus } (\beta^+) \text{ decay: } {}^1_1p \rightarrow {}^1_0n + {}^0_{-1}e + v$$

The two equations highlighted above show two important features of radioactive decay. Firstly, nucleon number A is conserved; that is, there are as many nucleons after the decay as there were before. In β decay, a neutron has become a proton so that the total number of nucleons is unchanged. In β decay, a proton becomes a neutron, so again A is conserved. Secondly, proton number Z is also conserved. In β decay, we start with a neutron (Z = 0). After the decay, we have a proton (Z = +1) and a (3 particle (Z = -1). Together these have Z = 1 - 1 = 0. Since Z tells us about the charge of each particle, we would be surprised if we had a different amount of charge after the decay than before the decay. A similar analysis shows that Z is conserved in β^+ decay. Do these conservation laws apply to a decay? Here is an equation that represents a typical a decay:

$${}^{222}_{86}Rn \rightarrow {}^{218}_{84}Po + {}^4_2He$$

However, the strong force cannot explain β decay. Instead, we have to take account of a further force within the nucleus, the weak interaction, also known as the weak nuclear force. This is a force that acts on both quarks and leptons. The weak interaction is responsible for β decay.