CHAPTER 1

Measurements and SI units

1.1 Units of measurements

All measurements are represented using the international system of units, **Standard International Unit (SI Unit). Table 1.1** shows the summary of SI units of measurements of the quantities:

Table 1.1 Quantities and their SI units

Quantity	**Name of SI base unit**	**Symbol for SI base unit**
Length	Metre	m
Mass	Kilogram	Kg
Area	Square metre or metre squared	m^2
Time	Second	s
Volume	Cubic metre or metre cubed	m^3
Current	Ampere	A
Voltage	Volt	V
Resistance	Ohm	Ω
Temperature	Kelvin	K
Angle	Degree	^{o}
Pressure	Pascal	Pa
Density	Kilogram per cubic meter	Kg/m^3
Speed	Metres per second	m/s
Velocity	Metres per second	m/s
Acceleration	Metres per second per second	m/s/s or m/s^2
Force	Newton	N
Work	Newton metre or Joule	Nm or J
power	Watt	J/s or W
Period	Second	s
Frequency	Hertz	Hz

1.4 Scale reading of measuring instruments

Measurement of length

The SI base unit of length is the **metre** (symbol m). Other units of lengths are as shown below:

1 kilometre (km)	= 1000 m	= 1×10^{3}m
1 centimetre (cm)	= $\frac{1}{100}$ m	= 1×10^{-2}m

Instruments for measuring length

Rule (ruler)

A meter rule is used to measure the lengths of distances between 1mm and 1metre.

mm 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150

160 **Figure 1.1** a rule (ruler)

The scale on the rule is found by checking the number of divisions between two values. On this ruler there are 10 divisions between 0 cm and 1 cm. The scale is found as:

$$\text{Scale} = \frac{1\text{cm}}{10}$$

Therefore, the scale is 0.1 cm.
Or we can use 10 divisions from 0 mm to 10 mm,

$$\text{Scale} = \frac{10}{10}\text{ mm}$$

Therefore, the scale is 1 mm.

Vernier calipers

Vernier calipers are used when smaller and accurate measurements are required. Vernier calipers consist of two parts:

a. The main scale which is fixed. It is usually numbered in cm.

b. The Vernier scale, the part that slides along the main scale. It has 10 divisions, each 0.9 (9/10) mm. The scale gives readings to 0.1 mm or 0.01 cm.

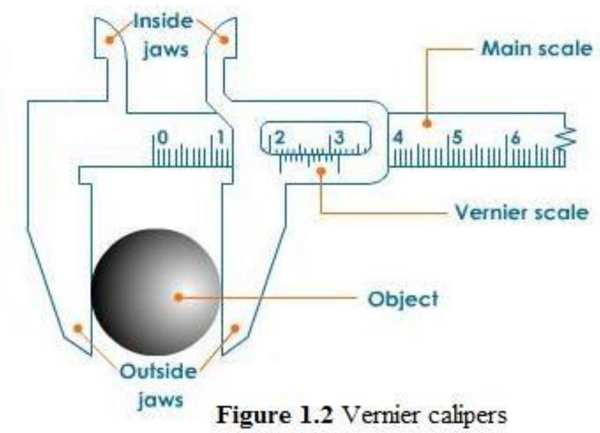


Figure 1.2 Vernier calipers

How to use the Vernier calipers

The object whose length is required is placed between the jaws. Close the jaws onto the object to be measured. Read the main scale, e.g. 1.4 cm. Identify the mark on the Vernier scale which coincides exactly with a mark on the main scale, e.g. 0.3 mm or 0.03 cm. Take this reading to give a second decimal place. The reading will be found as 1.4 cm + 0.03 cm = **1.43 cm**.

Micrometer screw gauge

The micrometer screw gauge, shown in **Figure 1.3**, is used to measure accurately the dimensions of all small objects.

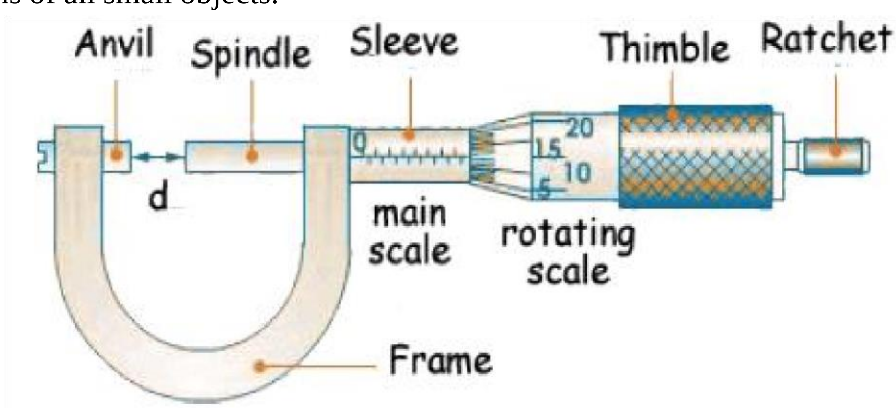


Figure 1.3 micrometer screw gauge

How to use micrometer screw gauge

Rotate the thimble until the wire is firmly held between the anvil and the spindle.
To take a reading, first look at the main scale. This has a linear scale reading on it. The long lines are every millimetre and the shorter ones denote half a millimetre in between. The scale on the linear scale is 0.5 mm or 0.05 cm. The rotating scale is 0.01 mm or 0.001 cm. Then look at the rotating scale. Add the 2 numbers, on the scale on the right.

From Figure 1.3:

Sleeve reads = 8 mm or 0.8 cm
Thimble reads = 0.12 mm or 0.012 cm
Total reading = **8.12 mm** or **0.812 cm**

Measurement of mass

The Mass of a substance is the quantity of matter contained in the substance. The SI base unit for mass is the kilogram (kg).
Other units of mass are as shown below:

1 tonne (t)	=	1000kg	= $1x10^{3}$kg
1 gram (g)	=	$\frac{1}{1000}$ kg	= $1x10^{-3}$kg
1 milligram (mg)	=	$\frac{1}{1000\ 000}$ kg	= $1x10^{-6}$kg

Measurement of time

The SI base unit of time is the second (s).
Other units of time are as follows:

1 millisecond (ms) = $\frac{1}{1000}$ s =$1x10^{-3}$ s

1 microsecond (μm)	=	$\frac{1}{1000\ 000}$ s	=$1x10^{-6}$s

Time is measured by clocks and watches.
The time intervals are found by using a stop watch.

Experiment 1.1

AIM: To measure time intervals using a stop watch.
MATERIALS: Stop watch, meter rule, 50g mass, clamp stand, clamp and a string.
PROCEDURE:

1. Set up the apparatus as shown in **Figure 1.5** below.

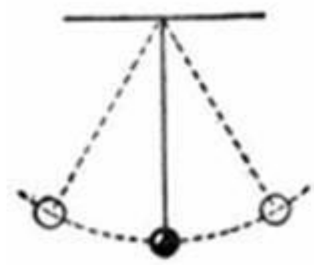


Figure 1.5

2. Pull the mass to one side at an angle of about 10^0 and leave it to vibrate freely.
3. Start the stop watch after one or two oscillations.
4. Read and record the time taken to make 10 complete oscillations.
5. Repeat the experiment using lengths 30 cm, 20 cm and 10 cm.

Compare your results with your friends'.

Measurement of volume

Volume is the quantity of space an object occupies. The SI base unit for Volume is meter cubed (m^3)
Volume can also be measured using the centimeter cubed (cm^3)

$$1cm^3 = \frac{1}{1000\,000}m^3 = 10^{-6}m^3$$

$$1000\,000cm^3 = 1m^3$$

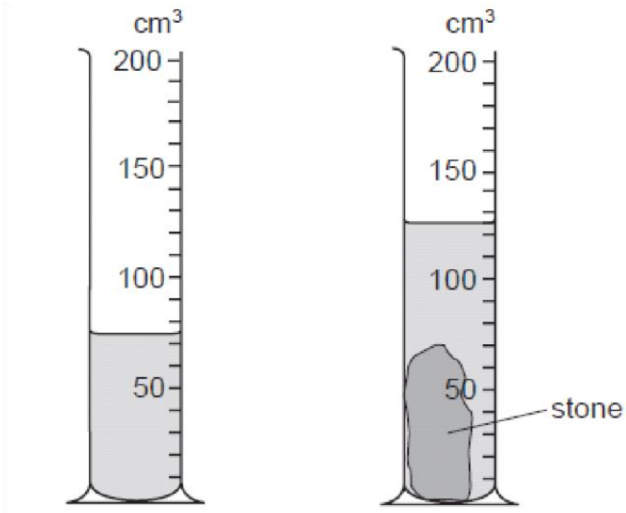
Volumes of regular solids

For a regular block, volume = **length x width x height**

For a cylinder, volume = base area x height = $\boldsymbol{\pi r^2 h}$
For a sphere = $\boldsymbol{4/3\pi r^3}$

Volumes of an irregular solid

Volume = the volume of a displaced liquid in a measuring cylinder



A **B**

Figure1.6 measuring a cylinder used to measure the volume of an irregular solid

Volume of an irregular solid = volume B - volume A

$= 125cm^3 - 75cm^3$

Volume of an irregular solid = $\mathbf{50cm^3}$

Experiment 1.2

AIM: To measure volume using a measuring cylinder
MATERIALS: water, measuring cylinder, thin string and 3 stones of different sizes
PROCEDURE:

1. Pour water in the measuring cylinder about half-full.
2. Read and record the volume of water as VA.
3. Insert a stone tied to a thin string in the water.
4. Read and record the new volume of water as VB.
5. Calculate the volume of the stone by using the formula, V = VB – VA.
6. Repeat the experiment with the other two stones.

Volume of a liquid

The volume of a liquid is measured in **litres.**

Other units of volume of a liquid are as follows:

1 litre = 1000 cm^3

$1dm^3 = 1000\ cm^3$

$1l = 1dm^3$

$1l = 1000$ ml

$1cm^3 = 1$ ml

Volume of a liquid is found by pouring the liquid in a measuring cylinder.

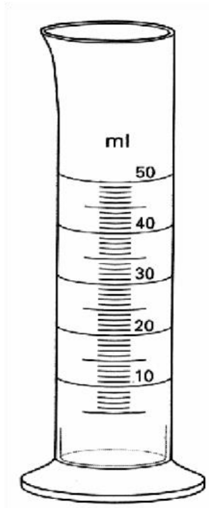


Figure 1.7 measuring cylinder

Chapter 2

Scientific investigations

2.1 Designing a scientific investigation

Designing a scientific investigation involves the following stages:

- Identifying a problem
- Hypothesizing
- Deciding the type of data to collect
- Identifying variables

Identifying a problem

In an investigation, start with the problem that you want to investigate. This is like a question that you need answers for. For example: **what is the effect of voltage on current in the circuit?**

Hypothesizing

This is the stage where you make a prediction. The prediction is called **hypothesis.** For example: **current in the circuit increases when voltage increases.** The hypothesis may not be right. Therefore, this prediction is tested during an investigation.

Deciding the type of data to collect

The data to be collected during an investigation must be decided before carrying out the investigation. **For example,**

- Decide the range of voltage readings to be collected
- Decide the range of current values to be collected

Identifying variables

In this case we identify what is going to be observed or measured. These are called **variables.**

Variables can be defined as factors that would affect the results of the investigation. Variables can be anything that can change. Variables are mainly taken from the hypothesis. Variables in this investigation are number of cells, voltage and current.

Independent variable: The variable that you are changing in an investigation or experiment. This variable affects what happens in an investigation. In this investigation the independent variable is number of cells. Changing the number of cells will change the amount of voltage and current in the investigation.

Dependent variable: This is what you will be measuring. **For example:** voltage and current.

Control variables
During an investigation, some variables do not have to be measured. These variables need to be controlled. **For example:** temperature and the value of resistor.

2.2 Carrying out a scientific investigation

Experiment 2.1

AIM: To investigate the effect of voltage on current
MATERIALS: Connecting wires, ammeter, voltmeter, 4 cells, switch and resistor
PROCEDURE:

1. Set up the experiment as shown in **Figure 2.1.**

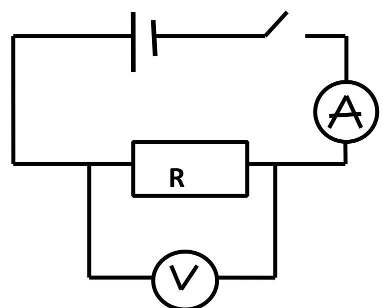


Figure 2.1

2. Close the switch and take the voltmeter and ammeter readings.
3. Repeat the experiment with 2, 3 and 4 cells.
4. For each number of cells, take the voltmeter and ammeter readings.
5. Record the results in **table 2.1** below:

Number of cells	Voltmeter reading (V)	Ammeter reading (A)
1		
2		
3		

Table 2.1

6. Discuss your results with other students in your class.

RESULT
The voltmeter and ammeter readings increase when the number of cells increases.

EXPLANATION

The voltage increases because the force pushing electrons in the circuit increases. This causes an increase in the amount of current in the circuit.

CONCLUSION

Therefore, an increase in voltage causes an increase in current

Controlling variables

In experiment 2.1, temperature and the resistor are the variables that are controlled. To get a fair result, you should change one variable (e.g. number of cells) at a time and check how it affects other variables (e.g. voltage and current).

Collecting scientific data

Make sure you have written the observations properly. State the unit in which each measurement is made, for example 0.1 A for current.

You can use a table. Make sure you enter the observations in the table and indicate the units at the top of each column only. In a table draw rows and columns. Rows are horizontal gaps while columns are vertical gaps. Place **independent variables** (this is what you are changing in the experiment) in the first column. Place the **dependent variables** (this is what you will be measuring) in the next column (s).

Table 2.2 below shows the results for an experiment like **experiment 2.1.**

Independent variable **Dependent variables**

Number of cells	**Voltage (V)**	**Ammeter (A)**
1	1.5	0.1
2	3	0.2
3	4.5	0.3
4	6	0.4

Table 2.2

No measurement is exact. There is always some uncertainty about it. For example, if the values are like in **Table 2.3**, it is very important to give your calculations to an approximate number of significant figures.

Voltage (V)	**Current (A)**	**Resistance (Ω) =** $\frac{\textbf{Voltage (V)}}{\textbf{Current (A)}}$
1.0	0.15	6.666666667
3.0	0.48	6.25
5.0	0.81	6.17283906

Table 2.3

In this case the measurements of voltage and current are given to 2 significant figures. Therefore, the calculations for resistance should also be rounded off to 2 significant figures.

Voltage (V)	Current (A)	Resistance (Ω) = $\frac{\text{Voltage (V)}}{\text{Current (A)}}$
1.0	0.15	6.7
3.0	0.48	6.3
5.0	0.81	6.2

Table 2.4

2.3 Analyzing data from a scientific investigation

Errors and accuracy during experiments

The results of an experiment can be slightly inaccurate for two main reasons:

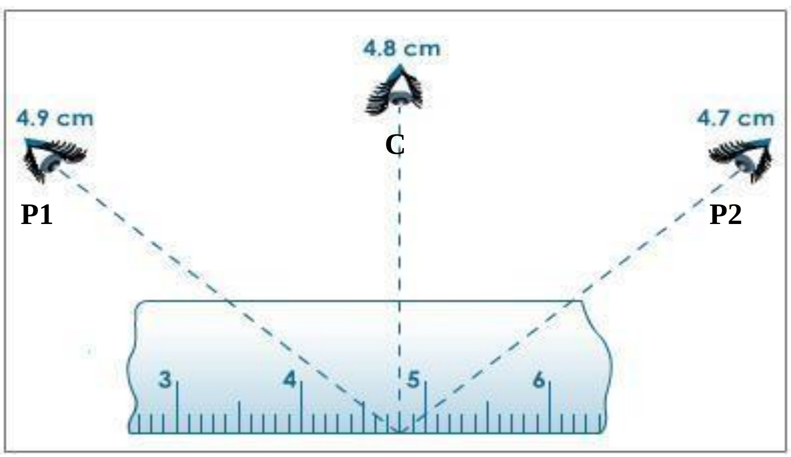
1. You can make personal errors in the observations.
2. The apparatus itself can be capable of only limited accuracy.

The errors can be grouped into:

1. Personal errors

The common personal error is due to parallax. **Parallax error** is the apparent change in the position of an object due to a change in the position of your eyes and every time you measure a length or read a pointer moving over a scale it is likely to arise.

Figure 2.2 shows how the position to be read varies, with respect to the scale, as the eye is moving from P1 to C to P2.



Positions **P1** and **P2** are wrong while position **C** is only correct one.

When reading a liquid level, you take the reading from the meniscus. The meniscus should always be viewed horizontally to avoid parallax as shown in **Figure 2.3**.

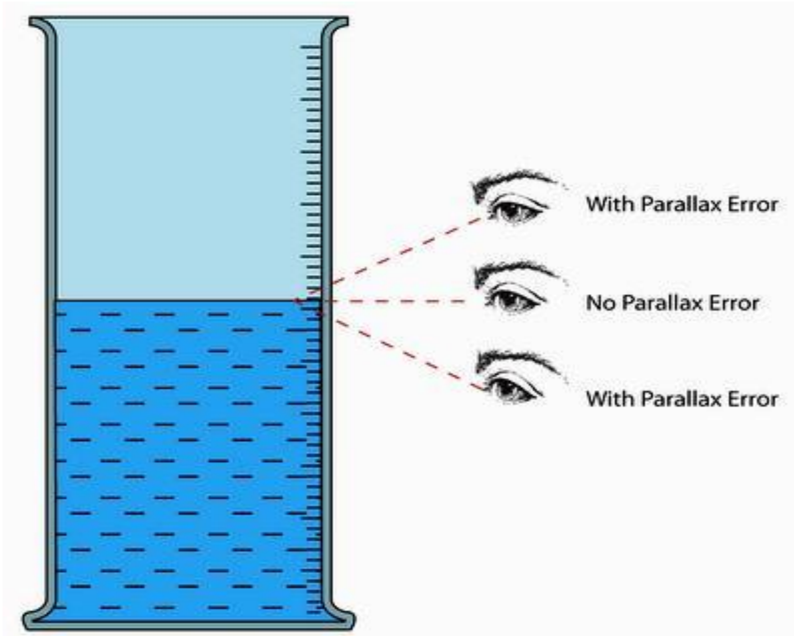


Figure 2.3 Taking the reading from the meniscus

2. Errors of the instrument

If you are using an apparatus which is not sufficiently sensitive, it is difficult to produce a good experimental result. For example, it is difficult to time a race using a watch with no second hand. So you will be unable to produce a good experimental result with apparatus which is not sufficiently sensitive. Another example can be a measuring cylinder. Consider the determination of the volume of a solid by displacement of water in a measuring cylinder. In a 100 cm^3 cylinder every cm^3 is marked, but the graduations on a 500 cm^3 vessel are only every 5 cm^3. In this case, the smallest cylinder into which the solid will go should be used because a more accurate reading is possible.

Zero error: The error which occurs when the measuring instrument does not indicate zero when it should.

3. Reading and recording

Estimation of reading to one-tenth of the smallest scale division is often necessary and should be practiced. Always imagine the division divided up into ten equal parts and estimate which tenth coincides with the mark to be read.

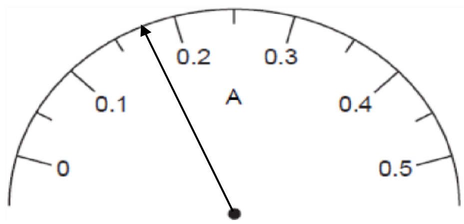


Figure 24 reading scale

The reading on an ammeter **is 0.155 A.**

Minimization of errors

You can produce accurate results from an experiment by reducing the errors.
Errors can be reduced by:

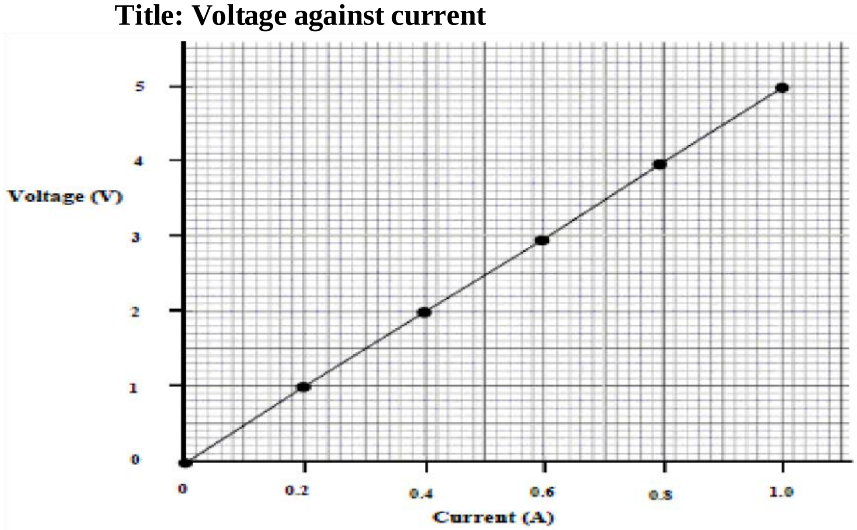
- Taking an average of several readings. Therefore, you repeat the experiment.
- Avoiding parallax error. Therefore, if you are reading from a scale, make sure you look at right angles to it so that you read a correct number.
- Avoiding the zero error. Therefore, make sure that the instrument is pointing at zero before it is used in the experiment

Plotting the graph

The results can be plotted on the graph.
The following are the hints on drawing graphs:

- Choose your scale so that the graph fills the paper, and label the axes.
- Mark each point by a dot or with a cross.
- Join only those points that are on the same lines in the straight line graph.
- Use a ruler to draw an obviously straight line graph, putting the line in such a way that the points are evenly distributed about it.
- Write the title of the graph.

Title: Voltage against current



During an experiment, not all the points can be on a straight line. So you should draw a straight line on a graph that goes through as many points as possible. This is called **a line of best fit**.

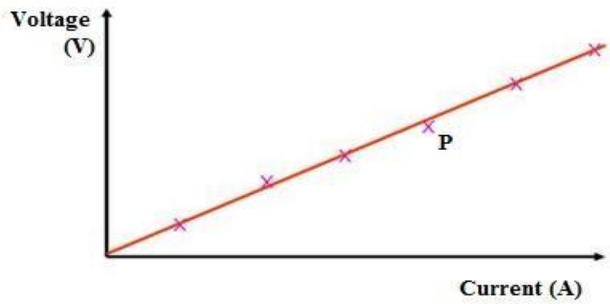


Figure 2.7 line of best fit

If a point is lying outside the range of the straight line, it is treated as an error and do not include it when drawing the straight line. For example: point **P**.

If points are scattered, you can draw the graph of the best fit which is an average of all the points as shown in **Figure 2.8.**

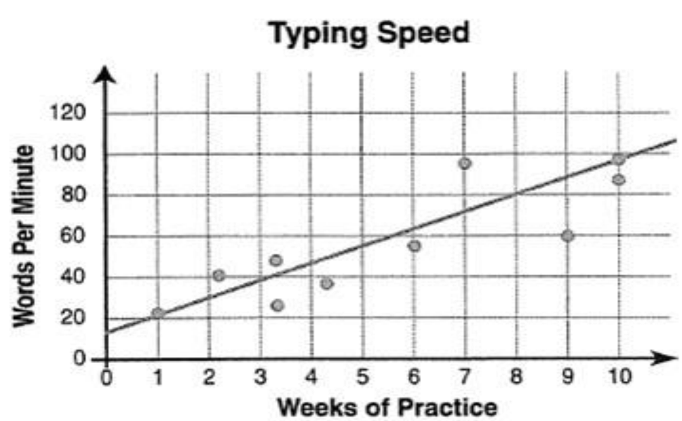


Figure 2.8 graph of best fit

Conclusion from the graph

Give a clear conclusion in simple and straight forward sentences. Be honest when writing the account and conclusion.

From the graph in **Figure 2.6**, you can draw the conclusion depending on the shape of the graph. We can observe that the current in the circuit increases with an increase in voltage or we can say that the current in the circuit decreases with a decrease in voltage. When voltage is doubled current is also doubled. This is only true when temperature and other physical factors are kept constant. Therefore, voltage and current are in **direct proportion.**

2.4 Communicating results from experiments

You can communicate your results from an experiment by including the following points:

- Organizing results from the experiment
  Making oral and poster presentation of the findings
- Sketching and labeling experimental set up
- Writing laboratory report.

Laboratory report

Aim

The aim of this investigation was to determine the relationship between the length of nichrome wire and its resistance.

I knew that I can find the resistance of the nichrome wire by finding the voltage and current across the nichrome wire. Then I can work out the resistance by using a formula shown below:

$$\text{Resistance } (R) = \frac{\text{Voltage } (V)}{\text{Current } (A)}$$

In this case I would connect a nichrome wire in a circuit then measure voltage across it and current in the circuit. I would do this for different lengths of nichrome wire.

Hypothesis

Length being one of the factors that affect resistance of a wire, it means when the length of the wire is changing its resistance will also change. My prediction was that the resistance of the wire will increase when the length of the wire increases and vice versa.

Variables

The key variables in this experiment were:

- *Length of nichrome wire: measured by a metre rule in centimetres (cm).*
- *Voltage: measured by a voltmeter in volts (V)*
- *Current: measured by an ammeter in amperes (A).*

The variables that I controlled were:

- *Temperature: this was controlled by connecting the nichrome wire in a beaker of cold water. Temperature must be controlled because when current flows through a nichrome wire it produces heat and this heat affects the resistance of the wire.*

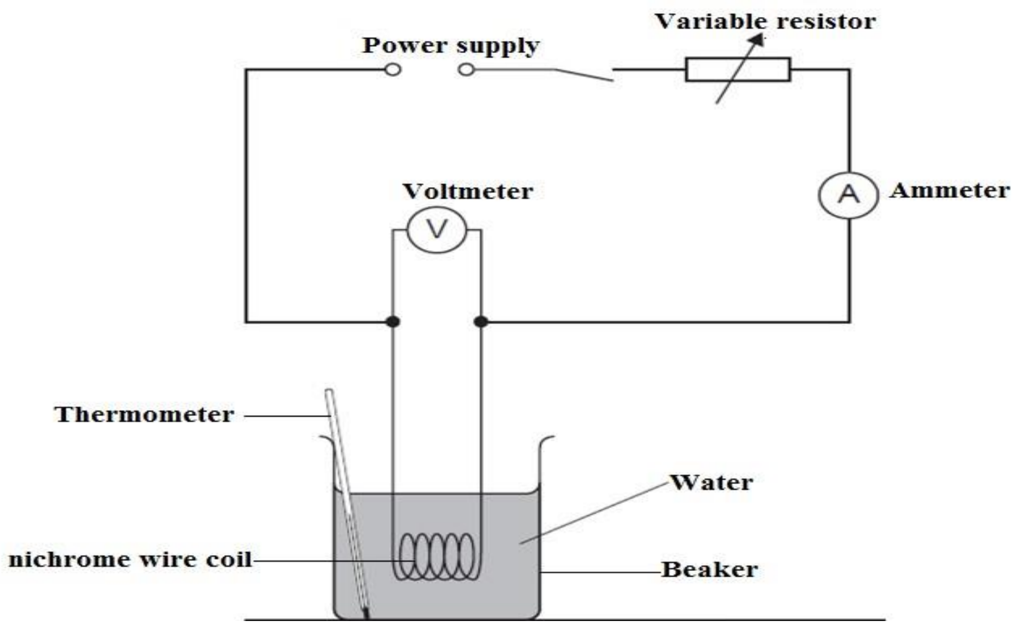
- *Diameter (thickness) of nichrome wire: this was controlled by using the wire of the same thickness. So in my investigation I was using the same wire and simply changing its length. Thickness of the wire must be controlled because it affects the resistance of the wire.*

Materials

The materials that I used during this investigation were: 100 cm nichrome wire (0.28 mm diameter), ammeter(0-3A), voltmeter(0-6V), metre rule, connecting wires, crocodile clips, cold water, beaker, cells (battery) and a variable resistor.

Procedure

I set up the experiment as shown below:



I connected a 100 cm nichrome wire in the circuit and recorded the voltmeter and ammeter readings.

I repeated the experiment with 80 cm, 60 cm, 40 cm and 20 cm nichrome wires. For each length, I recorded the voltmeter and ammeter readings.

I recorded the results in the table as shown below:

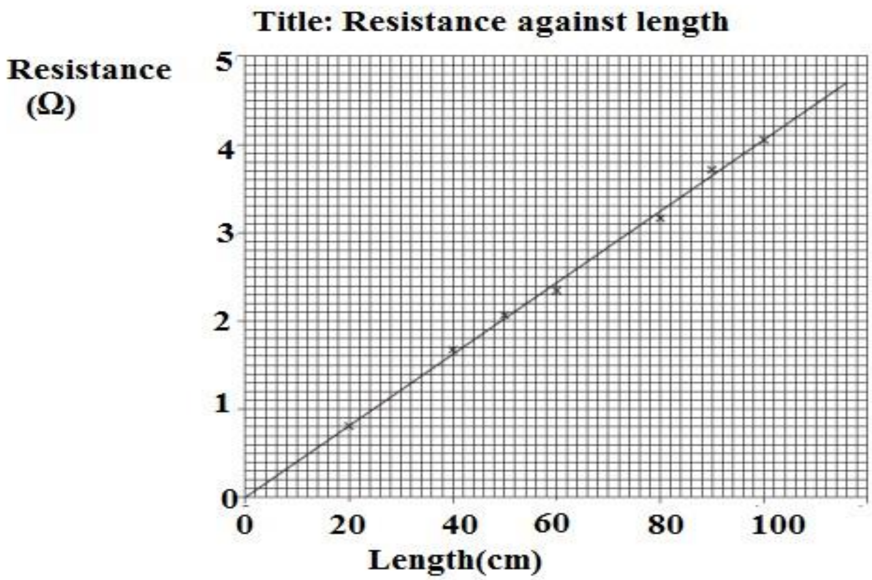
Length of the wire (cm)	*Current (A)*	*Voltage (V)*	*Resistance(Ω) = voltage(V) / current(A)*
100	*1.0*	*4.2*	*4.1*
80	*1.3*	*4.2*	*3.2*
60	*1.8*	*4.2*	*2.4*
40	*2.5*	*4.2*	*1.7*
20	*4.7*	*4.2*	*0.9*

Safety: When I was carrying out this experiment, I made sure that the power supply was switched off before I removed the nichrome wire to change its length.

I used my results to calculate the resistance of each length of the wire.

Drawing the graph

I used the values in the table to plot a graph of resistance against length with on the horizontal axis because it is the independent variable and resistance on the vertical axis because it is a dependent variable.



The points on my graph are a little bit scattered but I have used a line of best fit which is a straight line.

Conclusion

From my prediction I expected the graph of resistance against length to be a straight line, which showed that the resistance of the nichrome wire increases as the length of the wire increases.

Therefore, I can conclude that resistance of the wire is directly proportional to its length. This agrees with my original hypothesis that doubling the length of nichrome wire also doubles its resistance and vice versa.

Evaluation

The points on my graph are uneven but I am sure they would lie on a straight line. There are reasons why my points may have been scattered. Some of the reasons are:

- *Personal error due to parallax*
- *Scale on the instruments*

To get more accurate results I would have done the following:

- *Repeated the experiment to get average results that are accurate*
- *Avoid parallax error – make sure I look at a right angle to the scale of the instrument so that I read a correct value*
- *Avoid the zero error- make sure that the instrument is pointing at zero before it is used in the experiment.*

2.5 Evaluating a scientific investigation

An evaluation helps to decide how reliable your conclusions are. It also helps how the experiment could be improved. In examinations, you may be asked to comment on how precise or reliable the evidence is. You may also be asked how to improve that accuracy or reliability.

Reliability

You must comment about uncertainties in your measurements. This can be the reliability of the readings, especially in relation to the scale of the measuring apparatus.
In an experiment, you will find some results which do not agree with the others. These results look like mistakes and we call them **anomalous results.**
The reliable results must be the results that if the measurements are repeated, the same result should be obtained. On a best fit line, the reliability of the results can be checked by checking the closeness of the points to the line. When most of the points are very close to the best fit line, we say the results are reliable.

Ways of reducing factors that may affect a scientific investigation

After completing the experiment, you must suggest ways of improving it. This is important in order to have more reliable conclusion.

1. Precision

To be **precise** means that the measurements were done as accurately as possible.
For example
If you are carrying out an experiment to measure very small quantities, e.g. voltage, you may use a millivoltmeter instead of a voltmeter in order for the results to be more precise.
If you are measuring time intervals, e.g. time taken for one oscillation of a pendulum to be performed, it is very important to record the time for 10 oscillations. Divide the total time for 10 oscillations by 10. In this case, the errors by the human reaction time are minimized because they are spread out over many oscillations.

2. Reliability

Reliability of the results can be improved by repeating the experiment and compare the results. The results are close to each other, and then the results are reliable.

Chapter 3

Kinetic theory of matter

3.1 Three states of matter

What is matter? Matter covers all the substances and materials from which the physical universe is composed. **Matter** is anything which has mass and volume or occupies space. All the substances and materials are categorized as solids, liquids and gases. Therefore, the three states of matter are **solid**, **liquid** and **gas**.

Particle arrangement in the three states of matter

Solids: Solids have very strong intermolecular forces. Their particles are closely packed in a regular pattern. Their particles vibrate within a fixed point when heated.

Liquids: Liquids have weak intermolecular forces compared to solids. Their particles not closely packed and they slide over each other because there are spaces between them.

Gases: Gases have weakest intermolecular forces. Their particles are further apart and move freely because there are larger spaces between them.

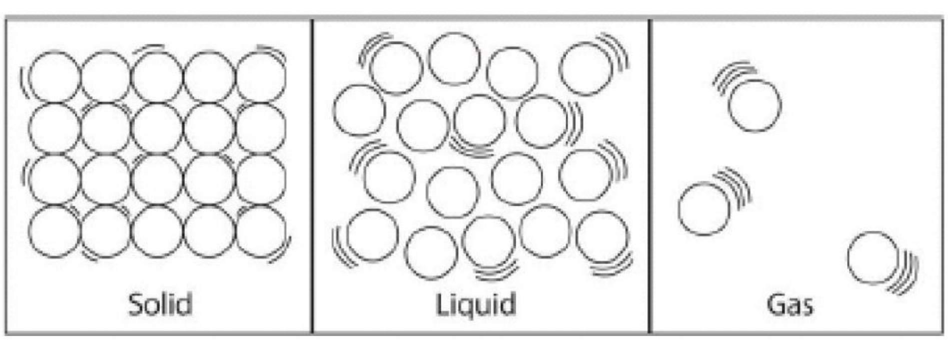


Figure 3.1 arrangement of particles in the three states of matter

3.2 The kinetic theory

Kinetic theory is a scientific explanation of the behavior of these three states of matter. It is a theory which accounts for the bulk properties of matter in terms of constituent properties.

The main points of the kinetic theory are:

- All matter is composed of smaller **particles** (molecules, atoms or ions) which have different sizes. These particles are invisible to the naked eye.
- The particles are held together by intermolecular forces (IMFs). **Intermolecular forces** are forces of attraction between particles of a state of matter.

Factors that affect the size of intermolecular force in the given state of matter are:

Distance between particles

An increase in distance **d** between particles decreases the strength of intermolecular forces and vice versa.

Figure 3.2 effect of distance on the size of intermolecular forces

The size of the particles

Increasing the size of the particles increases the strength of intermolecular forces and vice versa.

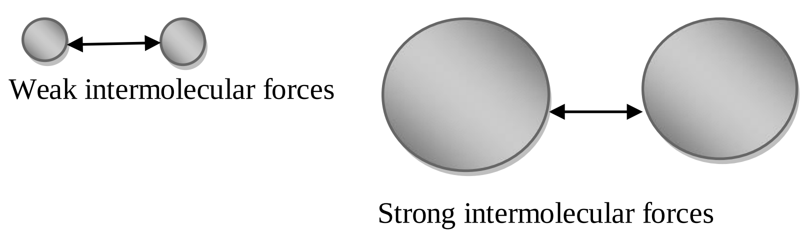


Figure 3.3 effect of size of the particles on intermolecular forces

- Kinetic theory also states that the vibrations of the particles become greater as the temperature rises.

Experiment 3.1

AIM: To investigate the kinetic molecular theory of matter **MATERIALS:** Balloon, string, heat source and fridge (freezer)
PROCEDURE:
1. Inflate a balloon.
2. Put the balloon in a freezer for some time.
3. What happens to the size of the balloon? Explain in terms of kinetic theory.
4. Remove the balloon and put it near the heat source or under the sun.
5. What happens to the size of the balloon? Explain in terms of kinetic theory.

From **Experiment 3.1**, compare your results with the following results:
3: The balloon contracts because particles lose kinetic energy and move closer to each other.
5: The balloon expands because particles gain kinetic energy and move further apart.

CONCLUSION
From the results in **experiment 3.1,** we can conclude that particles in a state of matter are always in motion.

3.3 Properties of matter

Properties of Solids

Solids have the following properties**:**
- They have a fixed shape because solids are crystalline and atoms in it are set in well – defined patterns.
- They have a fixed volume.
- They have high density because their molecules are held closer to each other.
- The volume occupied by particles is less compared to other states.
- They are incompressible because there are no spaces between particles of solids.
- Their particles vibrate about a fixed mean position.
- Their particles' vibration increases as temperature increases and their separation increases slightly.

Properties of Liquids

Liquids have the following properties;

- Their particles are closer to each other but relatively further apart when compared to solids.
- They take the shape of a container which holds them because their molecules slide over each other.
- They have a fixed volume.
- They cannot be compressed because the spaces between molecules are very small.
- Molecules in liquids vibrate more and they move at a very high speed throughout the body of the liquid.

Properties of gases

The properties of gases are as follows:

- They do not have a fixed shape because their molecules are far apart and there are a lot of free spaces between them.
- They take the shape of the container.
- They do not have fixed volume because their molecules can easily escape; therefore, they take the volume of the container which holds them.
- They have low density because they occupy a greater space (greater volume).
- They can easily be compressed because there are a lot of spaces between molecules.

3.4 Gas pressure

Pressure is defined as force exerted per given area. In gases, pressure is caused by the force exerted by gas molecules per given area on the surface of the container.

From **experiment 3.1**, when the balloon was placed near the heat source, it expanded. The pressure inside the balloon is caused by the gas particles striking the walls of the balloon. An increase in temperature causes an increase in kinetic energy of the particles. The particles that have more energy move faster and strike the inside surface of the balloon more frequently. This causes an increase in pressure.

Gas pressure can also increase by increasing the number of molecules of the gas.
When using a pump to inflate a balloon, the number of gas molecules increases. This increase in gas molecules makes the molecules to strike the inside surface of the balloon most frequently in all directions. This causes an increase in pressure. Hence the balloon expands.

3.5 Molecular motion and temperature.

Experiment 3.2

AIM: To determine the melting point of ice and boiling point of water.
MATERIALS: Bunsen burner, matches, ice blocks, tripod stand with wire gauze, thermometer, beaker, stop watch and graph paper.
PROCEDURE:

1. Put ice blocks in a beaker. Measure the temperature of ice blocks.
2. Light a Bunsen burner and heat the ice blocks.
3. Record the temperature changes every minute until the ice blocks melt and the liquid boils. Record your results in the table.

Time(min)	1	2	3	4	5	6	7	8	9	10
Temperature(^{0}C)										

Table 3.1

Plot a graph of temperature (^{0}C) against time (min).
Discuss your observations with your friends in class.

4. Write down the melting point of ice and the boiling point of water.

Figure 3.6 shows a sketch of the graph from **experiment 3.2**

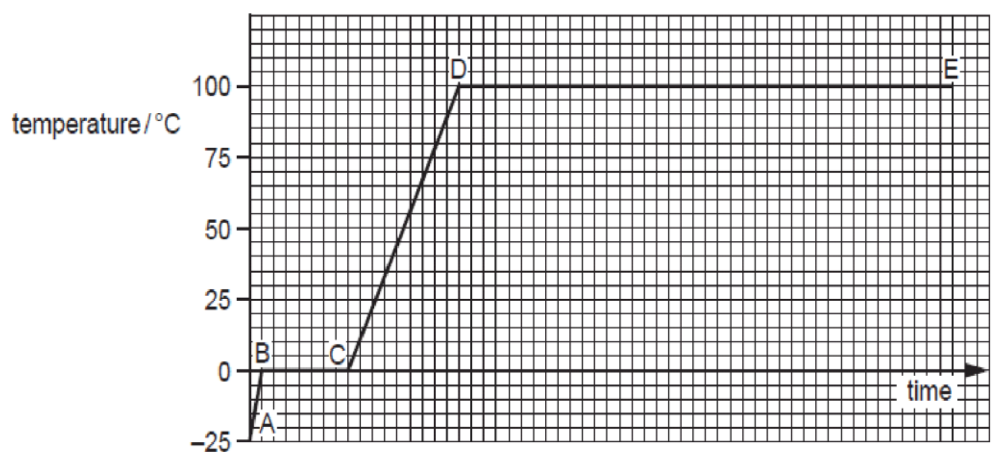


Figure 3.6 the heating graph of matter

The kinetic theory of matter can be used to explain how a substance changes from one state to another.
When a solid is heated, its temperature increases (between A and B). Its particles gain kinetic energy and vibrate more, moving further away from each other. The heat energy supplied between B and C weakens the intermolecular forces. This heat energy is called **latent heat of fusion.** This breaks the regular pattern. The particles now move around

each other. Solid forms a liquid and the process is called **melting.** This takes place at a constant temperature called **melting point.**
The temperature remains constant while melting because all the heat energy supplied is used to break down the internal bonds.

When a liquid is heated its temperature starts increasing again (between C and D). Its particles move faster by gaining kinetic energy. The particles that are on the surface have enough energy to overcome the forces between themselves. These particles of the liquid escape to form a gas. The process is called **evaporation.** Further heating makes the particles to escape from the liquid so quickly. The liquid starts **boiling** (between D and E). The temperature is called **boiling point.** This temperature is also constant because the substance gained latent heat called **latent heat of vaporization** which is used to break down the internal bonds.

Table 3.2 shows the boiling and melting points of some substances

Substance	**Melting point (^{0}C)**	**Boiling point (^{0}C)**
Water	0	100
Aluminium	661	2467
Sulphur	113	445
Ethanol	-117	79
Magnesium oxide	2827	3627
Mercury	-30	357
Methane	-182	-164
Oxygen	-218	-183
Sodium hydroxide	801	1413

When a gas is cooled, its temperature decreases. The average kinetic energy of the particles decreases and they move closer to each other. The intermolecular forces increase and this causes the change of gas to liquid. The process is called **condensation.**

When a gas is cooled, its temperature decreases. The average kinetic energy of the particles decreases and they move closer to each other. The intermolecular forces increase and this causes the change of liquid to solid. The process is called **freezing.**

NOTE: During condensation and freezing, heat energy is given out.

Figure 3.7 is a summary of changes of state of matter.

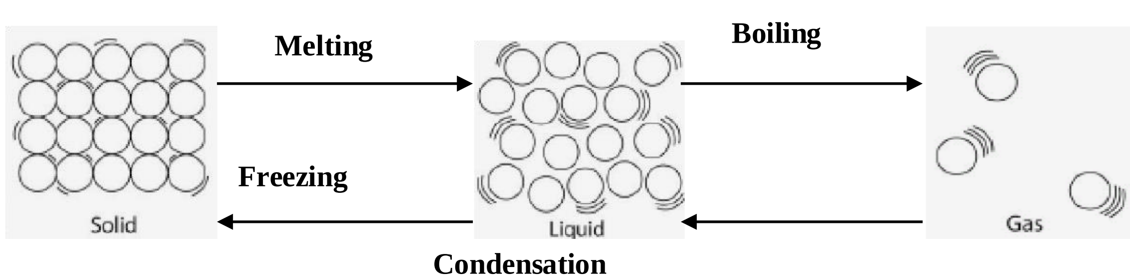


Figure 3.7 changes of states of matter

Motion of gas molecules

Gas molecules move at high speed at random in a container. The movement is known as **Brownian motion.**

When the temperature of the gas increases, the speed of molecules also increases because particles gain kinetic energy. This is shown by the collisions or bombardment of invisible molecules on the visible particles.

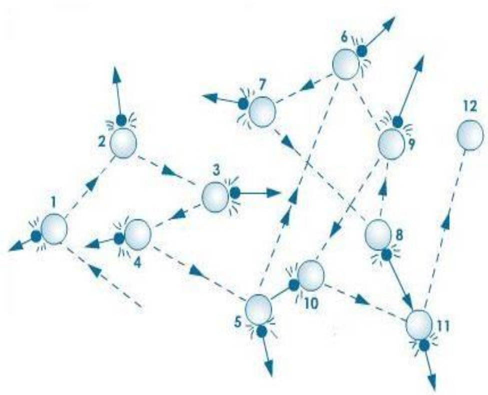


Figure 3.8 Brownian motion of gas molecules.

Diffusion

Diffusion is the movement of molecules (fluid molecules) from a region of high concentration to a region of low concentration. This is the process by which different substances mix as a result of the random motions of their particles.

Diffusion stops when there is even distribution of the fluid.

If you open a bottle of perfume in one corner of a room the scent can be detected throughout the whole room because the scent will move from a region of high concentration (where the bottle is) to a region of low concentration (where there is no perfume).

Demonstrating diffusion

Diffusion of bromine gas and air can be demonstrated as shown in **Figure 3.9**.

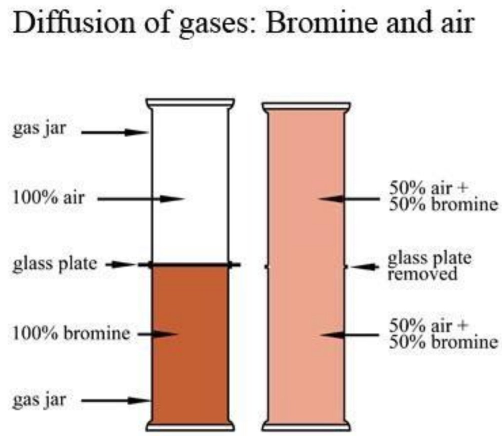


Figure 3.9: diffusion of bromine gas and air

When the glass plate is removed so that the two open ends of the jars are in contact, bromine gas diffuses rapidly into the air.

Diffusion of bromine gas into the air is noticed by the paler brown colour of bromine in air. This takes place until there is uniform paler brown colour in both jars. The air molecules again diffuse into the bromine gas.

NOTE

Diffusion can take place at a high rate if it is carried out at high temperature because high temperature increases the kinetic energy of the particles.

Lighter molecules diffuse faster than heavy molecules.

Diffusion also occurs in liquids but it takes much longer days because molecules in liquids are not very fast as explained in kinetic theory of liquids

It also occurs in solids. But diffusion is not noticeable in solids because it takes many years for a very small layer of the substance to diffuse. This is so because molecules in solids are held close together by strong forces.

Applications of diffusion

Diffusion has the following applications in the body:

- Oxygen diffuses from alveoli (air sacs) into the blood capillaries in the lungs.
- Carbon dioxide diffuses from the blood capillaries to the alveoli in the lungs.
- Digested food diffuses from the small intestines into the blood capillaries of the villi.

3.6 Absolute temperature

Absolute temperature is the minimum temperature that any substance can reach when it is cooled. If you put water in the freezer, the temperature of the water decreases and goes beyond

0^0C. This substance's temperature will stop decreasing when it reaches -273^0C. This temperature is called **absolute zero.** The Lord Kelvin proposed his temperature scale in 1854, called **Kelvin scale**, which has 0 K at absolute zero.

When the temperature of water decreases, the kinetic energy of the particles also decreases. This decreases the volume of water. At absolute zero the particles do not have any motion.

Therefore, we can also define **absolute temperature** as the temperature at which molecules have the minimum possible kinetic energy.

Figure 3.10 is a graph showing the relationship between the volume of a gas and temperature.

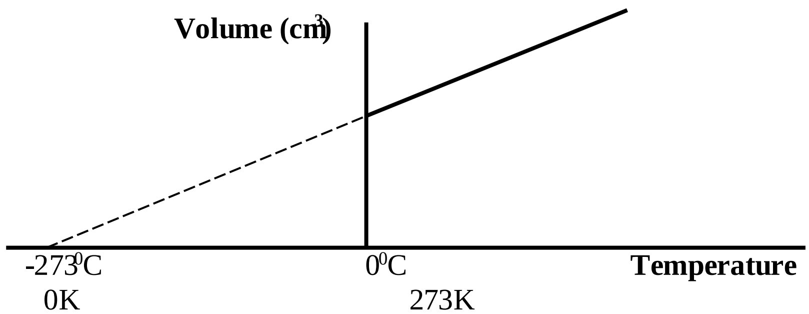


Figure 3.10 Volume of a gas against temperature

Chapter 4

Thermometry

4.1 Types of temperature scales

Measurement of temperature

Temperature is measured using instruments called **thermometers.** Temperature is measured either in Kelvin (K) or Degrees Celsius (^oC). Therefore, the two types of temperature scales are Celsius scale and Kelvin scale.

Celsius temperature scale

A Celsius scale has a lower fixed point of 0^oC and the upper fixed point of 100^oC. Extensions can be made above 100^oC or below 0^oC. The absolute zero temperature on the Celsius scale is -273^0C.

Kelvin temperature scale

Temperature is the measure of the hotness and coldness of a substance or an object. Temperature is measured using instruments called **thermometers.**

Kelvin temperature scale is the scale found by Lord Kelvin in 1854. This is the scale which is used by scientists in scientific work.

The lower fixed point of the Kelvin scale is at 273.15 K (approximately 273 K).

The upper fixed point of a Kelvin scale is 373.15 K (approximately 373 K). The absolute zero temperature on the Kelvin scale is 0K.

Converting Celsius to Kelvin

If you want to convert degrees Celsius to Kelvin, you must add 273 to the temperature in degrees Celsius.

Kelvin = degrees Celsius + 273

K = ^oC + 273

Worked examples

Convert the following degrees Celsius to Kelvin:

1. 100^0C

Solutions K = ^0C + 273 K = 100 + 273

K = **373 K**

Converting Kelvin to degrees Celsius

If you want to convert Kelvin to degrees Celsius you must subtract 273 from the temperature in Kelvin.

^oC = K – 273

Worked examples

Convert the following to degrees Celsius:

1. 350 K
2. 310 K

Solutions

1. ^0C = K - 273

   ^0C = 350 - 273

   ^0C = **77 ^0C**

4.2 Types of thermometers

Temperature is measured by an instrument called **thermometer.** There are different types of thermometers depending on the physical property that varies with temperature.

Liquid-in-glass thermometer

Liquid-in-glass thermometer uses expansion and contraction of a liquid.

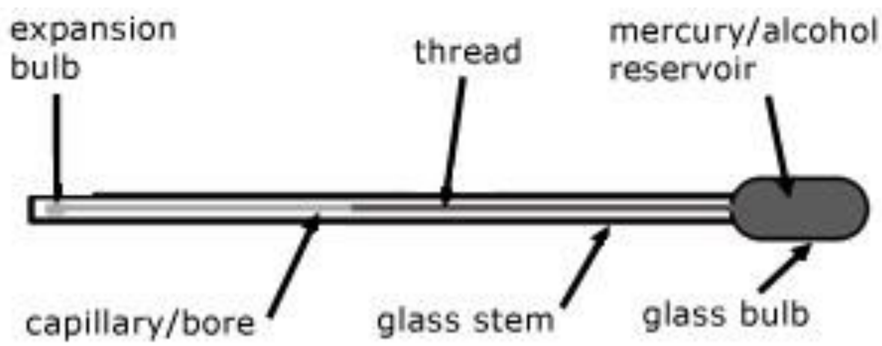


Figure 4.1: a liquid-in-glass thermometer

How a liquid-in-glass thermometer works

In the thermometer shown in **Figure 4.1** above, mercury and ethanol liquids are used. The liquid is in a thin capillary tube. When temperature increases, the walled bulb enables heat to pass through quickly, and the liquid is heated. The liquid expands to attain the temperature of the surrounding. When temperature decreases the liquid contracts and gives the temperature of the surrounding.

A bulb of a thermometer is thin in order to enable heat energy to pass through quickly. The capillary tube is very narrow so that a small change in temperature causes a reasonable movement of the liquid. The glass stem is thick in order to prevent the glass from breaking. The glass also acts as a measuring glass. Examples of liquid-in-glass thermometer are laboratory thermometer and clinical thermometer.

Liquids used in liquid-in-glass thermometers

There are two major liquids used in liquid thermometers. These liquids are mercury and Ethanol (alcohol). Each of these liquids has the following advantages and disadvantages:

Mercury

The advantages of using mercury in a liquid thermometer are:

- **a.** It expands uniformly.
- **b.** It does not wet the sides of the tube or it does not cling to the walls of the tube.
- **c.** It is a good conductor of heat.
- **d.** It has a high boiling point of 357^{o}C.
- **e.** Its specific heat capacity is very low.

The disadvantages of using mercury in liquid thermometers are:

- **a.** It freezes at -39^{o}C, therefore mercury cannot be used in very cold regions that have temperatures below -39^{o}C.
- **b.** It is poisonous. It would cause health hazards if the tube broke.
- **c.** Its expansivity is low.

d. It is very expensive.

Alcohol

The advantages of using alcohol in liquid thermometers are:

- **a.** It expands uniformly and its freezing point is -115°C. Therefore, it can be used in very cold regions.
- **b.** It has a large expansivity. Alcohol can therefore be used in wide tubes as well.

The disadvantages of using alcohol in liquid thermometers are:

- **a.** It has to be coloured to be seen clearly.
- **b.** It wets the tube because it clings to the walls of the tube.
- **c.** It has a low boiling point of 78°C.
- **d.** Its thread has a tendency of breaking.
- **e.** It has a high specific heat capacity.

Clinical thermometer

A clinical thermometer is used to take the temperature of the body. The thermometer uses expansion and contraction of mercury. It has a constriction in the capillary tube just above the bulb.

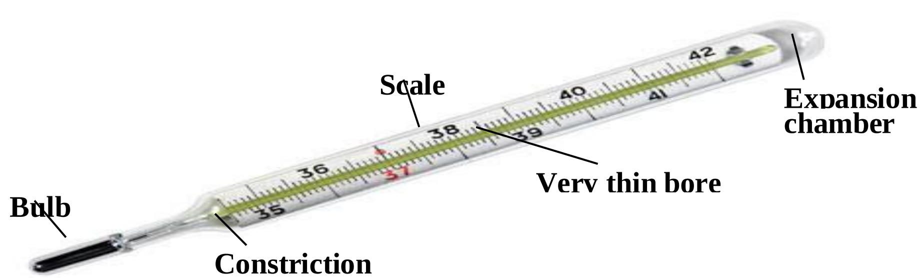


Figure 4.2 clinical thermometer

How a clinical thermometer works:?

When a clinical thermometer is put in the patient's mouth or under the armpit the temperature rises. The mercury in the capillary tube expands and it is pushed through the constriction and up the tube. When a clinical thermometer is taken out of the patient's mouth or armpit, the mercury cools and contracts. The mercury cannot go back through the constriction and the thread breaks.

This is an advantage because the mercury in the tube cannot go back into the bulb and patient's temperature can be read off. You must shake the thermometer to get the mercury back into the bulb.

The scale of the clinical thermometer ranges from 35^0C to 42^0C since the normal body temperature is only 37^0C. The short range enables the thermometer to be short. The thermometer is more accurate and has high sensitivity.

Thermocouple thermometer

A thermocouple thermometer is a thermometer which uses a thermo-electric property. It consists of two wires of different materials e.g. copper and iron.

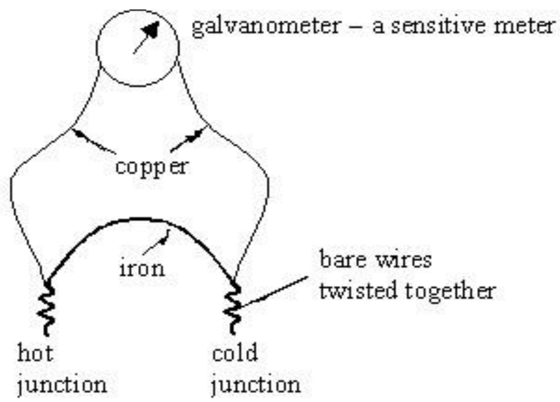


Figure 4.3: thermocouple

How a thermocouple thermometer works?

When the hot junction is heated an electric current flows and produces a reading on a sensitive meter. The value of current produced depends on the temperature difference.

Advantages of a thermo couple thermometer

- **a.** It has low heat capacity. It can be used to measure fluctuating temperatures.
- **b.** It has a very large range. The range is from -200^{0}C to 1500^{0}C.
- **c.** It can measure the temperature at a point.

Disadvantage: A thermocouple thermometer can only be used over a certain temperature range where variation of current with temperature is uniform.

Resistance thermometer

Resistance thermometer uses the variation with temperature of the resistance of a coil of wire. **For example:** In platinum wire, the resistance of the wire decreases with an increase in temperature. In nichrome wire, the resistance of the wire increases with an increase in temperature.

Advantages of a resistance thermometer

- **a.** It is far more accurate.
- **b.** It has a very large range.
- **c.** It can be read at a distance if it has longer leads. This enables the observer to be far from where the temperature is being measured, e.g. in a blast furnace.

Chapter 5

Pressure

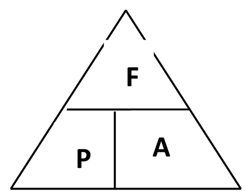
5.1 What is pressure?

When forces act on a surface their effect is spread over an area. This effect creates pressure. **Pressure** is defined as the force exerted per unit area.

Pressure is calculated by dividing the force acting at right angles to the surface by the area over which it acts.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area on which force acts}}$$

$$\mathbf{P = \frac{F}{A}}$$



If force is measured in Newtons (N) and area in cm^2, then pressure is measured in N/cm^2.
If force is measured in Newtons (N) and area in m^2, then pressure is measured in N/m^2.

$1N/m^2$ is equivalent to 1 Pascal.

$1N/m^2$ = 1

Pa For example:

If a force of 50 N acts on an area of $10cm^2$, the pressure is **5 N/cm^2** If a force of 50 N acts on an area of $10m^2$, the pressure is **5 Pa.**

5.2 Pressure exerted by solids

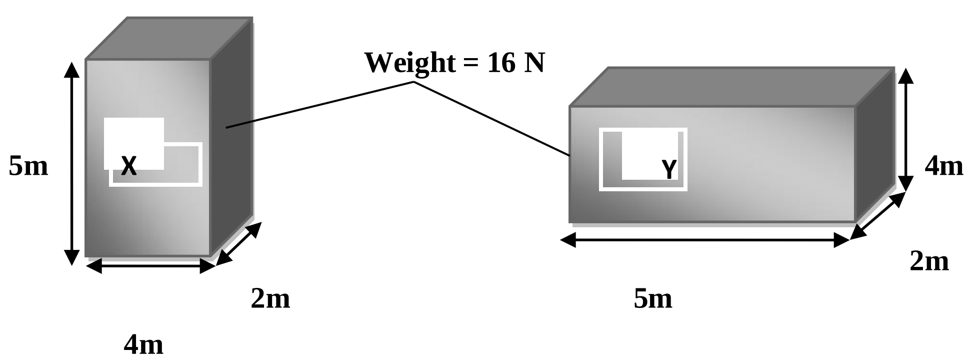


Figure 5.1

Area = 4m x 2m = 8m² **Area = 5m x 2m = 10 m²**

$$\text{pressure} = \frac{16}{8m^2} \qquad \text{pressure} = \frac{16N}{10m^2}$$

Pressure = 2Pa **Pressure = 1.6 Pa**

Figure 5.1 shows a box in position X and position Y
In position X a box is exerting a force on a smaller area while in position Y a box is exerting a force on a larger area. When the force is spread over a larger area, pressure is reduced because the force on each square metre is reduced and vice versa. From **Figure 5.1**, the pressure under block X is less than the pressure under block Y.

Factors that affect pressure exerted by solids

1. Contact surface area

As it was explained in **Figure 5.1**, the size of pressure is affected by the surface area on which force is exerted.
A large surface area causes less pressure. A small area of contact increases pressure or causes high pressure. This can be demonstrated by the following examples:

When the ground is very soft, a farmer is encouraged to use a vehicle with wheel B because it has a large flat surface. A large surface produces less pressure to the ground.
If a farmer uses a vehicle with wheel A, the car is likely to sink due to the small area of contact. This causes high pressure.

a. If you stepped on the point of a sharp nail with your bare foot, it would be extremely painful because the surface area is very small. Hence a sharp nail exerts greater pressure on your bare foot.

b. If you lie on a bed of nails-points with a large number of nails, it would not be extremely painful because the surface area of the nails has increased. Hence sharp-nails exert less pressure on your body.

2. Size of the force

Pressure exerted by solids can increase with an increase in the size of the force when surface area is kept constant because more force acts per given area.

Worked examples

1. A block weighing 200 N rests on an area of 2 m^2. Calculate the pressure exerted by the block on the surface which supports it.

Solution

F =200 N A= 2 m^2 P =?

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

$$P = \frac{200\ N}{2\ m^2}$$

P= **300 N/m²** OR P = **300 Pa.**

2. Pressure exerted by a regular solid of base area $10cm^2$ is $3N/cm^2$. Calculate the weight of a solid.

Solution $P=3N/cm^2$ A= 10 cm^2 F=?

$F = P \times A$

$F = 3\ N/cm^2 \times 10\ cm^2$

F = **30 N**

3. A block of mass 20 kg has the base measured 0.2 m x 1.5 m. Calculate the pressure exerted by the block to the ground.

Solution

$F = 20 \times 10\ N = 200\ N$ $A= 0.2 \times 1.5 = 0.3\ m^2$ p =?

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

$$P = \frac{200\ N}{0.3\ m^2}$$ P= **666.7 Pa**

Pressure in liquids

Pressure in liquids is caused by the force exerted by the liquid molecules on the wall of the container.

Internal stresses are set up in the liquid by external forces, and these allow the pressure in a liquid to be transmitted in all directions.

Factors affecting pressure in liquids

1. Pressure in a liquid increases with depth

The deeper into the liquid, the greater the pressure because as you go deep the weight of the liquid above increases. When the weight of the liquid increases, pressure also increase

Experiment 5.1

AIM: To show that pressure in a liquid increases with depth.
MATERIALS: Spouting can, 3 beakers and water
PROCEDURE:

1. Punch 3 equal sized holes at different heights in a spouting can as shown **Figure 5.3** Below.

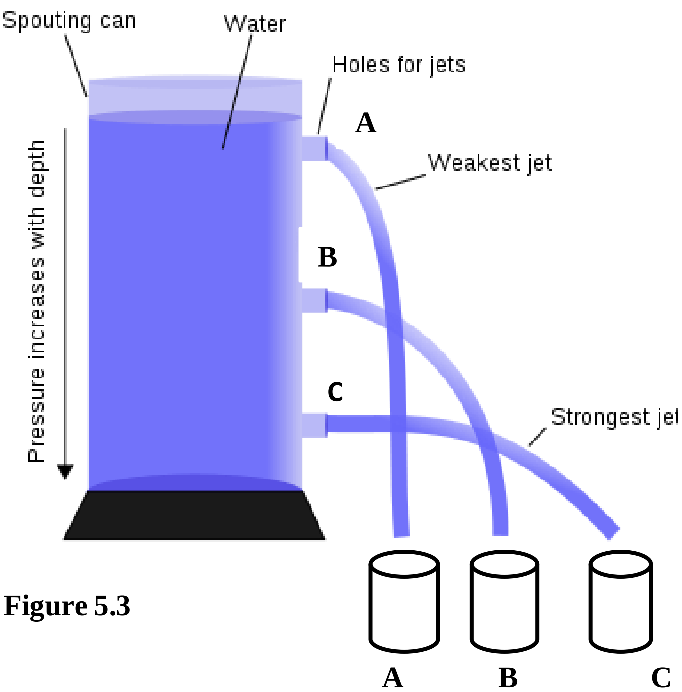


Figure 5.3

2. Stand the spouting can on one end.
3. Position 3 beakers to catch the water.
4. Fill the spouting can with water.
5. Keep on adding water in the spouting can for some minutes.
6. From which outlet is water thrust further horizontally?
7. Which beaker has highest water level?

RESULTS

Water from outlet C is thrust further horizontally compared to outlet B. Water from outlet B is thrust further horizontally compared to outlet A. Beaker catching water from outlet C has the highest level of water, seconded by beaker catching water from outlet B then A has the lowest level of water.

EXPLANATION

Water squirts (comes out) with greatest pressure at outlet C.

Water squirts (comes out) with least pressure at outlet A.

CONCLUSION

This shows that the pressure of water is greatest at the deepest point in the liquid. Therefore, pressure in liquid increases with depth.

2. Density

Pressure in liquid increases with density because denser liquid is heavier or has a greater weight than a less dense liquid of the same volume. **For example,** if 1*l* of water of density 1g/cm^3 and 1*l* of mercury of density 13.6g/cm^3 are placed in identical containers, mercury will produce more pressure at the bottom of the container than water would because mercury is more dense t

Experiment 5.2

AIM: To show that pressure in liquid is affected by density
MATERIALS: A solid, spring balance, water, mercury, 2 beakers and ruler.
PROCEDURE:

1. Pour the same volume of water and mercury in separate identical beakers.
2. Weigh the block in air using the spring and record its weight as W1.

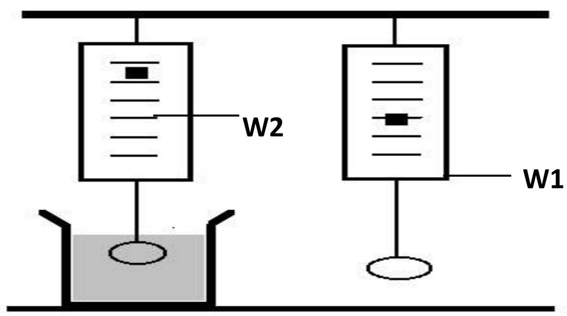


Figure 5.7

3. Immerse the base of the solid in water to a measured height.
4. Record the new weight on the spring as W2.
5. Calculate the weight of water as:
   Weight of water = apparent loss in weight
   Weight of the water = W2- W1
6. Repeat the experiment by immersing the block of wood in mercury to the same measured height.

RESULTS:
When a solid was immersed in water the apparent loss in weight was less than the apparent loss of weight when it was immersed in mercury.

EXPLANATION/CONCLUSION
Apparent loss of weight in water was less because water is less dense and has less weight. Apparent loss of weight in mercury was greater because mercury is denser and has more weight. The pressure exerted by water on a given area of a solid is less than the pressure exerted by mercury. Therefore, pressure in liquid is affected by density.

Calculation of pressure in a liquid

The pressure of a liquid depends on its density and depth.

To derive the formula $p = \rho hg$

Using the container shown in **Figure 5.8** below:

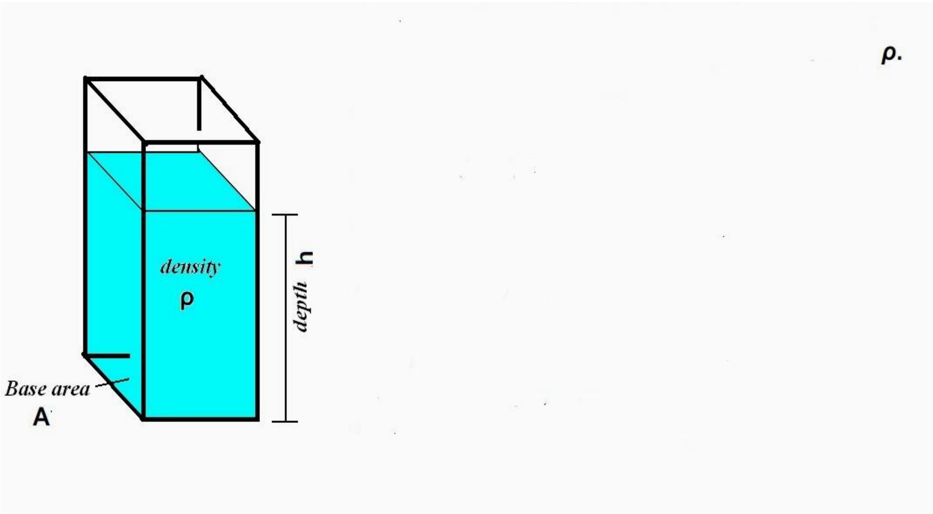


Figure 5 .6 Pressure in liquid

We consider base area of a liquid, **A** at a depth (height) of **h** and density of a liquid **ρ**.

Volume of a liquid = base area x depth = **Ah**

Mass of a liquid = density x volume = **ρ x v**

But v = A x h

Therefore, mass of a liquid = **ρAh**

Weight of a liquid = mass x acceleration due to gravity = **m x g**

But mass = **ρAh**

Therefore, weight of a liquid = **ρAhg**

$$\text{Pressure} = \frac{\text{Force (weight)}}{\text{Area}}$$

$$\text{Pressure} = \frac{\rho A h g}{A}$$

Therefore, **pressure = ρhg.**

The pressure of a liquid = density x depth (height) x acceleration due to gravity

Whereby: density is in kg/m^3, depth(height) is in m and acceleration due to gravity is 10 m/s^2.

Worked examples

1. Calculate the pressure exerted by a column of a liquid at the base of a container if the density of a liquid is 13600 kg/m^3 and its depth is 0.1m. ($g = 10m/s^2$)

solution

$\rho = 13600kgm^{-3}$ $h = 0.1m$ $p = ?$ $g = 10m/s^2$

$P = \rho hg$

$P = 13600\ kg/m^3 \times 0.1 \times 10\ m/s^2$

P = 13600 pa OR **P= 13.6 Kpa**

2. A pressure of 1000pa is exerted by a column of petrol in a tank of a car. Calculate the height of the petrol column (Density of petrol = $800kg/m^3$, $g = 10m/s^2$)

$P = 1000pa$ $\rho = 800kgm^{-3}$ $g = 10ms^{-2}$ $h = ?$

$P = \rho hg$

$$h = \frac{p}{\rho g}$$

$$h = \frac{1000\ Pa}{800kg/m^3 \times 10m/s^2}$$

H = 0.125m OR **h= 12.5 cm.**

5.4 Pascal's principle

Blaise Pascal was a French mathematician. Pascal came up with his principle of transmission of fluid pressure. Pascal's principle of transmission of pressure in fluids states that pressure exerted anywhere in an enclosed incompressible fluid is transmitted equally in all directions throughout the fluid.

The pressure applied anywhere to a body of fluid causes a force to be transmitted equally in all directions; the force acts at right angles to any surface in contact with the fluid. This causes the pressure variations (initial differences) to remain the same.

Experiment 5.3

AIM: To investigate the transmission of pressure in liquids
MATERIALS: Large syringe, smaller syringe, water and a pipe.
PROCEDURE:

1. Set up the experiment as shown in **Figure 5.7** below.

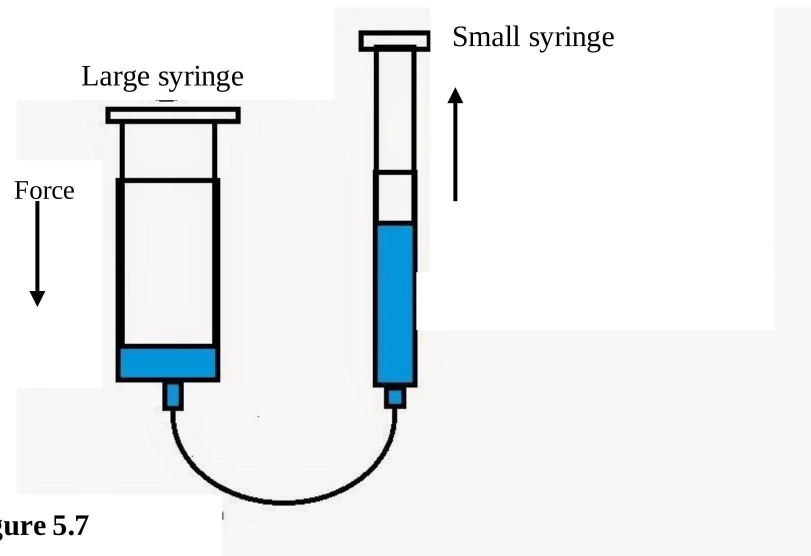


Figure 5.7

2. Push the plunger on the larger syringe while holding the plunger on the smaller syringe.

How do you feel on the smaller syringe?

DISCUSSION
When the piston on the plunger on the large syringe is pushed in, the person holding the plunger on the smaller syringe will feel the plunger moving out. The pressure has been transmitted through the liquid in the system.

Using Pascal's principle, the pressure in a large syringe equals the pressure in the smaller syringe.

Pressure in a large syringe = pressure in a small syringe

$$\frac{\text{Force}}{\text{Area for the large syringe}} = \frac{\text{Force}}{\text{Area for the small syringe}}$$

$$\frac{\textbf{Force}}{\textbf{larger area}} = \frac{\textbf{Force}}{\textbf{small area}}$$

Worked example

If the force on a large syringe is 80 N and the area is 0.5 m^2, calculate the force on the small syringe with area 0.1 m^2.

Solution

Pressure in a large syringe = pressure in a small syringe

$$\frac{\text{Force}}{\text{large area}} = \frac{\text{Force}}{\text{small area}}$$

$$\frac{80\ \text{N}}{0.5\ \text{m}^2} = \frac{\text{Force on a small syringe}}{0.1\ \text{m}^2}$$

$$\text{Force on the small syringe} = \frac{80\text{N} \times 0.1\ \text{m}^2}{0.5\ \text{m}^2}$$

Force on a small syringe = **16 N**

5. 5 Atmospheric pressure

Atmospheric pressure is experienced because air that is called atmosphere exerts pressure on objects. This pressure is normally called **Air pressure**.

Demonstrating atmospheric pressure

1. Collapsing can experiment

Experiment 5.4

AIM: To demonstrate atmospheric pressure
MATERIALS: A can, tap water, very cold water, heat source
PROCEDURE:

1. Pour some tap water into a can.
2. Heat some water in an open can until it boils.
3. Remove the can from the heat and screw on its cap tightly.
4. Cool the can by running cold water over it.
   The can suddenly crumples as shown in **Figure 5.8** below. Explain why.

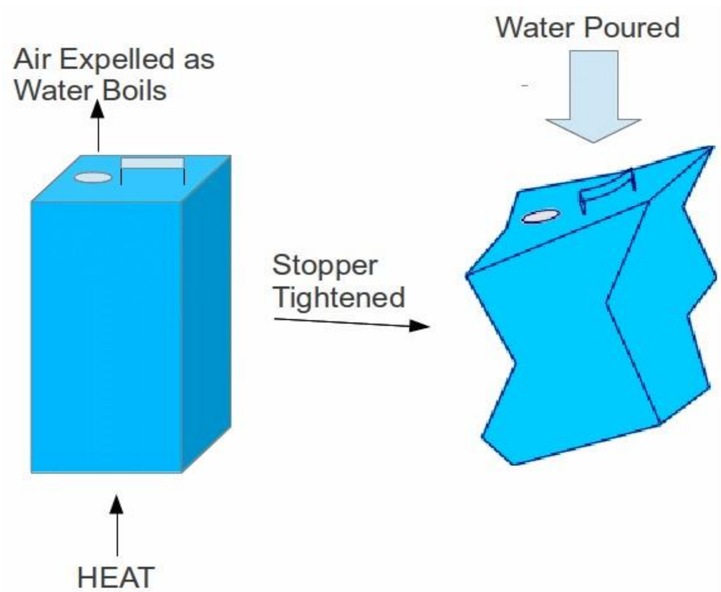


Figure 5.8 crushing can experiment

The steam produced in a can replaces the air and molecules in the steam and exerts pressure on the walls of the can equal to the atmospheric pressure. The tightly screwed can suddenly crumples when it is cooled by running cold water. The steam inside the can has condensed into a very small volume of water. This leaves a partial vacuum behind. The decrease in temperature decreases the kinetic energy of molecules inside the can. The pressure inside the can decreases and it is less than the atmospheric pressure. The pressure difference on opposite sides of the walls of the can results in a very large unbalanced force acting inwards.

2. Drinking straws

In the drinking straw, air is first sucked out of the straw. The pressure of air inside the straw is less than the atmospheric pressure which is pressing down on the surface of the liquid outside the straw. Therefore, the liquid is forced out up the straw and into the mouth.

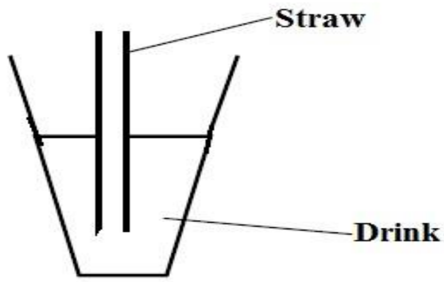
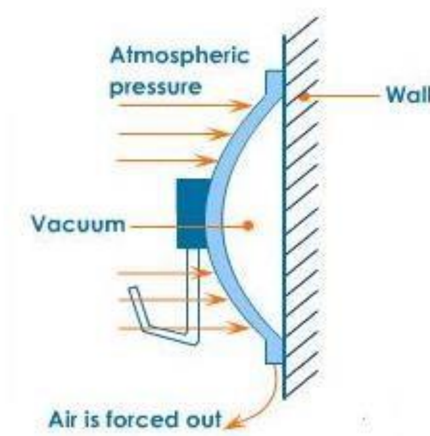


Figure 5.9 drinking through a straw

3. Rubber sucker

When the moistened concave surface of the rubber sucker is pressed against a flat surface the air between the two surfaces is squeezed out. This leaves the pressure in the enclosed space much reduced and creates a vacuum. The atmospheric pressure acting on the sucker forces the sucker against the flat surface.



4. Vacuum cleaner

In a vacuum cleaner, a fan lowers the air pressure just beyond the bag. This creates a pressure difference between the inside and outside the vacuum cleaner. The atmospheric pressure rushes in, carrying dust and dirt with it. The dust and dirt is stopped by the bag but the air is not stopped.

Measuring atmospheric pressure

The instruments that are used to measure atmospheric pressure are called **barometers.** The following are the types of barometers used:

1. Mercury barometer

A simple mercury barometer uses a thick walled tube of about 1 m long. It uses mercury that is poured into the tube. This mercury tube is inserted into a wider vessel containing mercury. Some mercury runs out of the tube into the vessel leaving the space at the top of the tube. The space left at the top of the tube is called a **Vacuum**.

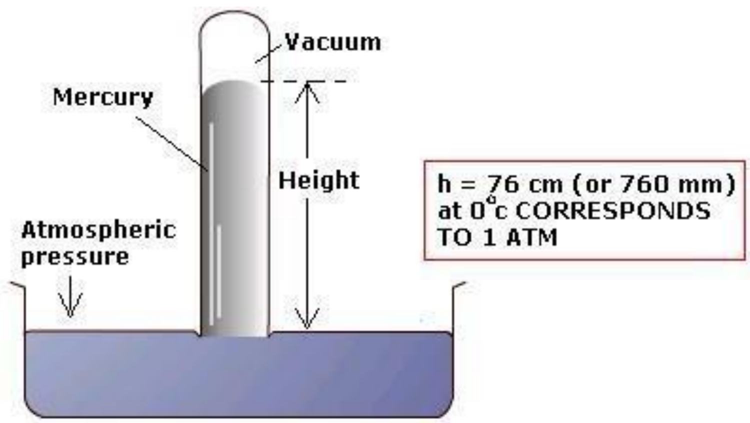


Figure 5.12 diagram of a simple mercury barometer.

How a mercury barometer works?

When atmospheric pressure is acting on mercury in the vessel it pushes mercury downwards and forces it up into the tube. The mercury rises to a height that is equivalent to atmospheric pressure. The height of mercury, **h** is measured on a ruler.

Standard pressure

At sea-level, the mercury level inside the tube rises up to 760 mm of mercury (760 mm Hg). The height, **h** of mercury at sea-level is called **Standard atmospheric pressure.** Therefore, standard atmospheric pressure is 760 mmHg. 760mm Hg can also be expressed as 0.76 m Hg or 76 cm Hg.

Worked example

Calculate the atmospheric pressure in Pascals (pa) when a mercury barometer supports a column of mercury 76 cm high. (Density of mercury = $13600 kg/m^3$)

Solution

$P = ?$ $h = 76$ cm $= 0.76$ m $\rho = 13600 kg/m^3$ $g = 10 m/s^2$

$P = \rho h g$

$P = 13600 kg/m^3 \times 0.76 m \times 10 m/s^2$

Pressure = **103360pa.**

2. Water barometer

Water can be used in a barometer instead of mercury. The first water barometer was built by **Von Guericke** in the seventh century. A longer tube is required to use water in a barometer because water is far much less dense than mercury. For example, at sea level where the atmospheric pressure is 100 000 Pa, we can calculate the height of the water in the tube as follows:

density of water = 1000 kg/m^3,   g = 10m/s^2 and p = 100 000 Pa

pressure = ρgh

100 000 pa = 1000 kg/m^3 x 10 m/s^2 x h

$h = \frac{100\,000 \text{ pa}}{1000 \text{ kg/m}^3 \times 10}$

m/s^2 h = **10 m**

Therefore, the level of the column of water at sea level is 10 m. The water barometer is not very useful in practice.

3. Aneroid barometer

The main feature of the aneroid barometer is the small sealed metal box containing air at low pressure.

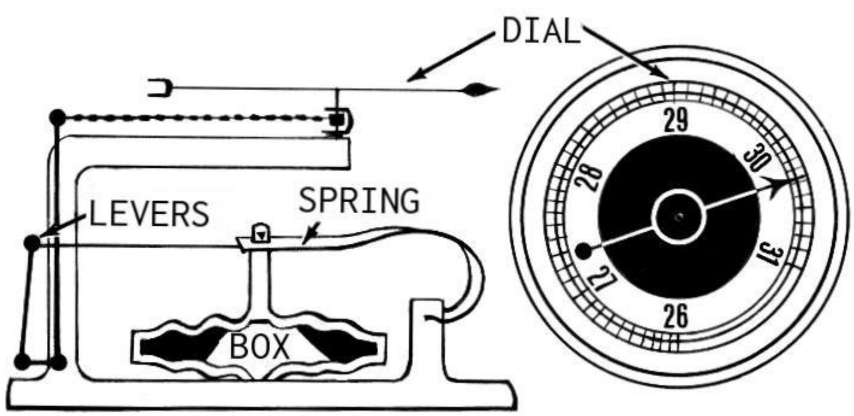


Figure 5.13 aneroid barometer

How an aneroid barometer works.

Atmospheric pressure tries to squash the metal box which is corrugated to make it more flexible in the middle. If the pressure rises, the top and the bottom of the metal box become even more squashed in. The movement of the box is magnified by a lever. The lever pulls a chain which moves the pointer further up the scale.

Aneroid barometers are more portable, much easier to use and cheaper than mercury barometers.

5.6 Applications of pressure
Applications of pressure in liquids

Pressure in liquids is used in the following:

1. Hydraulic machines

Hydraulic machines are used to lift the weight of a body. Examples of hydraulic machines are hydraulic folk lifters, hydraulic jacks, hydraulic brakes and hydraulic loaders. Hydraulic machines operate by using Pascal's principle of transmission of pressure in fluids. This happens because liquids are incompressible, so when the liquid is pressed, pressure is transmitted to all parts of the liquid and the pressure is the same.
In hydraulic machines a small force (effort) move a large force (load) as shown in **Figure 5.14**.

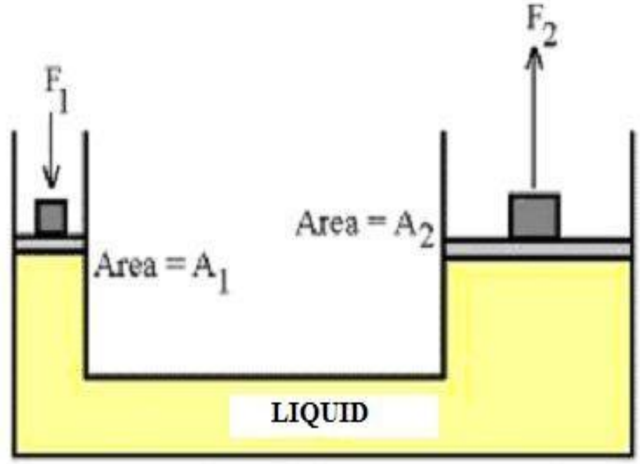


Figure 5.14 hydraulic machine.

When an effort, F_1 is applied at A_1, the small piston is pushed down and a liquid gets pushed through the pipe.
The liquid is forced to push the load at A_2 upwards. The same pressure applied by the liquid at A1 is the same pressure that is used to lift up the load.

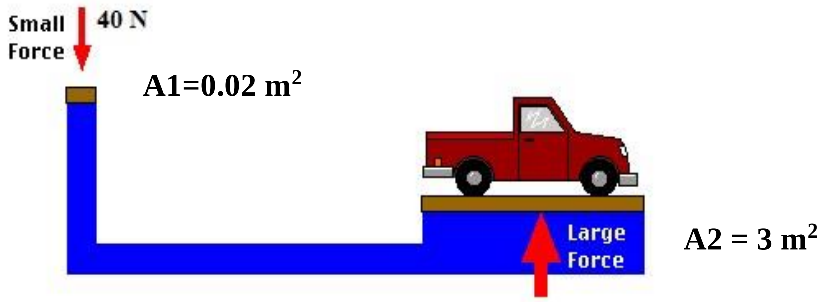
$$\text{Pressure at } A_1 = \frac{\text{force}}{\text{Area}}$$

Pressure at A_2 = pressure at A_1

Upward force on a load at A_2 = pressure at A_1 x Area at A_2

Worked example

Figure 5.15 is a diagram showing a simple hydraulic machine used to lift a load.



a.Figure 5.15 Calculate the pressure exerted on the liquid by an effort of 40N.

b. Calculate the thrust (Force) on the load.

Solution

Effort = 40 N $A_1 = 0.02\ m^2$ Load =? $A_2 = 3m^2$

a. Pressure exerted by a load of 40N

$P = \frac{F}{A} = \frac{\text{effort}}{A_1}$

$P = \frac{40\ N}{0.02\ m^2}$

P = **2000 pa**

b. Thrust(force) on the load

Force = pressure x area, A_2 F = 2000 pa x 3 m^2 F = **6000 N.**

OR

$\frac{\text{Force (effort)}}{A_1} = \frac{\text{Force (load)}}{A_2}$

$\frac{\text{Force (load)}}{A2} = \frac{\text{Force (effort)}}{A_1}$

Force (load) = <u>Force (effort) x A2</u>

$$A_1$$

$$= \frac{40\ \text{N} \times 3\ \text{m}^2}{0.02\ \text{m}^2}$$

Force on the load =
6000N.

2. Construction of dams

Liquid pressure is used in construction of dams. The bottom of the dam is made thicker in order to withstand liquid pressure which increases with depth.

3. Water supply systems

The water supply comes from a reservoir on high ground. The water flows through the pipe to the taps and storage tanks that are at a lower level because liquid pressure increases with depth.

Applications of Atmospheric (air) pressure

The following are the applications of atmospheric pressure in our everyday life:

1. Drinking straw
2. Rubber sucker
3. Syringe

These applications have already been explained in **section 5.5**.

5.7 Archimedes' principle

Archimedes' principle

When an object is immersed in a liquid the liquid exerts an upward force which is known as **upthrust.** Therefore, an object weighs less in water than in air. If an object weighs 10 N in air and it weighs 7 N when immersed in water, the upthrust is found as:

Upthrust = Weight of an object in air– weight of an object in water
Upthrust = 10 N – 7 N = **3 N**

The weight of an object in water which is lower than the real weight of an object is called **apparent weight.**
Upthrust is proportional to the weight of displaced liquid.

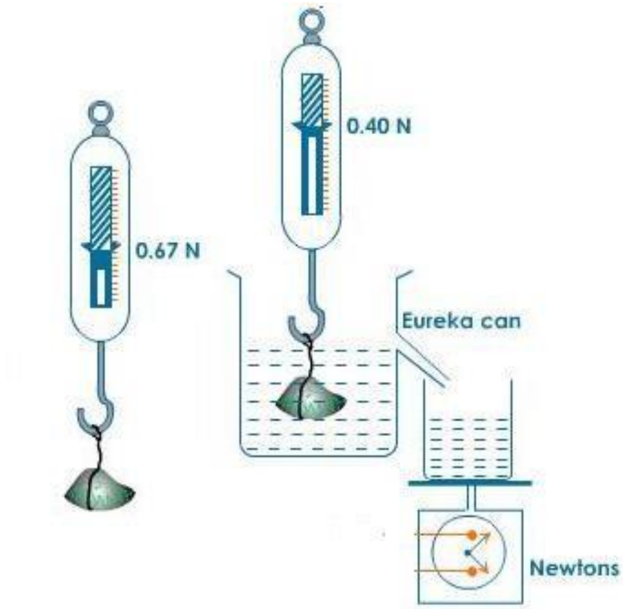


Figure 5.16 apparent weight

The upthrust of the object in **Figure 5.16** = 0.67 N – 0.40 N = **0.27 N**

The 0.67 N object has an upthrust of 0.27 N. Therefore, it displaces 0.27 N of water.
The 0.67 N object feels like it only weighs 0.40 N under water. Therefore, apparent weight of an object is 0.40 N.

Archimedes' principle states that **'if a body is totally or partially immersed in a fluid (gas or liquid) the fluid exerts an upthrust which is equal to the weight of the fluid displaced'.**

Experiment 5.5

AIM: To verify Archimedes' principle
MATERIALS: Beaker, mass, displacement can, spring balance, top pan balance, a small block
PROCEDURE:

1. Suspend (hang) the block in air from the spring balance. Record its weight.
2. Fill the displacement can with water until it reaches a point of overflowing.
3. Place a clean, dry empty beaker on a top pan balance. Calculate its weight as m (in kg) x 10 kg/N.
4. Place an empty beaker under the spout of the displacement can.
5. Carefully lower the block, still attached to the spring balance.

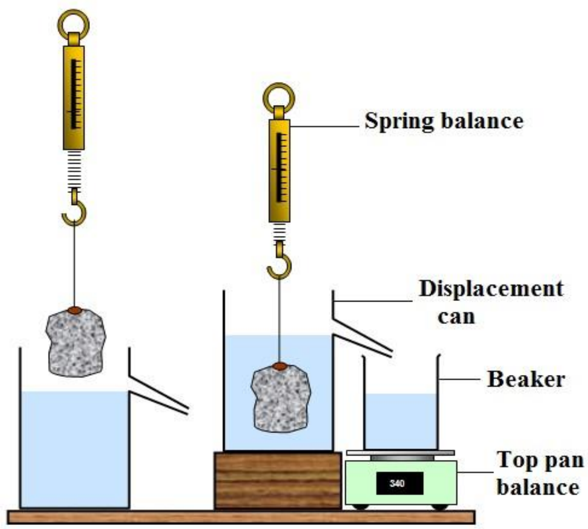


Figure 5.16

6. Record th
7. Calculate the apparent loss in weight (upthrust).
8. Place a beaker containing displaced water on a top pan balance. Calculate its weight as m (in kg) x 10 kg/N.
9. Calculate the weight of the displaced water as follows:
   Weight of displaced water = weight of beaker containing water – weight of an empty beaker.
10. Set down the results as follows:

Weight of a block in air	=	N
Weight of a block in water	=	N
Apparent loss in weight of a block (upthrust)	=	N
Weight of an empty beaker	=	N
Weight of a beaker with displaced water	=	N
Weight of displaced water	=	N

Compare the apparent loss in weight of a block and weight of displaced water.
Discuss your results with your friends in class.

EXPLANATION/CONCLUSION

From **experiment 5.5** the apparent loss in weight (upthrust) of a block must be equal (or approximately equal) to the weight of displaced water.

Apparent loss in weight of a block (upthrust) = weight of the displaced water.

The displacement can in Archimedes' principle is also called **Eureka can.**

Relative density of a substance

Relative density of a substance is the ratio of the density of any volume of substance to the density of an equal volume of water.

$$\text{Relative density} = \frac{\text{density of any volume of substance}}{\text{density of an equal volume of water}}$$

For example: If the density of mercury is 13600 kg/m^3 and the density of equal volume of water is 100 kg/m^3,

$$\text{Relative density of mercury} = \frac{13600\ \text{kg/m}^3}{1000\ \text{kg/m}^3} = \mathbf{13.6}$$

Relative density of a substance can also be defined as the ratio of the mass of any volume of substance to the mass of an equal volume of water.

$$\text{Relative density} = \frac{\text{mass of any volume of substance}}{\text{mass of an equal volume of water}}$$

For example: If the mass of a block is 10 kg and the mass of water is 1 kg,

$$\text{Relative density of a block} = \frac{10\ \text{kg}}{1\ \text{kg}} = \mathbf{1}$$

Relative density of a substance can also be defined as the ratio of the weight of an object to the apparent loss of weight in water.

$$\text{Relative density} = \frac{\text{weight of an object}}{\text{apparent loss of weight in water}}$$

For example: If the weight of a block is 100 N and the apparent loss of weight in water is 40 N,

$$\text{Relative density of mercury} = \frac{100\ \text{N}}{40\ \text{N}} = \mathbf{2.5}$$

Law of floatation

An object which is placed in a fluid will float if the upthrust acting on it is strong enough to support its weight.

If a 100 N block is lowered into water, the upthrust acting on it rises. This causes more water to be displaced. The block will float when the upthrust reaches 100 N. Therefore, the weight of the displaced water is also 100 N. This means that the weight of the displaced water is equal to the weight of a block.

Weight of a displaced water = upthrust = weight of a block

The law of floatation states that a **floating object displaces its own weight of the fluid in which it floats.**

The concept of the law of floatation can be applied when considering why objects float. Consider 100 000 N block of solid iron. As iron is nearly eight times denser than water, it displaces only 1/8 of 100 000 N of water when submerged, which is not enough to keep it afloat. Suppose the same iron block is reshaped into a ship. It still weighs 100 000 N, but when it is put in water, it displaces a greater volume of water than when it was a block. The deeper the iron ship is immersed, the more water it displaces, and the greater the upthrust force acting on it. When the upthrust force equals 100 000 N, it will sink no farther.

Since a floating object displaces a weight of fluid equal to its own weight, every ship must be designed to displace a weight of fluid equal to its own weight. A 100 000 N ship must be built wide enough to displace 100 000 N of water before it sinks too deep in the water. The same is true for vessels in air (as air is a fluid): an aeroplane that weighs 10 000N displaces at least 10 000 N of air. If it displaces more, it rises; if it displaces less, it falls. If an aeroplane displaces exactly its weight, it hovers at a constant altitude.

Applications of Archimedes' principle

Archimedes' principle and law of floatation can be used in:

1. Floating of solids in a fluid: When a block is dropped in water, it floats because it displaces water equal to its own weight. The density of a block of solid is less than the density of water. A large ship floats on water by using law of floatation. This is also possible because the ship contains a lot of spaces that are filled with air. The average density of the ship becomes less than the density of water.
2. Explaining why hot-air balloons rise: When the air in the balloon increases, its volume also increases. An increase in volume increases the weight of the air displaced by the balloon. The balloon then floats. The balloon can also float when the gas burner can heat
   the air inside at 100^0C. The air in the balloon expands and pushes out through the hole at the bottom. This reduces the weight of the air in the balloon. The hot air also becomes less dense which helps in the floating of the hot air balloon.
3. Checking the purity of a material as it was done by Archimedes.
4. **Hydrometer:** a useful instrument in which the Principle of floatation is applied. It floats at different levels in liquids of different densities.
   Hydrometer floats less in methylated spirit than water because methylated spirit is less dense than water.
   The hydrometer sinks in the liquid and only floats when the weight of the liquid displaced is equal to the weight of the hydrometer. Therefore, it is used to measure the density of the liquid in kg/m^3, check the quality of beer and milk and test the state of charge of car batteries.

Calculations on Archimedes' principle and floatation

Worked examples

1. A boat floating on water weighs 8 000 N.

What is

a. the upthrust acting on the boat?

b. the weight of the water displaced by the boat?

Solution

a. weight of a boat = upthrust = **8 000 N**

b. weight of displaced water = weight of a boat = **8000 N**

2. The mass of a metal bar in air is 0.5 kg and its mass is 0.3 kg when immersed in water.

Calculate;

a. The weight of a metal bar in air.

b. The weight of a metal bar when immersed in water.

c. The apparent loss in weight of a metal bar.

d. The upthrust acting on a metal bar.

Solution

a. Weight in air = m x g

= 0.5 kg x 10 m/s^2

Weight in air = **5 N**

b. Weight when immersed in water = m x g

= 0.3 kg x 10 m/s^2

Weight when immersed in water = **3 N**

c. Apparent loss in weight = weight in air – weight when immersed in water = 5 N – 3 N Apparent loss in weight = **2 N**

d. Upthust = apparent loss in weight = **2N**

Chapter 6

Gas laws

6.1 Gas laws

Behaviour of a gas depends on three factors:

- Pressure
- Volume
- Temperature

Gas laws were discovered by using the volume, temperature and pressure of the gas. There were relations that were used to describe the gas laws. In these relations two of the factors mentioned above were varied while one factor was kept constant.

Boyle's law

Boyle was relating pressure and volume at constant temperature. Boyle's law was published in 1662.

Experiment 6.1

AIM: To investigate the relationship between pressure and volume at constant temperature.
MATERIALS: Boyle's law apparatus, foot pump
PROCEDURE:

1. Connect the apparatus as shown in **Figure 6.1.**

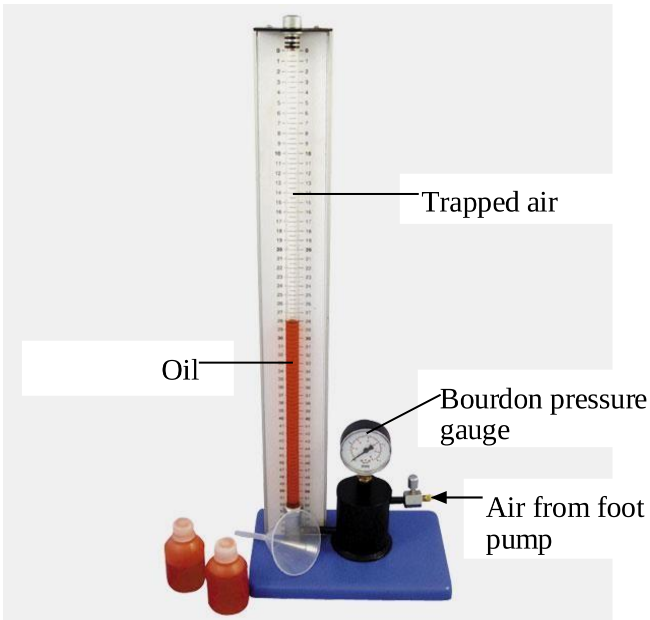


Figure 6.1

2. Pump in air by using a foot pump.
3. Check and record the volume of the trapped air in the tube then check and record the pressure reading on the Bourdon pressure gauge.

Explain what you have noticed.

RESULTS

When the air is pumped in from the foot pump, the level of air in the reservoir decreases and the oil is pushed upwards in the glass tube.

The following will be noticed:

- The volume of the trapped air in the tube decreases.
- The reading on the pressure gauge increases.

The readings can be plotted on the graph as shown in **Figure 6.2**.

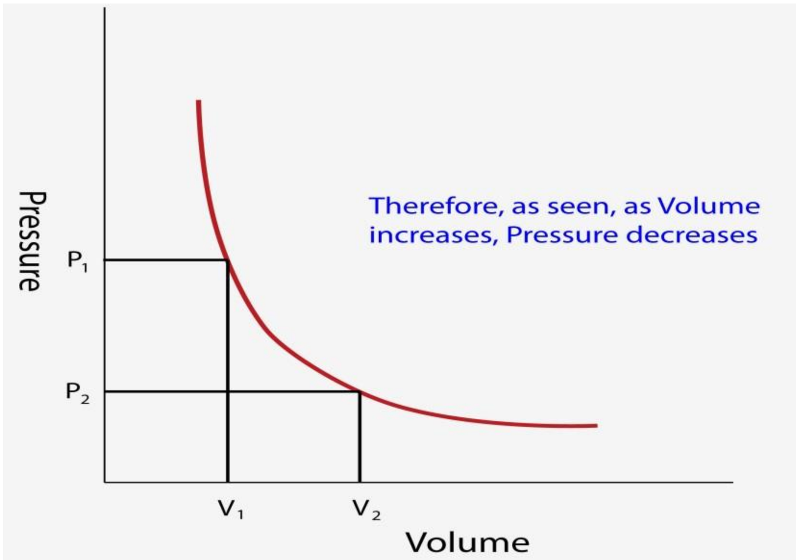


Figure 6.2 graph of pressure of the gas against volume

EXPLANATION

From the graph in **Figure 6.2,** we can notice that if the volume halves, the pressure doubles. This shows that the pressure of a fixed mass of a gas increases with a decrease in volume at a constant temperature. This can be demonstrated in **Figure 6.3.**

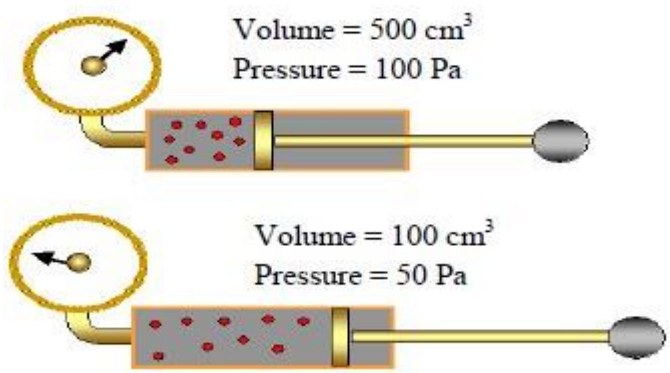


Figure 6.3 relationship between volume and pressure

When the volume of the container containing the gas is reduced, pressure increases because decreasing the volume of the container increases the impact on the walls of the container. Hence force increases that cause an increase in pressure.

Boyle's law states that the pressure of a fixed mass of gas is inversely proportional to its volume provided the temperature of the gas is kept constant.

$$P \propto \frac{1}{V}$$

PV = Constant, T

If pressure is plotted against 1/v, the graph is a straight line and it passes through the origin, as shown in **Figure 6.4**:

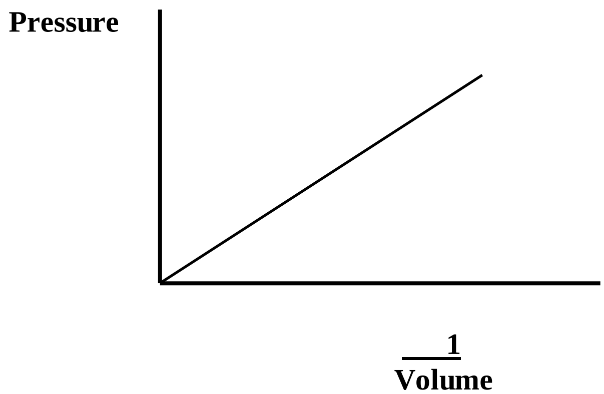


Figure 6.4 pressure is directly proportional to 1/volume

$\mathbf{P_1 \times V_1 = P_2 \times V_2}$

The pressure of a gas with volume 20 m^3 is 2000 Pa. Calculate the volume of the gas if its pressure is 5000 Pa.

Solution

P1 = 2000 Pa   P2 = 5000 Pa

V1 = 20 m^3 V2=?

$P_1 \times V_1 = P_2 \times V_2$

2000 x 20 = 5000 x V2

$$\frac{2000 \times 20}{500} = V2$$

V2 = **80 m^3**

Charles' Law

Charles was relating volume and temperature of a gas at constant pressure. Charles' law was found in 1787 by Jacques Charles.

Experiment 6.2

AIM: To investigate the relationship between volume and temperature at constant pressure.
MATERIALS: Thermometer, container, rubber band, oil, water, capillary tube and heat source
PROCEDURE:

1. Set up the experiment as shown in **Figure 6.5** below.

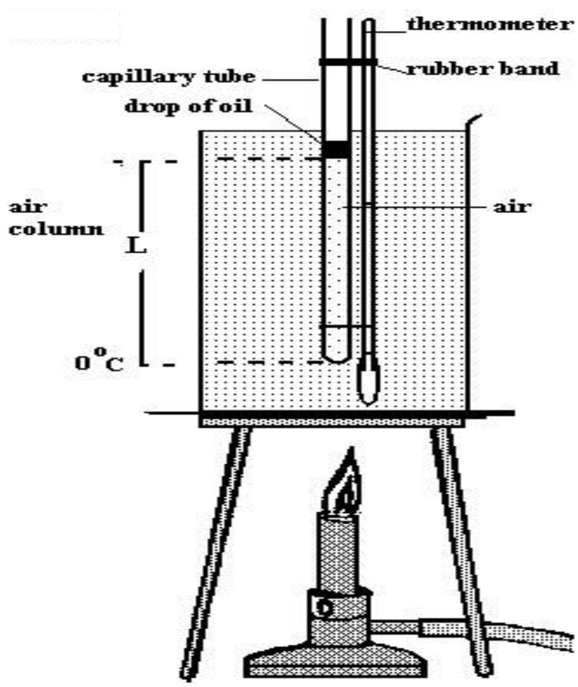


Figure 6.5

2. Heat the water in the container.
3. Check the change in the length of the trapped air column.

RESULTS
When the water in the container is heated, the length of the trapped air column also increases. The results can be plotted on a graph as shown in **Figure 6.6**.

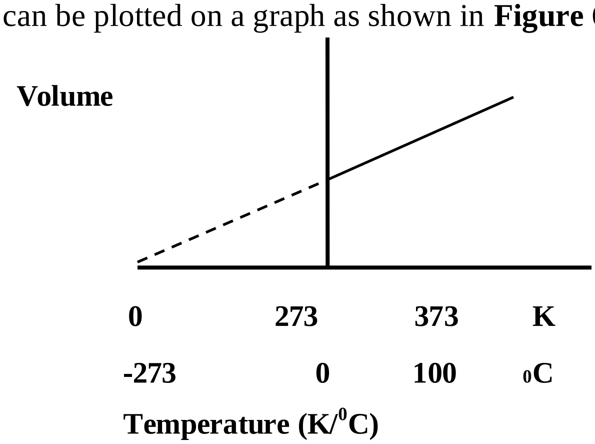


Figure 6.6 graph of volume against temperature

EXPLANATION From the graph in **Figure 6.6**, it shows that:

- It is a straightline graph.
- Volume is halved when temperature is halved.
- Volume is doubled when temperature is doubled.

Volume of a fixed mass of a gas increases with an increase in temperature at a constant pressure because the kinetic energy of the molecules increases. This makes the molecules move further apart. When the molecules move further apart the volume occupied by the molecules increases.

Charles' Law states that the volume of a fixed mass of gas is directly proportional to its absolute temperature provided the pressure of the gas is kept constant.

$$\mathbf{V \alpha T}$$

$$\frac{V}{T} = \text{constant, which is P.}$$

At constant pressure,

$$\frac{\mathbf{V1}}{\mathbf{T1}} = \frac{\mathbf{V2}}{\mathbf{T2}}$$

Worked example

At constant pressure, the temperature of 40 cm^3 of a gas is 55^0C. What is temperature of 80 cm^3 of the gas?

Solution

V1 = 40 cm^3 V2 = 80 cm^3

T1 = 55+273= 328 K T2 =?

$$\frac{V1}{T1} = \frac{V2}{T2}$$

$$\frac{40}{328} = \frac{80}{T2}$$

40 x T2 = 80x 328

$$T2 = \frac{80 \times 328}{40}$$

T2 = **656 K** or **383 ^{0}C**

Pressure law

Pressure law relates pressure to temperature at constant volume. Pressure law which is also known as **Gay-Lussac's law** was found by Joseph Louis Gay-Lussac in1809.

Experiment 6.3

AIM: To investigate the relationship between pressure and temperature at constant volume.
MATERIALS: Container, sources of heat, thermometer, flask, water, tubing, Bourdon pressure gauge, thermometer.
PROCEDURE:

1. Set up an experiment as shown in **Figure 6.7.**

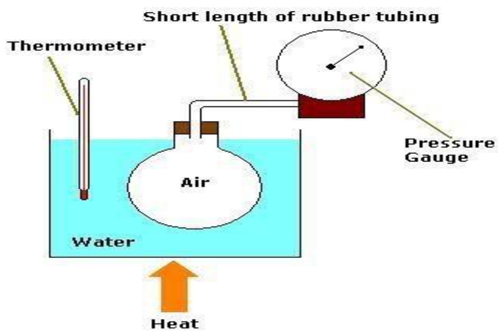


Figure 6.7

2. Heat the water in the container.
3. Record the temperature and pressure readings.

RESULTS:
When water is heated, both temperature and pressure increases. The results can be used to plot a graph as shown in **Figure 6.8** below:

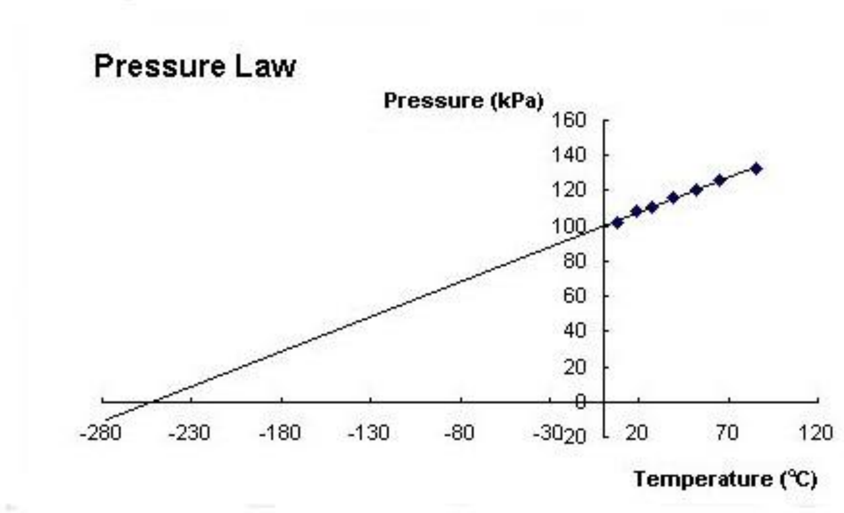


Figure 6.8 graph of pressure of the gas against temperature

EXPLANATION

Increasing the temperature of a gas increases the kinetic energy of gas molecules. Hence the force at which the molecules bombard the sides of the container increases since P=F/A. From the graph in **Figure 6.8**, it shows that:

- It is a straightline graph.
- Pressure is halved when temperature is halved.
- Pressure is doubled when temperature is doubled.

Pressure law states that the pressure of a fixed mass of a gas is directly proportional to its temperature at constant volume.

$P \alpha T$

$\frac{P}{T}$ = constant, which is V

$$\frac{P1}{T1} = \frac{P2}{T2}$$

Whereby:

P1is the initial pressure **P2** is the final pressure
V1 is the initial volume
V2 is the final volume

Worked example

At a constant volume, the pressure of a gas is 1.5×10^5 Pa and temperature is 80^0C. What will be the new pressure if the temperature has decreased to 25^0C?

Solution

$P1 = 1.5 \times 10^5$ Pa	P2 =?
T1 = 80 +273= 353K	T2 = 25 + 273 =298K

$$\frac{P1}{T1} = \frac{P2}{T2}$$

$$\frac{1.5 \times 10^5}{353} = \frac{P2}{298}$$

$$\frac{298 \times 1.5 \times 10^5}{353} = P2$$

P2 = **126629 Pa** or **1.3×10^5 Pa**

The combined gas equation

The combined gas law or general gas law is an equation formed by the combination of the three gas laws, and shows the relationship between the pressure, volume and temperature for a fixed mass of gas.

Gas equations can be summarized as follows:

Pressure law: $\frac{P}{T}$ = constant, which is V.

Boyle's law: PV = constant, which is T.

Charles' law: $\frac{V}{T}$ = constant, which is P.

For a fixed mass of gas, the combined gas equation becomes;

$$\frac{PV}{T} = \text{constant}$$

Initial gas law is given as:

$$\underline{P_1V_1} = \text{constant}$$

T_1

After changes the equation changes into;

$$\frac{P_2V_2}{T_2} = \text{constant}$$

These two equations are related as follows;

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Whereby: P_1 is pressure before change in any appropriate unit provided the same unit is used on both sides of the equation.

V_1 is volume before change in any appropriate unit provided the same unit is used on both sides of the equation.

T_1 is temperature before change in Kelvin (K).

P_2 is pressure after change in any appropriate unit provided the same unit is used on both sides of the equation.

V_2 is volume after change in any appropriate unit provided the same unit is used on both sides of the equation.

T_2 is temperature after change in Kelvin, K.

Worked Examples

1. A cylinder has a volume of 0.12 m^3 and contains nitrogen gas at a pressure of 1620 Pa and temperature of 20^oC. After some of the gas has been consumed, it is found that the pressure has fallen to 1100 pa and the temperature is then 10^oC. Determine the volume of the gas.

Solution

$V_1 = 0.12m^3$ $P_1 = 1620$ Pa $T_1 = 20+173K = 193K$

$V2=?$ $P2=1100$ Pa $T2= 10+173=183K$

$$\frac{P1V1}{T1} = \frac{P2V2}{T2}$$

$$\frac{1620 \text{ Pa x } 0.12m^3}{193K} = \frac{110\text{Pa x } V2}{183K}$$

$1.007 = 0.601 \text{ x}V2$

$V2= \frac{1.007}{0.601}$ $V_2 = 1.68 \text{ m}^3$

6.2 Applications of gas laws

Gas laws can be applied in the following:

1. **Bicycle pump**

A bicycle pump uses Boyle's law, which states that the pressure of the fixed mass of a gas increases with a decrease in volume at constant temperature.

2. **Car tyre**

When a car is travelling at a high speed its tyres get inflated. This happens because the gases inside the tyre get heated and collide on the walls of the tyre with greater force and, most often, which causes more pressure to be exerted on the walls of the tyre.

3. **Scuba diving**

Scuba stands for self-contained underwater breathing apparatus. Divers carry tanks of compressed gas to breathe under water. As they dive deeper, the water exerts pressure on their bodies and the tanks. The air in the tanks has to be regulated and the pressure reduced so that it is the same as the pressure of the surrounding water. The volume of air in their bodies decreases as the pressure increases, using Boyle's law. This makes the divers to descend quickly.

4. **The constant volume gas thermometer**

The constant volume gas thermometer is similar to the apparatus used to establish the pressure law. It uses pressure law, which states that the pressure of a gas increases with an increase in temperature at a constant volume, in order to measure the temperature.

6.3 Measuring gas pressure

Manometer is used to find gas pressure.
The manometer shown in **Figure 6.9** is used to measure gas pressure.

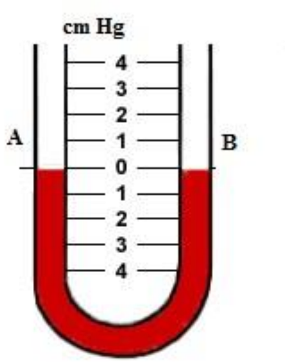


Figure 6.9 the level of mercury before opening the gas supply.

The levels of mercury in columns A and B are the same because they experience the same standard atmospheric pressure (760 mm Hg).

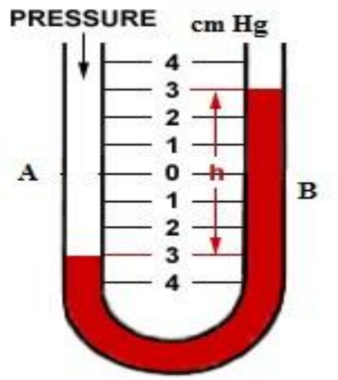


Figure 6.10 shows the same manometer after opening the gas supply.

The level of mercury in A has decreased while in B it has increased because gas pressure has pushed mercury downwards in A and forced mercury upwards in B.
For the mercury to rise in B, at first it was equal to atmospheric pressure, then it overcame the atmospheric pressure.
Gas pressure equals atmospheric pressure plus difference of levels of mercury in A and B.
Difference in the levels of mercury = h
Gas pressure = Atmospheric pressure + h
Gas pressure = 760 mm Hg + h

A manometer is used to measure lung pressure by blowing in gas from your lungs.
Lung pressure = 760 mm Hg + h

Worked example
Figure 6.11 is a diagram of a manometer used to measure gas pressure. The readings are in cm Hg.

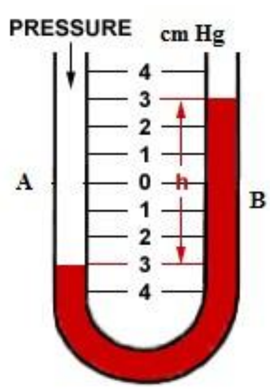


Figure 6.11

a. Read the pressure difference in mmHg.
b. Calculate the pressure of the gas supply if the atmospheric pressure is 760 mm Hg.

Solution

a. h = 6 cm Hg = 60 mm Hg

b. Pressure of the gas supply = standard atmospheric pressure + pressure difference

= 760 mm Hg + 60 mmHg

Pressure of the gas supply = **820 mm Hg**

Chapter 7

Scalar and Vector quantities

7.1 Scalar and vector quantities

Physical quantities can be analyzed by dividing them into scalar quantities and vector quantities.

Scalar quantities

Scalar quantities are quantities that give the magnitude (size or numerical value) only. **For example**, these could be distance, mass, length, height and temperature.

Addition and subtraction of scalar quantities

Scalar quantities are added or subtracted algebraically since they have no effect on direction.

Worked examples

1. 10 metres of cloth plus 5 metres of cloth

Solution

Total length of cloth = 10 m + 5 m

Total length of cloth = **15 m**

2. 100 kg of salt minus 50 kg of salt

Solution

Total mass of salt = 100 kg – 50 kg

Total mass = **50 kg**

Vector quantities

Vector quantities are quantities that have both magnitude and direction. **For example,** force, displacement, velocity and acceleration.

Distance and displacement

Why is distance a scalar quantity while displacement is a vector quantity?

Distance and displacement are two quantities that may seem to mean the same thing yet have distinctly different definitions and meanings.

Distance refers to how much ground an object has covered during the motion.

For example: 10 m. Therefore, distance is a scalar quantity because it has magnitude (size) only.

Displacement refers to how far and out of place an object is. It is an object's overall change in position. For example: 10 m eastwards. Therefore, displacement is a vector quantity because it has both magnitude and direction.

Worked example

Cecilia walked 10 m due west, 4 m due north, 10 m due east then 4 m due south as shown in **Figure7.1.**

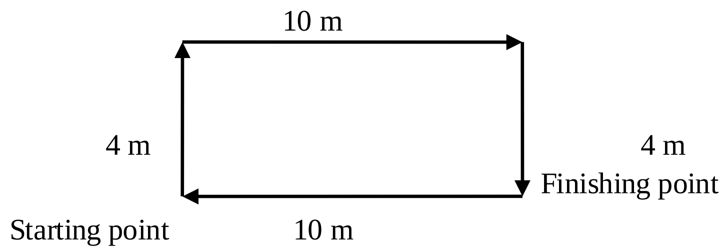


Figure 7.1

Calculate

- **a.** the distance she covered.
- **b.** the displacement during her journey.

Solutions

- **a.** the distance she covered = 10 m + 4 m + 10 m + 4 m = **28 m.**
- **b.** Total displacement = 4 m + 10 m – 4 m – 10 m – 0 m

  Total displacement = **0 m**

  (Displacement is 0 m because 10 m west is cancelled with 10 m east and 4 m north is cancelled with 4 m south. She will go back to the same starting point. Therefore, there is no displacement).

7.2 Representation of a vector quantity

The magnitude of a vector quantity is represented by a straight line while the direction is represented by an arrow.

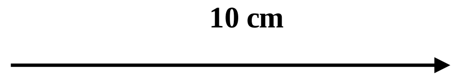
For example, a force of 10N can be represented as

Sketch Tail

Head

Scale diagram

Using a scale of 1 cm to represent 1N, we can draw a line of length 10 cm.



The vector quantity can also be represented as follows:

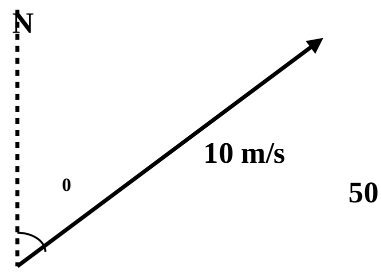


Figure 7.2

From **Figure 7.2** above:

- The magnitude of a vector is 10 m/s
- The direction of the vector is at an angle of 50^0 from north line.

7.3 Addition and subtraction of vectors

When adding or subtracting vectors, the final vector is called the Resultant Vector.

Addition and subtraction of in-line vectors (e.g. forces)

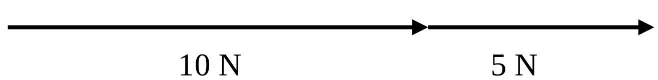
If two forces act in the same direction, their combined effect or resultant force is obtained by joining forces head to tail.

Worked example

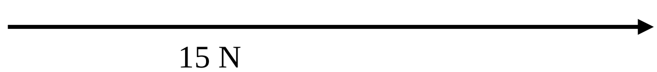
To find the resultant force when a 10 N and a 5 N forces are acting in the same direction.

Solution

Joining the forces head to tail:



The resultant force becomes:



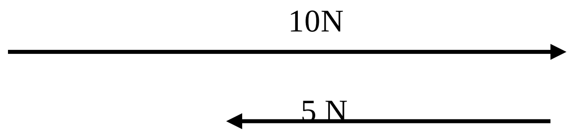
Therefore, the resultant force = **15 N to the right**

If forces are in opposite directions, the resultant force is obtained by subtracting the smaller force from the larger force.

Worked example

To find the resultant force when the forces stated above act in opposite directions.

Solution



The resultant force = 10 N – 5 N

The resultant force = **5 N in the direction of 10 N force (to the right).**

Vectors at an angle to each other

Vectors can act at an angle to each other. When vectors are acting at an angle to each other, the resultant vector is the final vector. The resultant vector can be found by using either triangle rule or parallel rule.

1. Triangle of forces rule

Triangle method of resolving forces is made by considering forces that act at the same point and on the same plane.

Worked examples

1. Find the resultant of two forces when 5N and 10 N act at right angle to each other.

Solution

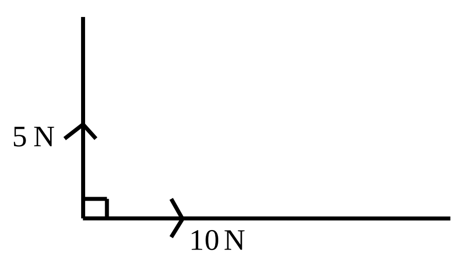


Figure 7.3

Join the forces head to tail

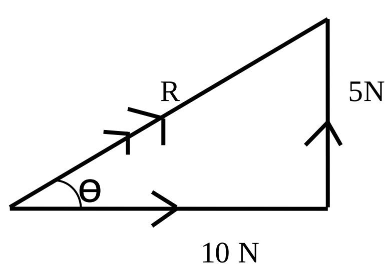


Figure 7.4

The resultant is the line that completes the triangle and the direction is represented by angle θ towards the direction of a greater force (10 N).

Calculation

Using Pythagoras' theorem

$R^2 = 10^2 + 5^2$

$R^2 = 100 + 25$

$R^2 = 125$

$R = \sqrt{125}$

$R =$ **11.18N**

The resultant force is **11.18 N** to the **10 N** force at an angle θ.

To find angle θ, use tangent

$\tan \theta = \frac{opp}{Adj} = \frac{5\ N}{10\ N}$

$\tan \theta = 0.5$

Angle $\theta = \tan^{-1} 0.5$

Angle $\theta = \mathbf{26.6^0}$

The Resultant force is **11.18N** at an angle of $\mathbf{26.6^0}$ to the horizontal ground in the direction of a 10 N force.

Drawing a scale diagram

Using a scale of 1cm = 1N

10 N = 10 cm,   5 N = 5 cm

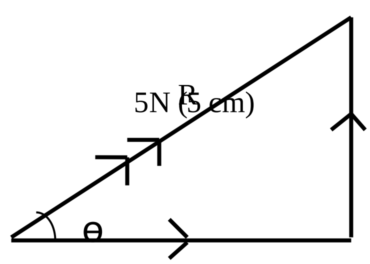


Figure 7.5

Measuring R with a ruler.

R = 11.2 cm

Resultant force = 11.2 x 1N

Resultant force = **11.2 N**

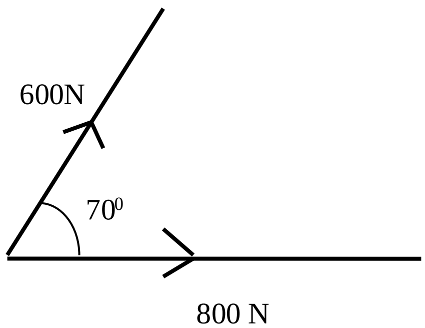
Measure angle θ using a protractor

Angle ɵ = **26.5^0**

The Resultant force is **11.2 N** at an angle of **26.5^0** to the horizontal ground in the direction of a 10 N force.

2. Two forces of 800 N and 600 N act on an object at an angle of 70^0, find the resultant force.

Solution



Join the forces head to tail **Figure 7.6**

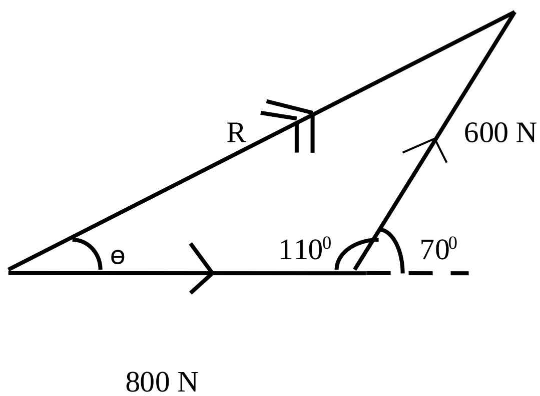


Figure 7.7

Calculation

To find R using cosine Rule

$R^2 = 600^2 + 800^2 – 2 \times 600 \times 800 \times \cos110^0$

$R^2 = 360\ 000 + 640\ 000 – (-328\ 339.3376)$

$R^2 = 1\ 000\ 000 + 328$

$339.3376\ R^2 = 1\ 328\ 339.$

338

$R = \sqrt{1\ 328\ 339.338}$

R = **1 152.5 N**

Resultant force is **1 152.5 N** to the 800 N force at an angle ɵ

Drawing a scale diagram

Using a scale of 1cm = 100 N
600 N = 6cm
800 N = 8cm

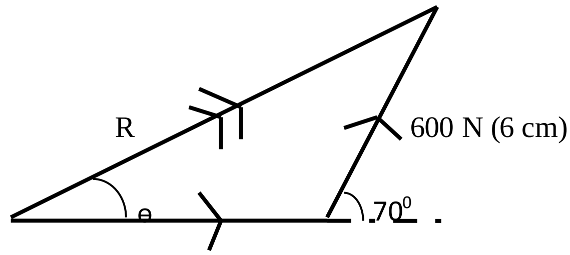


Figure 7.8

Measure the length of R using a ruler

R = 11.53 cm
Resultant force = 11.53 X 100 N
Resultant force = **1153 N**

Measure angle ɵ using a protractor
Angle ɵ = **29.2^0**

Therefore, Resultant force is **1153 N** at an angle of **29.2^0** to the horizontal ground towards 800 N force.

2. Parallelogram method

Parallelogram method is used to find the resultant of two forces acting at a given point. In a parallelogram rule, the forces complete the parallelogram. The resultant force is represented by a diagonal of the parallelogram. The angle between the diagonal and a horizontal force gives the direction of the resultant force.

Worked examples

1. Two forces of 6 N and 8 N are acting at an angle of 30^0. Find the resultant force by calculation and drawing a scale diagram.

Solution

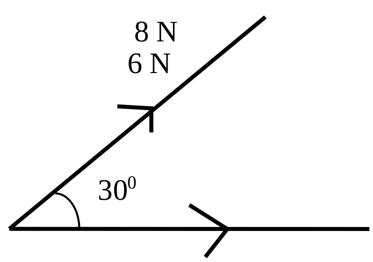
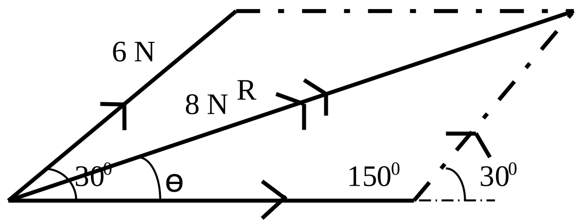


Figure 7.8

Draw in two more lines to complete the parallelogram. Then draw a diagonal line, and calculate its length.

Figure 7.9



The diagonal represents the resultant of the two forces.

Calculation

To find R, using cosine rule

$R^2 = 6^2 + 8^2 – 2 \times 6 \times 8 \times \cos150^0$

$R^2 = 36 + 64 – (-83.1384)$

$R^2 = 100 + 83.1384$

$R^2 = 183.1384$

$R = 183.1384$

$R =$ **13.5N**

Resultant force is 13.5N to the 8N force at an angle ө.

To find ө, using sine

$$\sin \theta = \frac{\sin150^0 \times 6}{13.5}$$

$\sin \theta = 0.2222$

12.8^0

Resultant force is **13.5 N** at **12.8^0** to the horizontal ground in the direction of 8 N force.

Drawing a scale diagram

Using a scale of 1 cm = 1 N

6 N = 6 cm

8 N = 8 cm

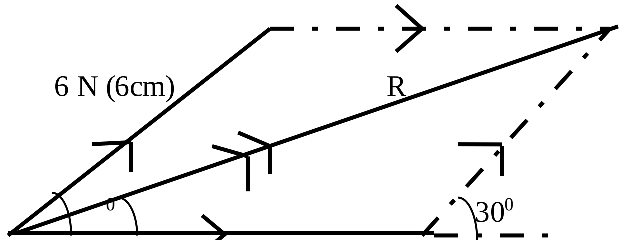


Figure 7.10

Measure the length of R using a
ruler R = 13.5 cm
Resultant force = 13.5 X 1 N
Resultant force = **13.5 N**

Measure angle ɵ using a protractor
Angle ɵ = **12.8^0**

Therefore, Resultant force is **13.5 N** at an angle of **12.8^0** to the horizontal ground towards 8N force.

3. James walks 5 km due north then 7 km due east. Draw a scale diagram to find the resultant of his displacement.

Solution

Scale: 1 cm to represent 1 km
5 km = 5 cm
7 km = 7 cm

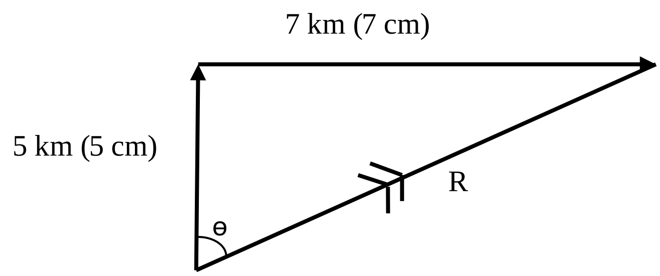


Figure 7.11

The length of R = 8.6 cm
Resultant displacement = 8.6 X 1km
Resultant displacement = 8.6 km
Angle ɵ = **54.5^0**

Therefore, resultant displacement is **8.6 km** at an angle of **54.5^0** from the north line.

Resolving components of vectors

Previously, two forces acting at a point were used to find a single force called **resultant force**. In this section we are going to look into the reverse of that process. In reversing the process, a single force called resultant force can be replaced by two forces having the same effect. Therefore, a force is said to be resolved. A force can be resolved into two components namely:

- vertical component

▪ horizontal component

These components of forces are perpendicular (at a 90^0 angle) to each other.

The vector sum of these two components is equal to the original force in magnitude and direction. These two forces must also pass through the same point of application as the original force.

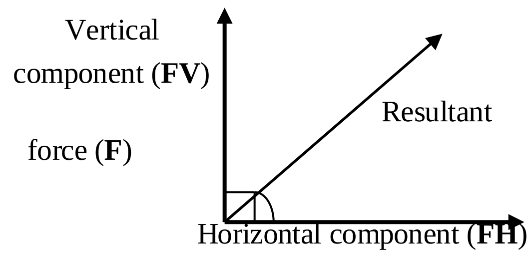


Figure 7.13 components at right angle

To calculate the values of forces acting at right angles as shown in **Figure 7.13:**

The vertical component = Resultant force x sine Θ

FV = F Sin Θ

The horizontal component = Resultant force x cosine Θ

FH = F Cos Θ

Worked example

Khataza pulls Tegha sitting in a trolley by using a string. The tension of the string is 100 N inclined at 60^o to the horizontal. Calculate:

a. the horizontal force pulling Tegha in the trolley.

b. the vertical force tending to lift the trolley.

Solution

Since we know that tension is100 N. This force is the resultant F. The sketch can be drawn as shown in **Figure 7.14.**

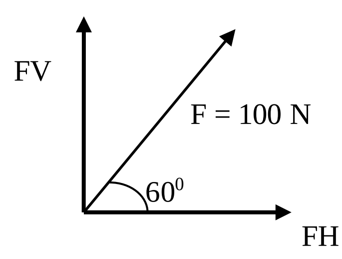


Figure 7.14

a. horizontal force FH = F cos Θ

FH = 100 N x cos 60^o

FH = **50 N**

b. Vertical force FV = F sin Θ
FV = 100 N x $\sin 60^o$
FV = **86.6 N**

Chapter 8

Linear motion

8.1 Distance, displacement, speed, velocity and acceleration

Distance and displacement

Distance

Distance refers to how much ground an object has covered during the motion. Distance is a scalar quantity because it has magnitude only.
For example: 10 km.

Displacement

Displacement is the distance moved in a particular direction. Displacement is a vector quantity because it has both magnitude and direction. **For example:** It is a displacement of 20 km due west.

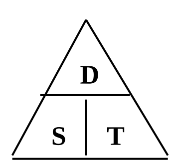
Speed

A car can go fast or slow. When a car goes fast it means its speed is high and when it goes slow it means its speed is low. In each case, to describe speed we use distance covered and time taken to cover that distance.
So, **speed** is defined as the distance covered per unit time. You can also define speed as the rate of change in distance.

$$\textbf{Speed} = \frac{\textbf{Distance covered}}{\textbf{Time taken}}$$

A speed of 1m/s is realized when a distance of 1m is covered in 1 second.

$$S = \frac{D}{T}$$



Whereby **D** is distance in meters (m), **T** is time in seconds (s) and **S** is speed in meters per second (m/s).
Therefore, the SI unit for speed is m/s.

If distance **D** is in kilometers (km) and time **T** is in hours (hrs), then speed **S** is given in kilometers/hour (km/hr).
Speed is a scalar quantity since it has magnitude only.

Worked example
An athlete covered a distance of 20 km in 5hours. Calculate the speed of the athlete.
Solution
To find the speed of the athlete, use the covered distance and time taken for that distance to be covered.

Distance = 20 km, t = 4 hours

$$\text{Speed} = \frac{\text{distance moved}}{\text{Time taken}}$$

$$\text{Speed} = \frac{20\text{km}}{4\text{hrs}}$$

Speed = **5 km/hr**

Experiment 8.1

AIM: To find the speed of a moving object
MATERIALS: Chalk, stop watch, trolley tape measure
PROCEDURE:

1. Find a smooth and flat area around your school.
2. Measure a distance of 5 m with a tape measure then mark the starting and finishing points with chalk.
3. One observer must be on the starting line with a stop watch and a trolley while the other observer must be on the finishing line.
4. The observer on the starting line must push the trolley and start the stopwatch immediately.
5. As the trolley crosses the finishing line, a second observer must raise his/her hand so stopwatch is stopped immediately.
6. Use the formula to find the speed of a trolley:

$$\text{Speed} = \frac{\text{distance (5 m)}}{\text{Time taken}}$$

Average Speed

When an athlete was running at different speeds or his speed was varying, his average speed can be worked out as follows;

$$\textbf{Average speed} = \frac{\textbf{Total distance covered}}{\textbf{Total time taken}}$$

Worked examples

1. A cyclist covers the first 90 km of the distance traveling at 30 km/hr then he covers the next 80 km traveling at 40 km/hr. Calculate the average speed of the cyclist.

Solution

The first part of the journey

D = 90 km S = 30 km/hr

$$T = \frac{D}{S}$$

$$T = \frac{90\text{ km}}{30\text{ km/hr}}$$

T = 3hrs

Second part of the journey

D = 80km S = 40km/hr

$$T = \frac{80\text{km}}{40\text{km/hr}}$$

T = 2hrs

$$\text{Average speed} = \frac{\text{Total distance covered}}{\text{Total time taken}}$$

$$\text{Average speed} = \frac{90\text{ km} + 80\text{ km}}{3\text{ hrs} + 2\text{ hrs}}$$

$$\text{Average speed} = \frac{170\text{ km}}{5\text{ hrs}}$$

Average speed = **34 km/hr**

2. A car starts at a speed of 0 m/s until it reaches a speed of 10 m/s. Find the average speed of the car.

In this case the average speed $= \frac{\text{sum of the speeds}}{\text{Number of speeds}}$

$$= \frac{0\text{ m/s} + 10\text{ m/s}}{2}$$

$$= \frac{10\text{ m/s}}{2}$$

Average speed = **5 m/s**

Experiment 8.2

AIM: To find the average speed of an athlete
MATERIALS: Tape measure, stop watch and whistle.
PROCEDURE:

1. Measure a distance of 20 m with a tape measure and mark the starting and finishing points.
2. An athlete must stand on the starting point.
3. An observer must have a stop watch and a whistle.
4. The athlete must start running as soon as the observer blows the whistle and starts the stop watch.
5. The athlete can cover the same distance three times then the observer stops the stop watch.
6. Record the total distance covered as 20 m x 3 = 60 m.
7. Record the total time taken.
8. Calculate the average speed of the1 athlete as follows:

$$\text{Average speed} = \frac{\text{Total distance (60 m)}}{\text{Total time taken}}$$

Velocity

Velocity is the distance covered in a stated direction (displacement) per unit time. Therefore, velocity is the speed in stated direction. Velocity, like speed, is measured in m/s.

Velocity is the vector quantity because it has magnitude and direction of travel.

Velocity is the distance covered in a stated direction per unit time or displacement per unit time.

$$\textbf{Velocity} = \frac{\textbf{Distance covered in a stated direction (displacement)}}{\textbf{Time taken}}$$

Worked example

A car travels 300 m in 20 s. What is its velocity?

Solution

$$\text{Velocity} = \frac{\text{Distance covered in a stated direction}}{\text{Time taken}}$$

$$\text{Velocity} = \frac{300\text{ m}}{20\text{ s}}$$

Velocity = **15 m/s**

Acceleration

An object accelerates when its velocity changes.

Acceleration is the rate of change of velocity per unit time. Acceleration can also be defined as the change in velocity per given time.

Let the initial velocity be **u**
The final velocity be
v Time to be **t**

Change in velocity becomes = final velocity (v) – initial velocity
(u) The acceleration becomes:

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

When **v** is greater than **u**, an object speeds up. Speeding up is called **acceleration.**
When **v** is less than **u,** an object slows down. Slowing down is called **deceleration.**
When **v** is equal to **u**, an object has zero acceleration (travels with a constant velocity) because there is no change in velocity.
Acceleration, like velocity is a vector quantity.

Worked examples

1. A motor cycle starts from rest (0 m/s) and reaches a velocity of 10 m/s in 5 seconds. Calculate the acceleration of the motor cycle.

Solution

u = 0 m/s v= 10 m/s
t = 5 s

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

$$a = \frac{10 \text{ m/s} - 0 \text{ m/s}}{5 \text{ s}}$$

a = **2 m/s/s or 2 m/s^2 or 2 ms^{-2}**
Acceleration of a motorcycle is **2 m/s^2**

2. An aeroplane wants to land. Its velocity drops from 20 m/s until it reached 5 m/s in 10 seconds. Calculate the average acceleration of the aeroplane.

Solution

u = 20 m/s v = 5 m/s t = 10 s

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

$$a = \frac{5 \text{ m/s} - 20 \text{ m/s}}{10 \text{ s}}$$

a = **-1.5 m/s^2**

NOTE the negative sign means that the acceleration is in the opposite direction to the chosen direction of the velocity. The negative acceleration is called **Deceleration** or **Retardation.**
Therefore, in the above example,

Deceleration = - acceleration

Therefore, Deceleration = **1.5 m/s^2**

Experiment 8.3

AIM: To determine velocity and acceleration of an object

MATERIALS: chalk, stopwatch, trolley, tape measure

PROCEDURE:

1. Find a smooth and flat area around your school.
2. Measure distances of 2 m, 5 m and 9 m with a tape measure then mark these points including the starting point on 0 m and finishing point on 9 m with chalk.
3. Four observers must be on the starting line (0 m), 2 m, 5 m and 9 m with stop watches.
4. The observer on the starting line must push the trolley and start the stopwatch immediately.
5. Each observer must start the stopwatch as the trolley crosses each point.
6. Use your results to complete the **Table 8.1**.

Section (m)		Time at start(s) (m/s) interval(s)	Time Length of section (m)	Velocity
0-2			2	
2-5			3	
5-9			4	

Table 8.1

7. Use the results in **Table 8.1** to calculate the velocity of a trolley using a formula velocity = $\frac{\text{displacement (length of a section)}}{\text{time interval}}$
8. Plot a graph of velocity against time
9. Calculate the acceleration of the trolley for each section by using the gradient of the velocity time graph.
   Gradient = $\frac{\text{change in velocity}}{\text{Change in time}}$

Determining the velocity and acceleration of an object by using a tickertape-timer

The tickertape-timer marks dots on a tape at regular intervals of 1/50 s(0.02s). This is taken from the frequency of alternating mains electricity because a ticker-time uses alternating current. In this case the frequency is 50 Hz (50 cycles per second).

Figure 8.1 shows a tickertape-time used to investigate the motion of a trolley.

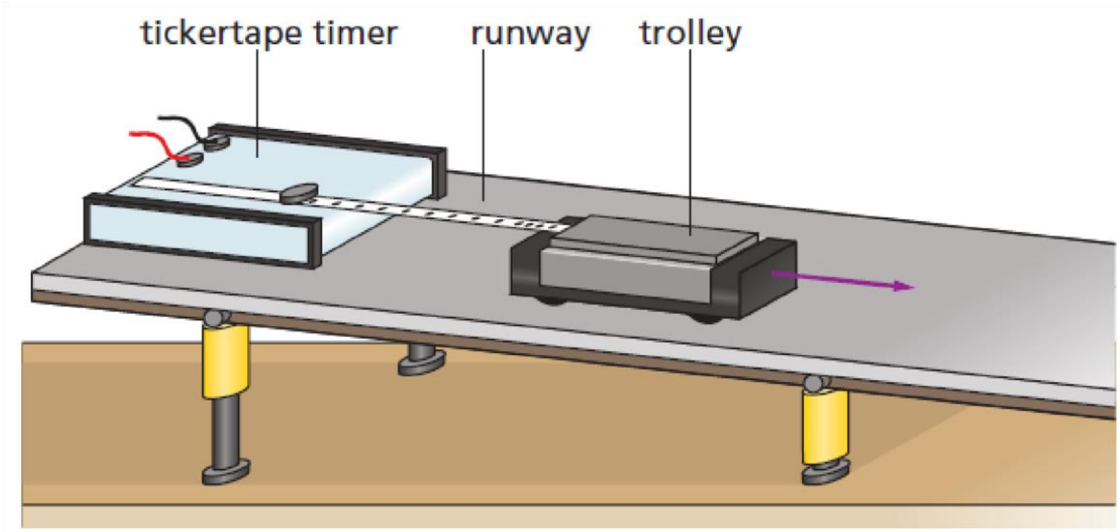


Figure 8.1 tickertape timer

When a trolley is connected to the tape and set in motion, the dots will be created on the tape.

The pattern of dots acts as a record of the trolley's movement. The time interval between adjacent dots is 1/50 s (0.02 s).

Even spacing on the tape: constant velocity

Increasing spacing: increasing velocity

The distance from the start to the fifth dot is covered at an interval of 1/10 s (0.1 s). This will be considered as the section which represents the trolley's displacement.

Measure and record the distance (displacement) of every fifth dot from the start of the tape. The velocity of a trolley for the first section can be calculated by using a formula:

$$\text{Velocity} = \frac{\text{displacement (length of the section)}}{\text{Time interval (0.10 s)}}$$

Repeat the measurement and calculation for the other two sections.

Now we can record the values in the **Table 8.2** for the three sections.

Section of a tape	Time at start (s)	Time interval(s)	Displacement(cm)	Velocity (m/s)
1	0.0	0.1	4.0	0.40
2	0.1	0.1	8.0	0.80
3	0.2	0.1	12.0	1.2

Table 8.2 An example of the graph obtained using a tickertape-timer

NOTE: The displacements must be converted to metres first.

Use the results in the **Table 8.2** to plot a velocity-time graph.

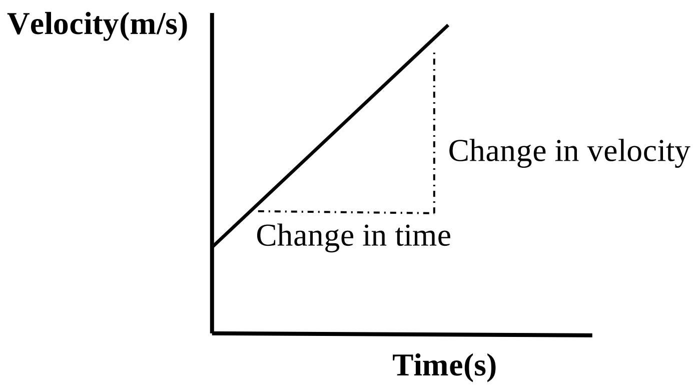


Figure 8.2 graph of velocity against time

We can calculate the acceleration of a trolley by calculating the gradient of the graph.

$$\textbf{Acceleration = gradient of a graph} = \frac{\textbf{change in velocity}}{\textbf{change in time}}$$

8.2 Acceleration due to gravity

All the objects that are near the earth surface fall freely. They do not experience any air resistance. They fall under the force of gravity and they fall with uniform acceleration. This acceleration is called the **acceleration due to gravity.** The acceleration due to gravity is also called the **acceleration of free fall.**

Free fall is the falling of an object with uniform acceleration under the force of gravity if air resistance is negligible.

Acceleration due to gravity is denoted a letter **g**. The value of acceleration due to gravity is approximately **10 m/s^2**. This value varies slightly from one place to another on the earth's surface. This is because the gravitational pull of the earth on an object also varies. The variation of acceleration due to gravity is less than 1%.

Experiment 8.4

AIM: To measure acceleration due to gravity, g
MATERIALS: Stop watch, bob, metre ruler, clamp stand, retort stand and string.
PROCEDURE:

1. Set up an experiment as shown in **Figure 8.3.**

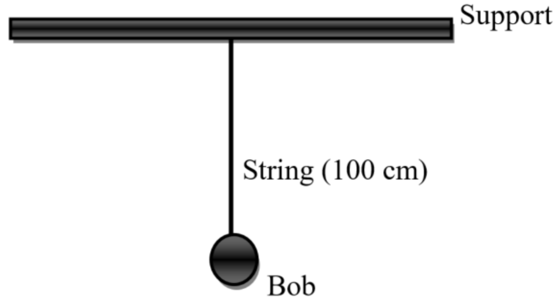


Figure 8.3

2. Pull the bob 5 cm to one side and release it so that it swings in one plane.
3. As the bob passes from left to right across your centre line begin to count 3, 2, 1, 0. Start the stop watch as you count 0.
4. Record the time taken for 50 oscillations.
5. Repeat the experiment for the length 80, 60, 40 and 20 cm long.
6. In each case the timing must be repeated as a check on the previous reading and the results can be recorded in **Table 8.2.**

Length l (cm)	**Time for 50 oscillations**			**Periodic time T (s)**	**T^2**	**$\frac{T^2}{l}$**
	1	2	mean			
100						
80						
60						
40						
20						

Table 8.2

7. Plot a graph of T^2 (y-axis) against l (x-axis) and measure its slope.

RESULTS/EXPLANATION

From the graph of T^2 against *l*, a straight line through the origin should be obtained. The gradient of the line gives a value of *g*.

The value of g can also be calculated from the results obtained as follows:

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

Therefore, $\boldsymbol{g = 4\pi^2 \div \frac{T^2}{l}}$

8.3 Graphical representation of motion

It is very difficult to be precise in describing the motion of the objects in motion. Therefore, graphs are used in science to assist our understanding and description of objects in motion.

Graphs are a convenient and accurate means of displaying information.

Graphs can be plotted as follows:

- displacement (distance) against time
- velocity (speed) against time

Distance–Time Graph

In a distance–time graph, distance or displacement (in the y–axis) is plotted against time (in the x–axis).

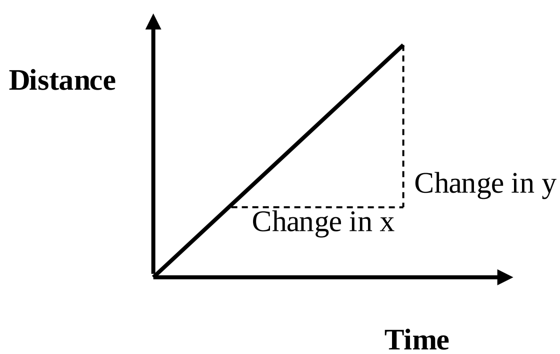


Figure 8.4 distance-time graphs.

$$\text{The gradient of a distance-time graph} = \frac{\text{change in y (distance)}}{\text{change in x (time)}}$$

$$\frac{\textbf{Distance}}{\textbf{Time}} = \textbf{speed}$$

Therefore, the gradient of a distance–time graph gives speed.

If the graph is plotted, displacement against time, its gradient gives velocity.

Interpreting the distance (displacement)–time graphs

The motion of the object under the distance –time graph can be described as follows:

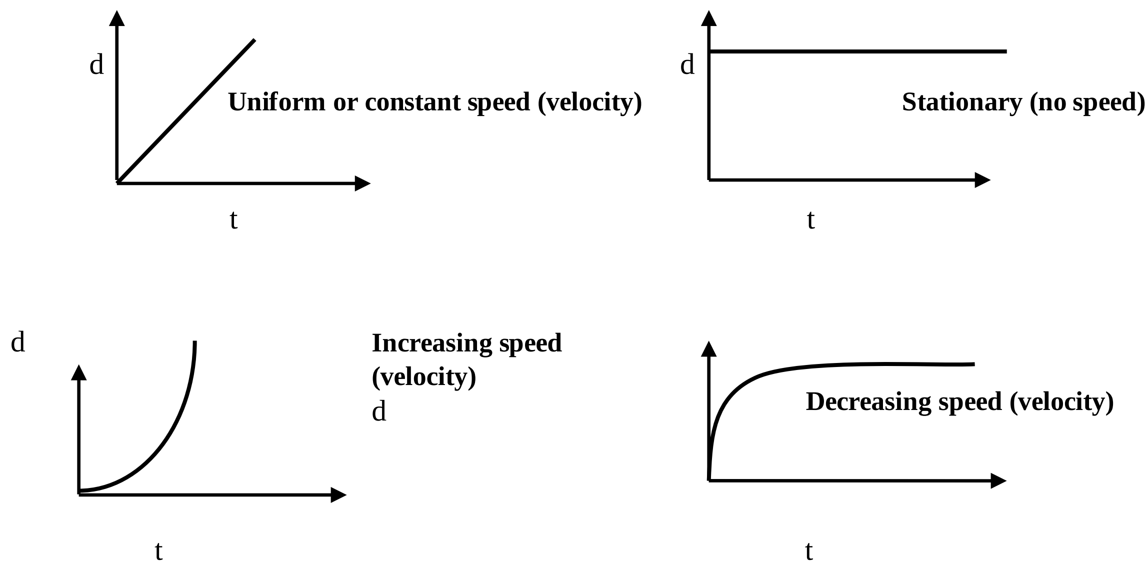


Figure 8.5 distance (displacement) – time graphs

Velocity (speed)–time graph

In velocity–time graph velocity (in the y–axis) is plotted against time (in the x–axis).

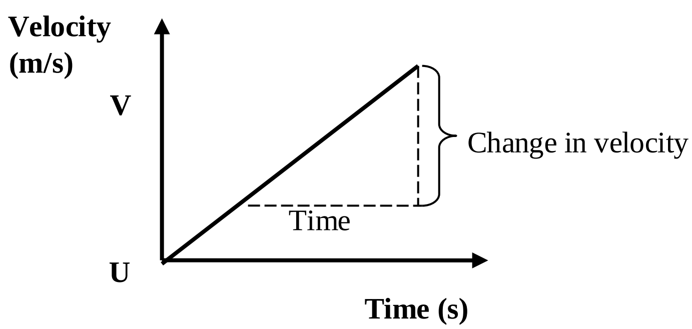


Figure 8.7 Velocity–time graph

$$\text{Gradient} = \frac{\text{change in velocity}}{\text{Time}}$$

$$\frac{\text{Change in velocity}}{\text{Time}} = \text{acceleration}$$

Therefore, a velocity–time graph gives acceleration.

Acceleration from the graph can also be found by using a formula:

$$a = \frac{V - U}{t}$$

Describing the motion on a velocity – time graph

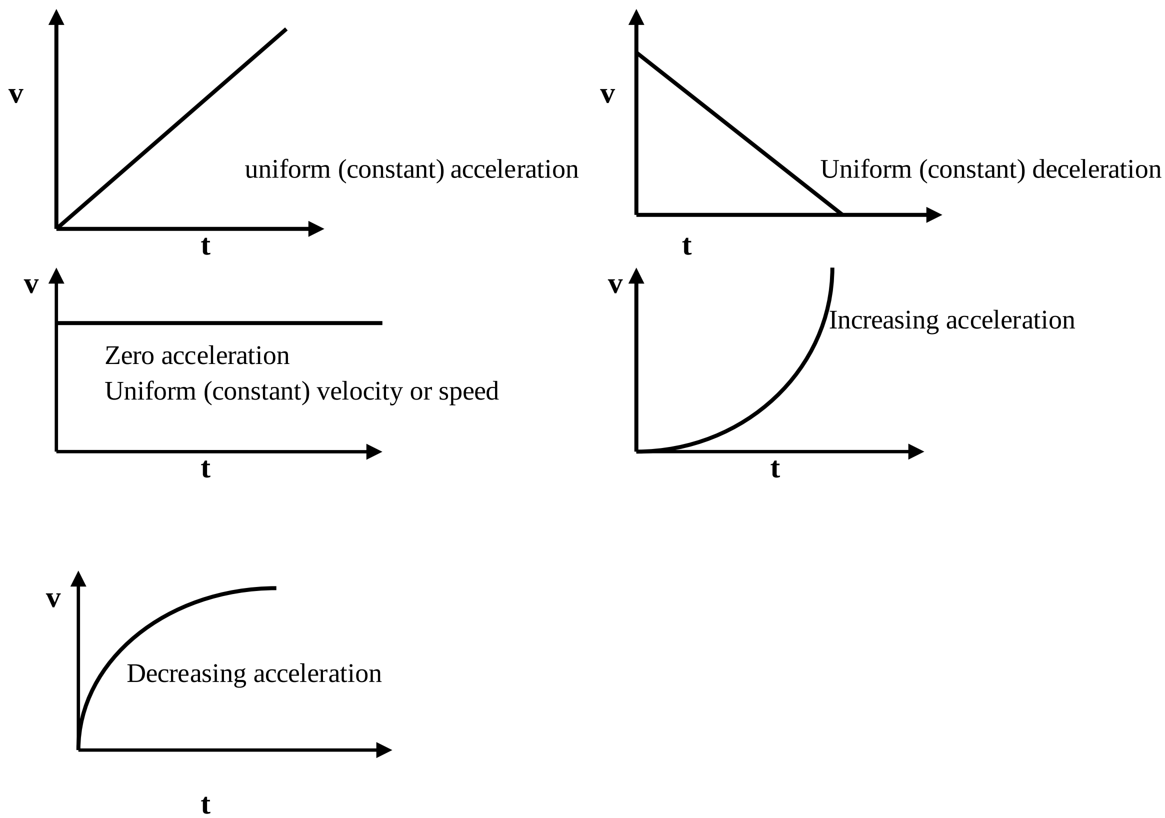


Figure 8.8 velocity- time graphs

Distance under Velocity (Speed)–Time Graph

Distance =Area under velocity–time graph

1. **Figure 8.10** is a speed – time graph for a cyclist. Use it to answer the questions that follow.

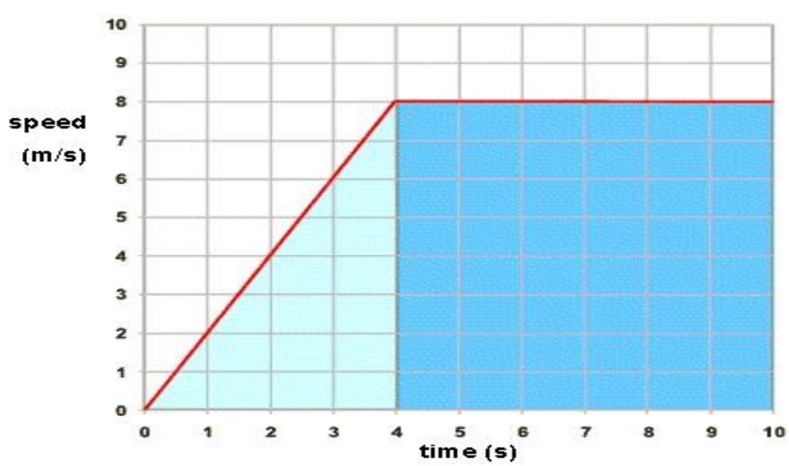


Figure 8.10

a. Describe the motion of the cyclist during the entire 10 seconds.
b. Calculate the acceleration of the cyclist during the first 4 seconds.
c. Calculate the total distance covered during the entire 10 seconds.
d. Calculate the average speed of a cyclist during the entire 10 seconds.

Solution

a. The motion of a cyclist

0 – 4 s = the cyclist accelerates uniformly

4 – 10 s = the cyclist had zero acceleration or the cyclist had a uniform speed

b. Acceleration during the first 4 seconds

$$a = \frac{V - U}{t}$$

U = 0 m/s

V = 8 m/s

t = 4 s

$$a = \frac{8\ \text{m/s} - 0\ \text{m/s}}{2\text{s}} = \text{Acceleration} = \mathbf{2\ m/s^2}$$

c. Total distance = Area of a trapezium.

$= ½ (a + b) h$

$= ½ (6 + 10) \times 8$

$= ½ \times 16 \times 8$

Total distance = **64 m**

d. Average speed = $\frac{\text{total distance}}{\text{total time}}$

$= \frac{64\ \text{m}}{10\ \text{s}}$

Average speed = **6.4 m/s**

3. A body starts from rest and accelerates at 10 m/s^2 for 5 s. It then continues at this speed for 5 s before decelerating to rest in 10 s.
a. Sketch a speed time graph of this motion.
b. Calculate the distance the object moved in the first 5 seconds.

Solution

a. Sketch of a speed time graph

Speed (m/s)

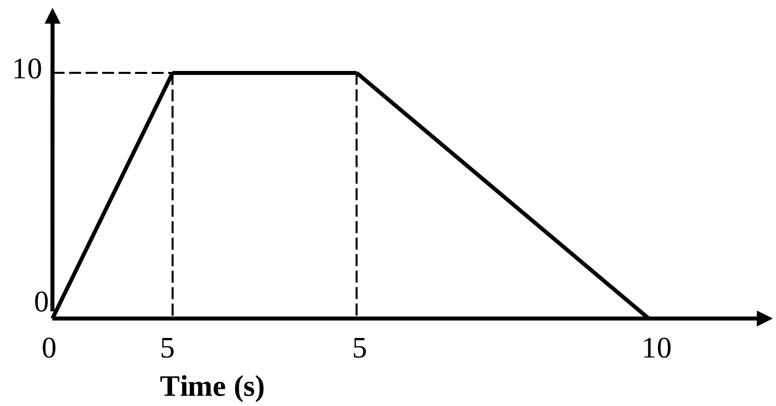


Figure 8.11

b. Distance moved in 5 seconds = Area of a triangle

= ½ x b x h

= ½ x 5 x 10 = 25M

8.4 Motions of falling bodies

Three forces acting on a falling body are:

- Gravitational force or weight (W) – It acts downwards
- Upthrust (U) – It is the push by the fluid. It acts upwards.
- Frictional force (Fr) – It opposes the motion. It acts upwards.

Acceleration of a free fall

In air, a coin falls faster than a feather because they experience different size of air resistance. Air resistance is greater to lighter bodies than to heavy ones. In a vacuum a coin and a feather fall at the same rate because they do not experience any air resistance. The coin and a feather are said to have a free fall.

Experiment 8.5

AIM: To investigate free fall of bodies
MATERIALS: Feather, coin, glass tube, vacuum pump and cork.
PROCEDURE:

1. Set up the experiment as shown in **Figure 8.13** below.

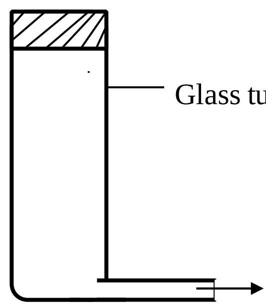


Figure 8.13

2. Drop the feather and a coin in a glass tube. Observe which one will reach the bottom of the tube first.
   Give a reason for this result.
3. Connect a vacuum pump and pump out all the air.
4. Drop the feather and a coin from the same height. Observe which one will reach the bottom of the tube first.
   Give a reason for this result.

   Discuss your results with your friends in class.

RESULT/EXPLANATION

When the feather and a coin are dropped from the same height and at the same time, the coin reaches the bottom of the tube first because it experiences less air resistance since it is heavier than the feather.

Vacuum pump connected:

When the feather and a coin are dropped from the same height at the same time, both the coin and the feather will reach the bottom of the tube at the same time because they do not experience any air resistance. They are falling under a free fall.

Figure 8.14 shows the falling of a coin and a feather in a vacuum and air.

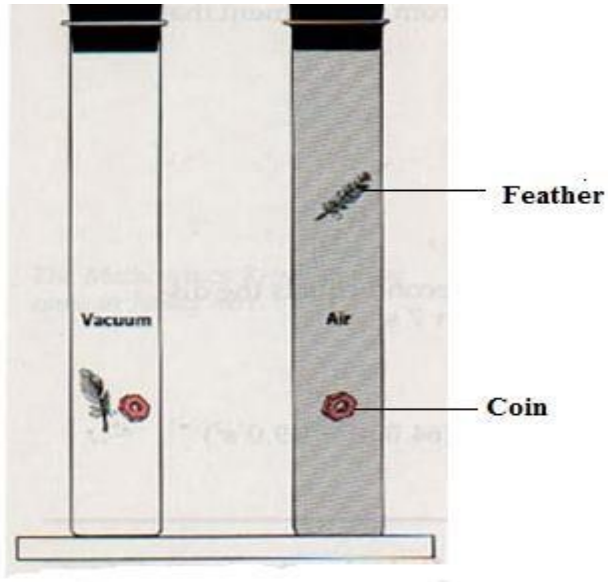


Figure 8.14 falling in a vacuum and air

Falling of heavy objects near the earth

In the 16th century the Italian scientist Galileo dropped a small iron ball and a large ball ten times heavier from the top of the Learning Tower of Pisa. In this story, we were told that, to the surprise of onlookers who expected the cannon ball to arrive first, both objects reached the ground almost at the same time.

From this story, untrue we now think, suggests that the heavy bodies, whatever their sizes, are only slightly affected by air resistance. Therefore, heavy objects near the earth fall under freefall.

Figure 8.15 Tower of Pisa

Falling in parachutes

Falling when a parachute is not opened

A parachutist falls at a very high speed, because W – (U + Fr) is very great since Fr is taken as negligible.

As a parachutist increases the speed or accelerates frictional force increases until W = (Fr + U). When W = Fr + U, a parachutist falls at a constant or uniform speed called **terminal speed** or **terminal velocity** of 50 m/s.

This terminal velocity without opening a parachute is called **Sky Diving**.

Falling when a parachute is opened

After opening a parachute, frictional force increases which reduces the speed of a parachutist. A parachutist decelerates since Fr has increased.

(Fr + U) > W

As the speed decreases, it causes Fr to decrease until (Fr + U) = W.

When (Fr + U) = W, a parachutist travels at another terminal speed or terminal velocity of 8 m/s. This is a **landing speed.** Hence a parachutist lands safely on the ground.

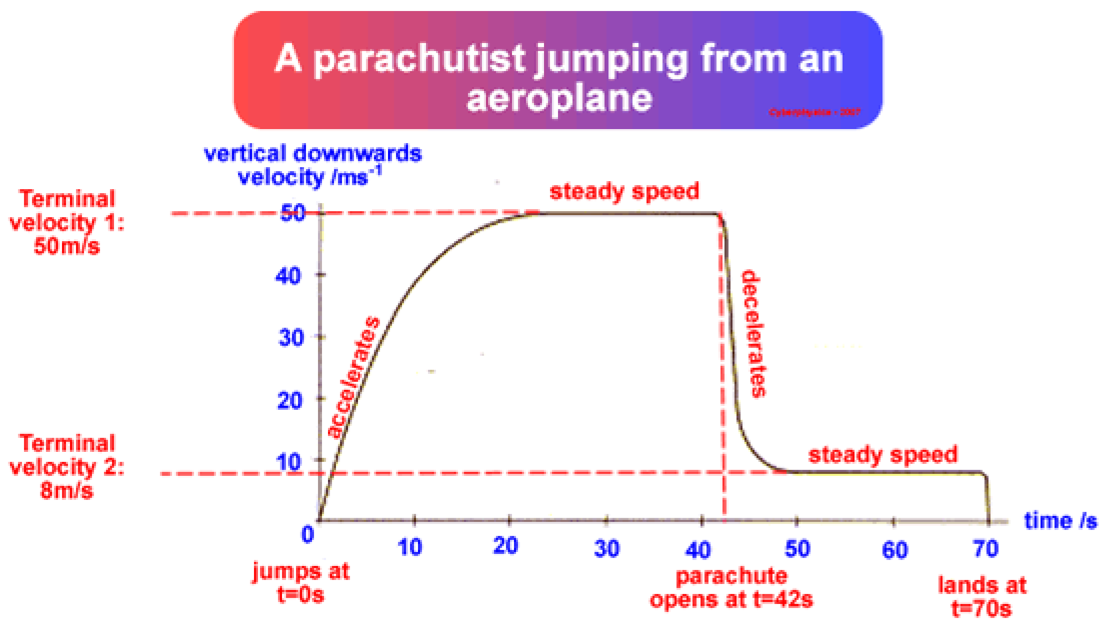


Figure 8.16 graph of a parachutist.

8.5 Equations of uniformly accelerated motion

Calculations involving the displacement, velocity, acceleration and time of motion of a moving body use the equations of motions. These equations are derived from the definitions of acceleration and average velocity.

Equation 1

If a body is moving with uniform acceleration **a** and its velocity increases from **u** to **v** in time **t**, the equation is given as;

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

Making v the subject of the formula, the equation that is obtained is

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

Equation 2

The velocity of a body moving with uniform acceleration increases steadily. Its average velocity therefore equals half the sum of its initial and final velocities. The equation is given as:

$$\text{average velocity} = \frac{u + v}{2}$$

From (1) $\quad v = u + at$

$$\text{average velocity} = \frac{u + u + at}{2} = \frac{2u + at}{2}$$

$$= u + \tfrac{1}{2} at^2$$

If s is the distance moved in time, t, then since average velocity = distance / time = s/t

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

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

Equation 3

The third equation is obtained by eliminating t between the first two equations.

Squaring both sides of the equation, v = u + at, we obtain

$$v^2 = u^2 + 2\,uat + a^2t^2$$

Taking out the factor 2a from the last two terms of the right-hand side,

$$v^2 = u^2 + 2a\,(ut + \tfrac{1}{2} at^2)$$

But the bracket term is equal to s

Hence $\quad \mathbf{v^2 = u^2 + 2as} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3)$

Worked examples

1. Yusuf rides a bicycle. He starts from rest and accelerates at 2 m/s^2 for 10 seconds. Calculate his maximum speed.

Solution u = 0m/s $\quad$ v =? $\quad$ a = $2m/s^2$

t = 10 s

v = u + at v = 0 + (2 x10) v = **20 m/s**

Chapter 9

Work and energy

9.1 Work

Work is done when a force produces motion. In physics work is defined if force applied on object displaces the object in the direction of force. The greater the force and the greater the distance moved, the more work is done.

For example: an example is when you are running, when you carry a load up a ladder and when a car is moving.

Work is said to be done when a force moves its point of application in the direction of the force.

Work done = force x distance moved by force in the direction of the force

If force is measured in Newton (N), distance in metres (m), then work is measured in Nm or Joule (J).

1 Joule of work is done when a force of 1 N moves an object 1 m in the direction of the force.

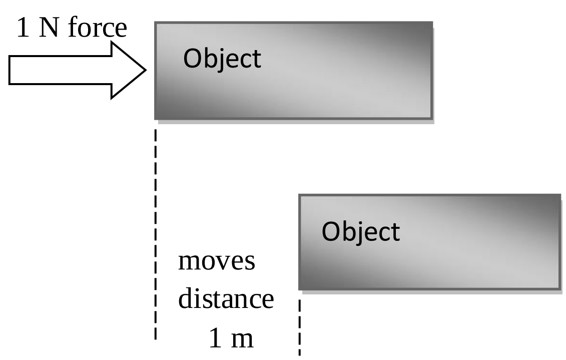


Figure 9.1 demonstrating work done

Worked examples

1. Ramazan provides a force of 50 N to move an object a distance of 100 cm. Calculate the work done.

Solution

F = 50 N d = 100 cm = 1 m

W = F x d

W = 50 N x 1 m

W = **50 Nm** or **50 J**

Experiment 9.1

AIM: To find the amount of work done
MATERIALS: Ruler or tape measure, spring balance, scale, masses, a wall, a ladder or stairs and a bench.
PROCEDURE:

1. Tie a rope to the mass and suspend it to the spring balance to find its weight or force in Newton (N). Use a ruler or tape measure to measure the distance from the ground to the top of a bench in metres (m). Lift the mass from the ground to the top of the bench. Calculate the work done ($w = f \times d$).

2. Step on a scale to find out your mass, then convert your mass from kilograms to Newtons by simply multiplying by 10. Use a ruler or a tape measure to measure the length of a ladder. Lean the ladder against a wall and climb it up to the end. Calculate the work done ($w = f \times d$).

Work done by a force acting at an angle

A force, F, can act on a body so as to move it in a direction other than its own. This situation can occur only if there is some other force preventing motion taking place in the direction of a force. **An example** is a man pulling a garden roller as shown in **Figure 9.2.**

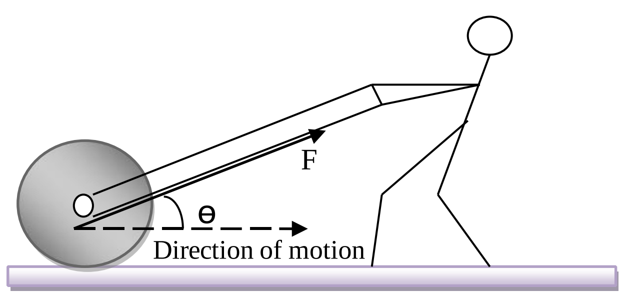


Figure 9.2 a man pulling a roller

In **Figure 9.2**, the man is holding the handle at an angle θ to the horizontal and exerts a force F in the direction shown. The work done by the force F in the direction of motion is found by using a formula:

$$\mathbf{W = F \times \cos\theta}$$

Worked example

A lady applies a force of 60 N to move a vacuum cleaner at an angle of 60^0 to the horizontal. Calculate the work done.

Solution

F = 60 N   Angle ɵ = 60^0

W = F x cos ɵ

  = 60 N x cos 60^0

W = **30 J**

9.2 Conversion of mechanical energy

Energy can be converted from one form to another. A common conversion of mechanical energy is from potential energy to kinetic energy or vice versa. When there is conversion of these mechanical energies, some energy is usually wasted in form of heat or sound.

This can be demonstrated by using a pendulum.

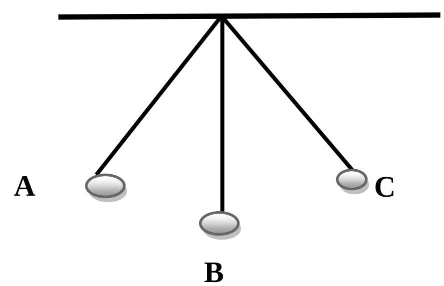


Figure 9.3 a pendulum

When a bob is made to oscillate, it converts kinetic energy to potential energy by moving to points A and C. The potential energy is maximum at points A and C. Kinetic energy is maximum at point B. This means that the energy of the bob is all potential energy at A and C and it is all kinetic energy at B.

In this case, Kinetic energy and potential energy are interchangeable continually

The energy changes can be summarised as follows:

A to B to C: ***Potential energy to kinetic energy to potential energy***

After some time, the bob fails to reach positions A and C, because potential energy changes to heat energy due to friction between the bob and the air particles.

Law of conservation of mechanical energy

From the pendulum, it is noticed that the loss in PE of a pendulum equals the gain of the KE and vice versa.

When a bob oscillates from point A to point B, its potential energy at point A equals its kinetic energy at point B. When the bob oscillates from point B to point A, its kinetic energy at point B equals its potential energy at point A. The total mechanical energy is kept constant during this oscillation. This means there is neither increase nor decrease in mechanical energy. Energy is not lost or created; it simply changes from one form to another. Therefore, mechanical energy is conserved and it is summarized as the law of conservation of energy.

Law of conservation of energy states that energy is neither created nor destroyed, but it can simply change from one form to another.

Energy–work theorem

Work is done whenever a force moves an object.
Work done = force x distance moved.

Energy is the ability to do work. Things have energy in order to do work. Whenever work is done, energy is transformed.
For example, if you lift a 20kg box to a height of 5 m, the work done by lifting the box will be:

W = F x d
W = 200 N x 5 m
W = **2000 J**

In this case, the box will gain a potential energy of **2000 J,** assuming there is no air resistance.

If this box is dropped to the ground, **2000 J** of work is done in accelerating the box. The box losses **2000 J** of potential energy. If the box is about to hit the ground, **2000 J** of kinetic energy is gained. If the box hits the ground and comes to rest, **2000 J** of kinetic energy is changed into heat energy.
Therefore, work done equals energy

Work done = Energy

Energy is measured in Joules (J).

Worked example

A 1.5 kg brick is lifted from the ground to a height of 3 m.
Calculate

- **a.** the work done in lifting the brick.
- **b.** the energy used in lifting the brick.
- **c.** the potential energy gained by the brick after being lifted to a height of 3 m.

Solution

a. W = F x d
W = 150 N x 3 m
W = **450 J**

b. E = W
E = **450 J**

c. PE = W
PE = **450 J**

Chapter 10

Machines

10.1 What are machines?

The term **'machine'**, makes many people think it is a complicated piece of mechanism. The term **'machine'** has tended to lose its original meaning. It does not matter how a machine is deemed complicated, but there are a limited number of basic mechanical principles:

- In a machine forces are involved in energy conversions. Therefore, a machine is a device that causes a change in the way that these forces act.
- Machines can help to raise heavy objects with a smaller effort. Therefore, a machine is a device that changes the magnitude of a force and makes work to be done easier.
- In a machine the direction of a force changes; therefore, a machine is a device that changes the direction that a force acts on.

From the principles explained above, machines are considered to change either the magnitude or direction of a force.

In physics, **a machine is any device in which a force applied at one point can be used to overcome a force at some other point.**

Examples of machines are levers, pulleys and inclined planes.

The lever

A **lever** is any rigid body which is pivoted about a point called the **fulcrum.** Examples of levers are claw hammer, wheelbarrow, pliers, nut crackers, sugar tongs, table knife and scissors

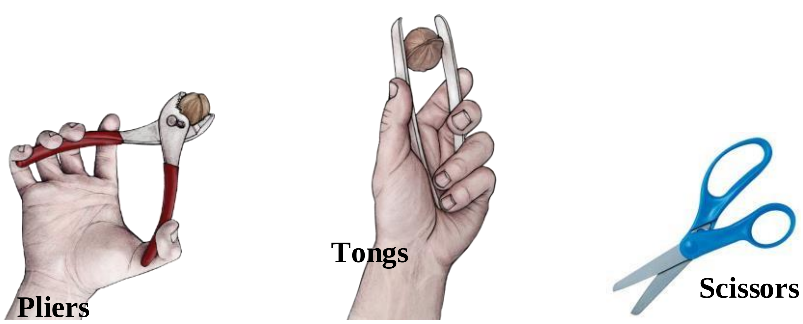


Figure 10. 1 levers

In levers, a force called the **effort** is applied at one end to overcome a force called the **load** at the other end. Levers use the principle of moments as discussed in book 2, chapter 6 and section 6.6.

A lever is used as a **force multiplier** because it uses a smaller effort to move a larger load. In ancient times, humans used levers to lift very heavy objects like stones. It was believed that a person can move the earth with a lever.

Pulleys

A **pulley** is a grooved rim (rims) mounted in a framework called a **block.** The effort is applied to a rope, chain or belt which passes over the pulleys.

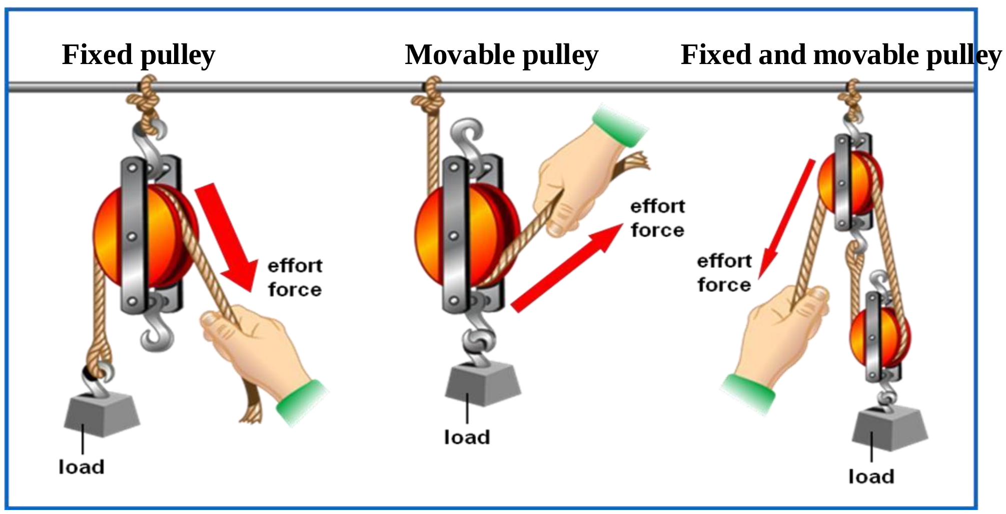


Figure 9.2 pulley systems

Inclined plane

An **inclined plane** is a plane surface at an angle to the horizontal. It is easier to move a heavy object up an inclined plane than to move it vertically upwards.

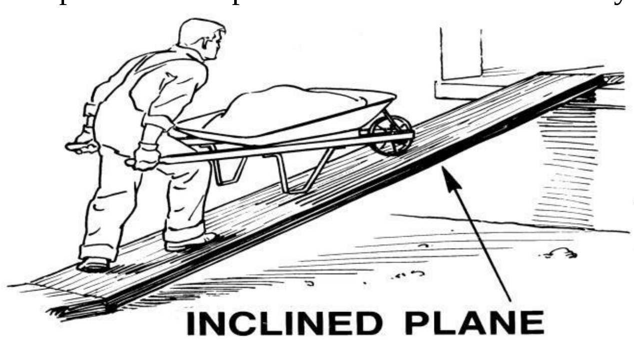


Figure 10.3 inclined plane

10.2 Efficiency, mechanical advantage and velocity ratio of a machine

Efficiency of a machine

Efficiency of a machine is the ratio of the work done by the machine to the total work put into the machine expressed in percentage.

Work done by the machine on the load = load x distance load moves. This work done is called **work output.**
Work put into the machine by the effort = effort x distance effort moves. This work done is called **work input.**

$$\textbf{Efficiency} = \frac{\textbf{work output (load x distance load moves)}}{\textbf{work input (effort x distance effort moves)}} \times 100\ \%$$

In a perfect machine, efficiency is 100 %. A **perfect machine** is a theoretical machine, with a useless load of zero. **Useless load** is the force needed to overcome the frictional forces between the moving parts of a machine to raise any of its moving parts. The efficiency of 100 % means the work output equals work input.
Using a perfect machine, if an effort of 100 N is moved at a distance of 2m to raise a 200 N force:

Work put into the machine by effort = work input = 100 N x 2 m = **200 J**

Work done by the machine on the load = work output = **200 J**

The load will move a distance of 1m
In practical machines, efficiency is always less than 100 %. Some work is always wasted to overcome the frictional force between the moving parts of a machine and raise any of its moving parts. The efficiency is less than 100 % because the useful work done by the machine is less than the work put into the machine by the effort.

Mechanical advantage of the machine

The Mechanical advantage of a machine is the ratio of the two forces, the load and the effort. The Mechanical advantage of a machine is found by dividing load by effort.

$$\textbf{Mechanical advantage} = \frac{\textbf{Load}}{\textbf{Effort}}$$

Where mechanical advantage is greater than 1, it means the machine is designed to overcome a load which is greater than the effort. An example is a car jack used to lift a motor car.

When mechanical advantage is less than 1, it means the machine is designed so that the effort used is greater than the load. For example, a bicycle has a mechanical advantage of less than 1. This can be noticed when the cyclist is cycling uphill where more effort is applied to work against the force of gravity. The cyclist is said to be working at a mechanical disadvantage. The cyclist simply dismounts and walks.

Velocity ratio of a machine

The **velocity ratio** of a machine is the ratio of the distance moved by the effort to the distance moved by the load in the same time. It has no units.

$$\textbf{Velocity ratio} = \frac{\textbf{distance moved by the effort}}{\textbf{Distance moved by the load in the same time}}$$

In a situation where mechanical advantage is greater than 1, velocity ratio is greater than 1 because the effort moves through a much greater distance than the load.

The velocity ratio of a machine can also be called **speed ratio**.

Relationship between mechanical advantage, velocity ratio and frequency:

work = force x distance

$$\text{Efficiency} = \frac{\text{Load x distance the load moves}}{\text{Effort x distance the effort moves}} \times 100\ \%$$

$$\text{But} \quad \frac{\text{Load}}{\text{Effort}} = \text{Mechanical advantage (M.A.)}$$

$$\frac{\text{distance the load moves}}{\text{distance the effort moves}} = \frac{1}{\text{velocity ratio (V.R.)}} \times 10\%$$

$$\text{Therefore, efficiency} = \text{M.A.} \times \frac{1}{\text{velocity ratio (V.R.)}} \times 100\ \%$$

$$\textbf{Efficiency} = \frac{\textbf{M.A}}{\textbf{V.R.}} \times \textbf{100 \%}$$

2. Figure 10.5 shows a pulley system used to raise a 180kg mass. The load moves a distance of 5m.

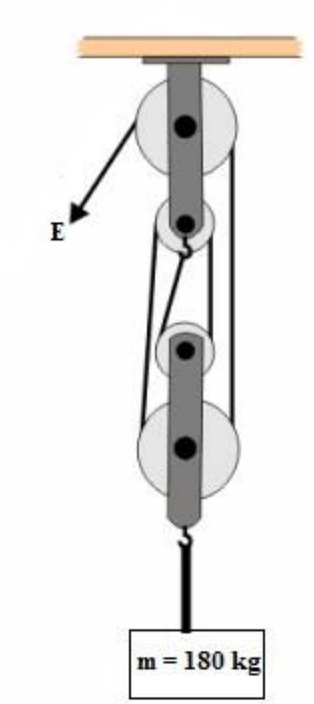


Figure 10.5

Calculate:

- **a.** the mechanical advantage, MA of the pulley system
- **b.** the effort used to raise the load
- **c.** the velocity ratio, VR for this system
- **d.** the distance moved by the effort
- **e.** work done by the effort
- **f.** work done on the load.

Solutions

a. MA = number of pulley systems MA = **4**

b. $MA = \frac{Load}{Effort}$

$$Effort = \frac{Load}{MA}$$

$$\frac{180 \times 10\ N}{4}$$

Effort = **450 N**

c. VR = **4** (the number of ropes supporting the load)

d. $VR = \frac{\text{distance moved by effort}}{\text{distance moved by load}}$

Distance moved by effort = VR x distance moved by load

= 4 x 5 m

Distance moved by effort = **20 m**

3. Figure 10.6 shows a 500 N object pushed to a lorry up the height 2 m using a plank of length 10 m.

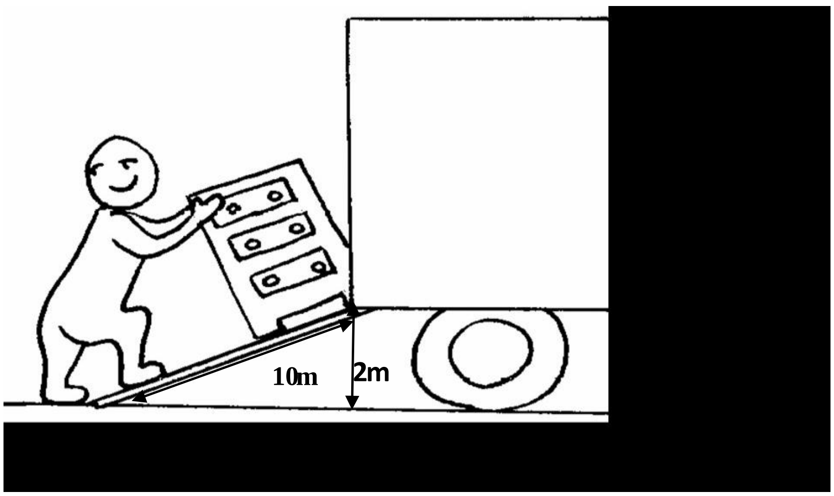


Figure 10.6

Calculate

a. the mechanical advantage, MA of an inclined plane, if the effort is 200 N
b. the velocity ratio
c. the work done by the effort
d. the work done on the object.

Solution

a. $MA = \frac{\text{Load}}{\text{Effort}}$

$= \frac{500\ N}{200\ N}$

MA = **2.5**

b. $VR = \frac{\text{distance moved by effort}}{\text{vertical distance moved by load}}$

$= \frac{10\ m}{2\ m}$

VR = **5**

c. work done by the effort = effort x distance moved by effort

= 200 N x 10 m

Work done by the effort = **2000 J**

d. Work done on load = load x distance moved by load

= 500 N x 2 m

Work done on load = **1000 J**

Chapter 11

Current electricity

11.1 Electric current

The atoms in a solid are held together by strong electrical forces. These atoms can only vibrate about a fixed mean position. A solid which is a conductor contains a great number of electrons which are loosely held and are free to move. These are known as **free electrons**. When an electric field is applied there is a drift of electrons in a conductor from the negative side to the positive side. This movement of charge is known as **electric current**.

Therefore, **electric current** is the flow of electric charges (electrons) from the negative side of an electric field to the positive side.

Figure 11.1 shows the direction of electrons or electric current in the circuit.

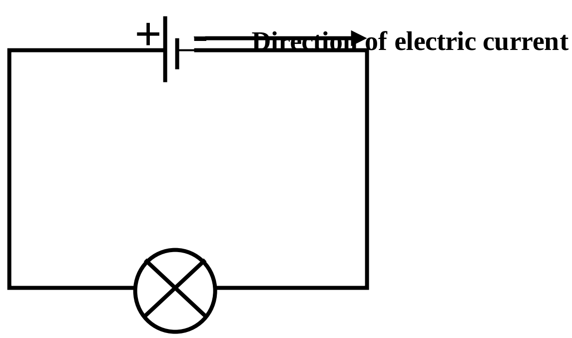
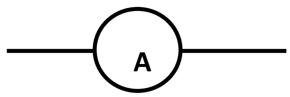


Figure 11.1 direction of electric current

The unit of electric current (I) is the **Ampere (A)**. Therefore, the SI unit of current is Ampere (A).
Current is measured by an ammeter in the circuit.

The symbol for an ammeter is:



Using an ammeter in the circuit to measure current

- Connect the positive (red) terminal of an ammeter to a positive terminal of a power supply (e.g. cell or battery) and the negative (black) terminal to a negative terminal of a power supply. Any mistake on connection will break an ammeter.

- Connect an ammeter in series circuit because it measures current passing through a component or a wire. An ammeter has very low resistance and has a negligible effect to the flow of current.

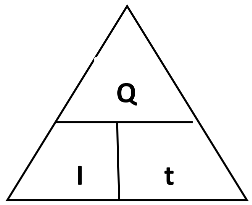
The smaller currents are measured by a **milliammeter**. The unit then is **milliampere** (**mA**).

1 A = 1000 mA

The quantity of electricity (electric charge) which passes any point in a circuit will depend on the strength of the current and the time for which it flows. The quantity of electric charge is called **Coulomb.**
A coulomb is the electric charge which passes any point in a circuit in 1 second when a steady current of 1 ampere is flowing.

Using the following symbols:
Q for electric charge in Coulombs,
C **I** for current in Amperes, A
t for time in seconds, s
Electric current, I can be found as:

$$\mathbf{I = \frac{Q}{t}}$$



From the above equation, we can define **current** as the rate at which the electric charge flows.

Worked examples

1. An electric charge of 50 C flows past a point in a wire in 5 seconds. Calculate the current flowing in the wire.

Solution

Q = 50 C   t = 5 s

$$I = \frac{\mathbf{Q}}{\mathbf{t}}$$

$$I = \frac{50\ C}{5\ s}$$

I = **10 A**

2. A current of 30 mA flows in a circuit for 100 seconds. Calculate the quantity of electric charge.

Solution

I = 30 mA = 3 x10^{-3} A   t = 100 seconds

Q = It

Q = 30 x 10^{-3} A x

100 s Q = **3 C**

11.2 Potential difference (pd) or Voltage

When a cell is connected in the circuit, the electric charge flows because it has the energy called **potential or potential energy**. In a circuit, potential is the energy associated with a charge at a point in an electric field because of the force acting on it.

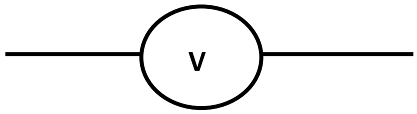
Work is done against the electric field when an electric charge is moved from a lower potential level to a higher potential level. The difference between the two levels is known as the **potential difference (pd)** or **voltage.**

Potential difference is defined as a difference in potential between two points, equal to the energy change when a unit electric charge moves from one place to another in an electric field.

The SI unit of potential difference is the **volt** (**V**).

Potential difference (which is also called **voltage**) is measured by a **voltmeter**.

The symbol for a voltmeter is:

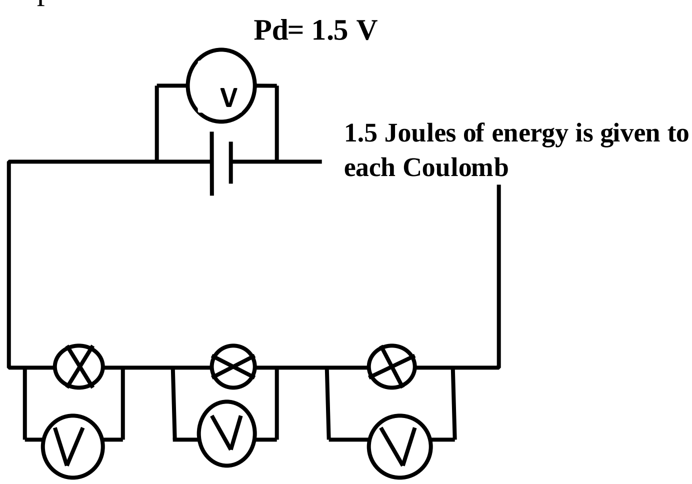


Connecting a voltmeter

A voltmeter is connected in the following ways:

- A positive side (red side) of a voltmeter is connected to the positive terminal of a cell or battery or any power supply while a negative side (black side) is connected to a negative terminal.
- A voltmeter is connected in a parallel circuit, across a component that it is measuring its voltage because it measures voltage between two points. A voltmeter has very high resistance. Connecting a voltmeter in a series circuit prevents the flow of current.

Two points are at a potential difference of 1 volt if 1 Joule of work is done per Coulomb of electric charge from one point to another.



0.7 V **0.7 Joule of energy is lost by each Coulomb**	**0.3 V** **0.3 J of energy is lost by each Coulomb**	**0.5 V** **0.5 Joule of energy is lost by each Coulomb**

Figure 11.4 Measuring potential difference using a voltmeter

Potential difference is lost in the bulbs and none is lost in the connecting wire. The sum of the potential differences lost in the bulbs equals the potential difference across the supply.

Sum of potential differences = 0.7 V + 0.3 V + 0.5 V = 1.5 V

Electromotive force (EMF)

Each cell or battery has the potential difference written across it, e.g. 1.5 V.
A cell or a battery produces its highest potential difference when it is not in the circuit and when it is not supplying current. This maximum potential difference is called the **electromotive force (EMF)** of the cell or a battery.

Electromotive force (EMF) is the maximum potential difference across a cell or battery when it is not in a circuit and not supplying current (when I = 0 A).

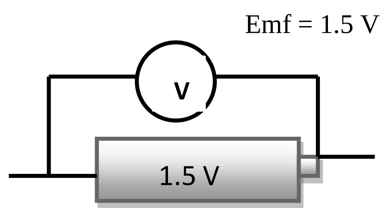


Figure 11.5 measuring Emf

When the cell is connected in the circuit and supplies current, the potential difference across the cell drops because of energy wasted inside the cell. For example, a potential difference across a 1.5 V cell can be 1.3 V. Part of the energy is used to push electrons and overcome internal resistance.

11.3 Electrical resistance

In **section 11.2**, it was explained that current flows through the conductor or circuit because of the potential difference (voltage which is applied across it.
Different materials have different conductivities when they are connected in the circuit. For example:

- In a copper wire current is high because electrons pass easily. This shows that a copper wire is a good conductor. Therefore, copper has low resistance.
- In a nichrome wire of a similar size as the copper wire gives low current because electrons pass with difficulties. This shows that a nichrome wire is not a good conductor. Therefore, nichrome wire has high resistance.

The conductivity of the wires mentioned above is different because the materials in the wires provide different opposition to the flow of electrons. This opposition is called **electrical resistance.**
Electrical resistance is the opposition to the flow of electrons in a wire or a circuit.

Therefore, copper wire has low electrical resistance while nichrome wire has high electrical resistance.

Electrical resistance is measured in **Ohms (Ω)**. Therefore, the SI unit of resistance is **Ohm (Ω)**.
If the electric current through a conductor is I when the pd across it is V, its electrical resistance can be calculated by the equation:

$$\textbf{Electrical resistance} = \frac{\textbf{Potential difference}}{\textbf{Current}}$$

$$\mathbf{R} = \frac{\mathbf{V}}{\mathbf{I}}$$

Worked example
The potential difference across a nichrome wire is 10 V. If the current flowing through the wire is 2 A, calculate the electrical resistance of a nichrome wire.

Solution
Pd = 10 V I = 2 A

$$R = \frac{\mathbf{V}}{\mathbf{I}}$$

$$R = \frac{10\text{ V}}{2\text{ A}}$$

R = **5 Ω**
The ohm is the electrical resistance of a conductor in which the current is 1 A when a p.d. of 1 V is applied across it.

Factors affecting the electrical resistance

There are four major factors that affect resistance of a wire.
These factors are length of a wire, temperature, cross-sectional area and nature of the material.
If you want to vary one factor, the other three factors must be kept constant.

Length of the wire

EXPLANATION
As the length of the wire decreases, there are few collisions that take place between flowing electrons and stationary positive ions. In other words, there is reduction in opposition to the flow of electrons because there are few stationary positive ions that can cause resistance.
In general,

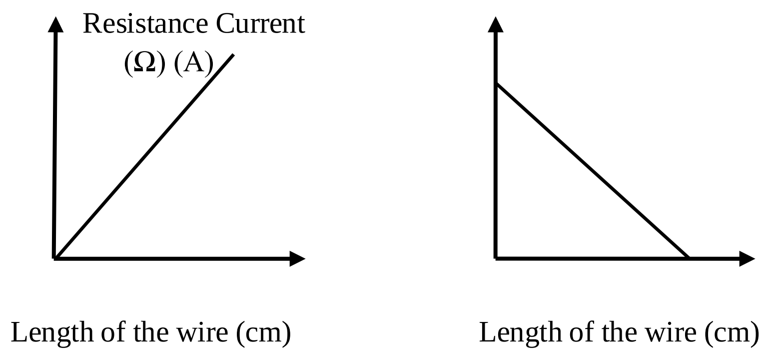
Shorter wire → lower resistance
Longer wire → higher resistance.

CONCLUSION

Therefore, the resistance of the wire varies directly with the length of the wire.

R α *l*

Figure 11.8 shows the shapes of the graphs that can be plotted from **experiment 11.1.**



(a) Resistance of the wire increases with an increase in length

(b) Current decreases with an increase in length of the wire

Figure 11.8 graphs showing the effect of the length of the wire on resistance

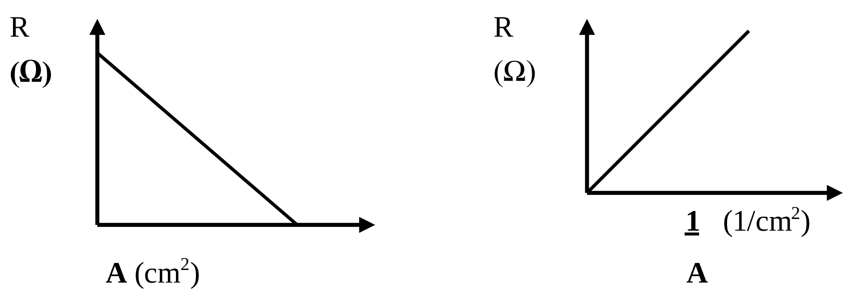
Thickness or cross-sectional area

Resistance of the wires decreases as the thickness increases.

EXPLANATION/CONCLUSION

As the thickness of the wire increases, electrons are able to flow with less resistance. Therefore, resistance of the wire varies inversely with its cross-section or thickness.

$$\mathbf{R \;\alpha\; \frac{1}{A}}$$



(a) **(b)**

Figure 11.10 graphs showing the effects of cross-sectional area of the wire on resistance

Temperature

The resistance of the wire increases as the distance of the Bunsen burner from the nichrome wire decreases.

EXPLANATION

As the distance between the burner and the wire decreases, the temperature of the wire increases. An increase in the temperature of the wire increases the kinetic energy of the stationary positive ions in the wire. These particles increase their vibrations and cause more collisions with the flowing electrons. Hence increases resistance.

In general:

Low temperature → low resistance

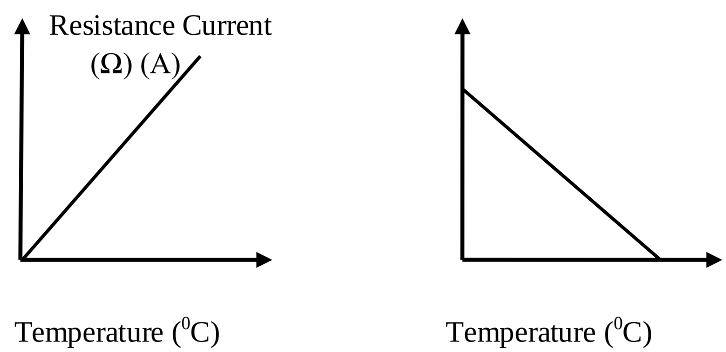
High temperature → high resistance.

CONCLUSION

Therefore, resistance of the wire varies directly with temperature.

R α T

Figure 11.12 shows the shapes of the graphs that can be plotted



(b) Resistance of the wire increases with an increase in temperature

(b) Current decreases with an increase in temperature

Figure 11.12 Graphs showing the effect of temperature on resistance

Nature of the material

RESULTS

Copper wire gives high ammeter reading while nichrome wire gives low current reading.

EXPLANATION

Copper wire gives high current reading because it has low resistance. Nichrome wire gives low current because it has high resistance.

This shows that copper wire is made up of copper material which has low resistance and nichrome wire is made up of nichrome material which has high resistance.

CONCLUSION

Therefore, different wires are made up of different materials that have different resistances.

Ohm's law

A German physicist, **George Simon Ohm** was a physics teacher. In 1826 he published a book containing details of the experiments he made to investigate the relationship between the current passing through the wire and the potential difference across the supply at a constant temperature.

The experiments that he carried out had the results equivalent to the ones shown in **Table 11.4.**

Table 11.4

Number of cells	**Potential difference (voltage) V**	**Current I (A)**	$\frac{\textbf{Voltage}}{\textbf{Current}}$	$\frac{V}{I}$
1	1.5	0.1	$\frac{1.5}{0.1}$	15
2	3	0.2	$\frac{3}{0.2}$	15
3	4.5	0.3	$\frac{4.5}{0.3}$	15
4	6	0.4	$\frac{6}{0.4}$	15

From Table 11.4, it has been noted that current increases as potential difference increases. This relation is called **Ohm's Law**.

Ohm's law states that the current in a conductor is directly proportional to the potential difference between its ends, at constant temperature.

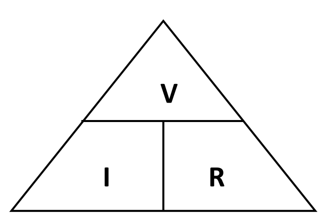
$$I \; \alpha \; V$$

$$V = I \times \text{constant}$$

$$\frac{V}{I} = \text{constant}$$

Constant is called **Resistance, R**

Therefore, $\underline{V} = R$



I

or **$V = IR$**

Verifying Ohm's law

Experiment 11.5

AIM: To verify Ohm's law

MATERIALS: Cells, switch, ammeter, voltmeter, resistor (a nichrome wire) and connecting wires.

PROCEDURE:

1. Set up the apparatus as shown in **Figure 11.15.**

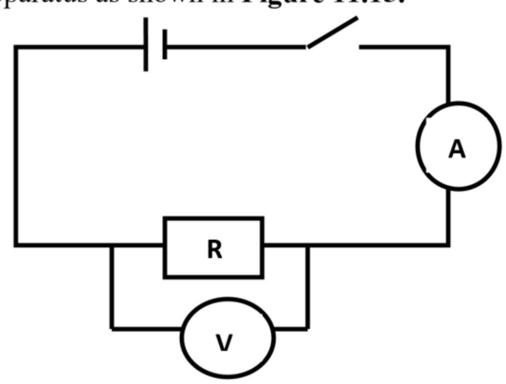


Figure 11.15

2. Close the switch and take the voltmeter and ammeter readings.
3. Repeat the experiment with 2, 3 and 4 cells. Take the voltmeter and ammeter readings for each number of cells in **Table 11.5.**

Number of cells	Voltmeter reading (V)	Ammeter reading (A)	Resistance (Ω) $\frac{\text{Voltage}}{\text{Current}}$
1			
2			
3			
4			

Table 11.5

DISCUSSIONS

1. Calculate the resistance for each number of cells.
2. What have you noticed about the results in question 1? Give a reason for your answer.
3. Do the results in **Experiment 11.5** verify the Ohm's law? Give a reason for your answer.

4. Plot a graph of voltmeter reading (V) against the current reading (A).
5. Describe the shape of the graph in question 4.
6. Does the graph in question 4 verify the Ohm's law? Give a reason for your answer.

Ohm's law is applied only to some materials (metals and some alloys). Materials that obey Ohm's law, and hence have a constant resistance over a wide range of voltages, are said to be **ohmic**. Ohmic materials have a linear current–voltage relationship over a large range of applied voltages as shown in **Figure 11.16.**

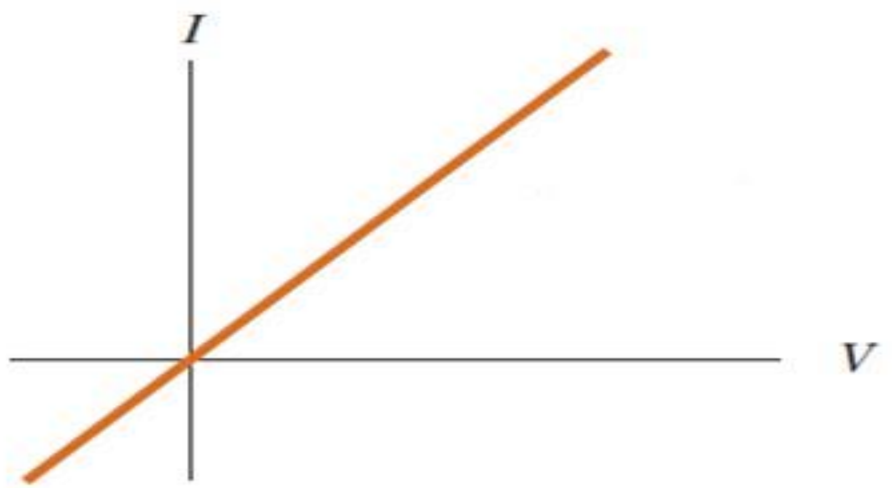


Figure 11.16 current-voltage-curve for an ohmic material

Materials having resistance that changes with voltage or current are **nonohmic**. Nonohmic materials have a nonlinear current–voltage relationship as shown in **Figure 11.17.**

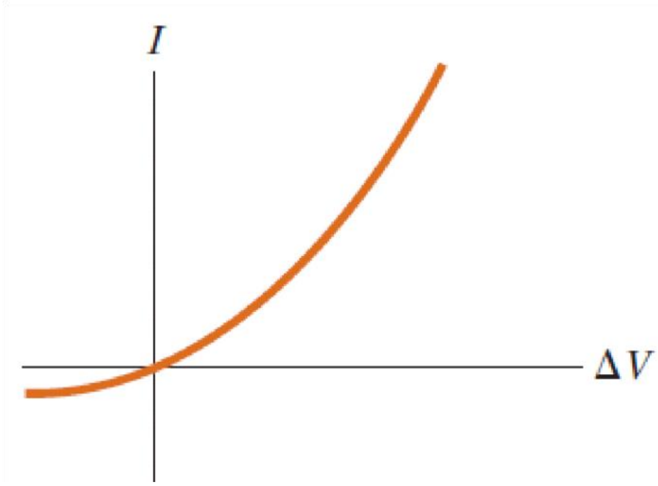


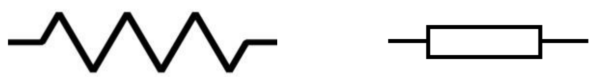
Figure 11.17 current-voltage curve for a nonohmic material

One common semiconducting device that is nonohmic is the diode.

Measuring resistance using an ohmmeter

A **resistor** is a device that causes resistance.

It is used to reduce the amount of current flowing in the circuit. The symbol for a resistor is shown below:



In Experiment 11.5, the resistance of the resistor is measured using the Ohm's law. Using Ohm's law, **y**ou connect a voltmeter across a resistor and an ammeter in series in the circuit. The resistance of a resistor is found by dividing the voltmeter reading by the ammeter reading.

$$\text{Resistance} = \frac{\text{Voltmeter reading}}{\text{Ammeter reading}}$$

$$\mathbf{R = \frac{V}{I}}$$

The resistance of a resistor can also be found by using an ohmmeter. An ohmmeter is an instrument which is used to measure resistance of a resistor. Using an ohmmeter, you connect one terminal of an ohmmeter to one side of a resistor and the other terminal of an ohmmeter to the other side of a resistor. Take the reading of resistance on an ohmmeter.

Calculating resistance using Ohm's law

Worked examples

1. A potential difference of 30 V is needed to make a current of 5 A to flow through a wire. Calculate the resistance of the wire.

Solution

V = 30 V I = 5 A R =?

$$R = \frac{V}{I}$$

$$= \frac{30\ \text{V}}{5\ \text{A}}$$

$$R = \mathbf{6\ \Omega}$$

Finding resistance of resistors using colour codes and standard notation

Colour codes

The resistance in ohms can be marked on the resistor using colours. This method is called **colour coding** or **resistance coding.**

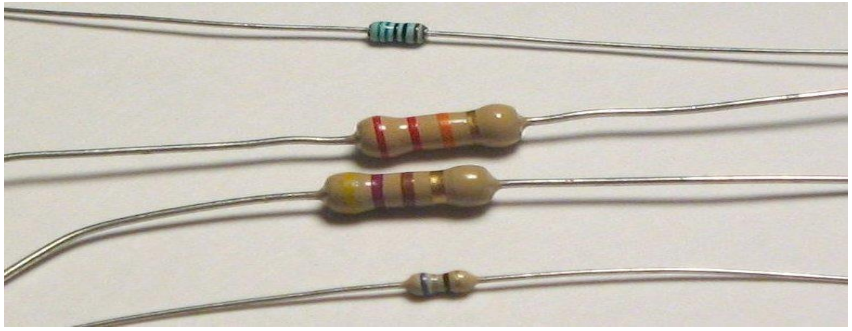


Figure 11.18 resistor colour codes

Each colour has its own standard notation (digit).
Resistors are colour coded with four or five bands to indicate their resistance.
Figure 11.19 shows a resistor that is colour coded.

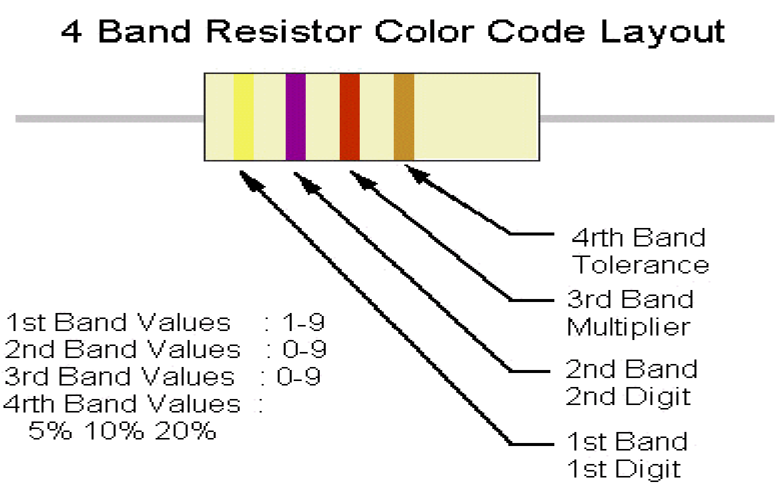


Figure 11.19 4 Band Resistor colour code layout

Explanation of bands on a colour coded resistor

The last band always gives tolerance. **Tolerance** is the extent to which the actual value of the resistance can vary.

The following are the values of tolerance:

Colour	**Tolerance**
Gold	± 5%
Silver	± 10%
No colour	± 20%

The band which is second from the last band gives the number of zeros called **multiplier.** Other bands give the digits.
The following are colour codes:

Colour	**digit**
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

Worked examples
Find the resistance of each of the following resistors.

1.

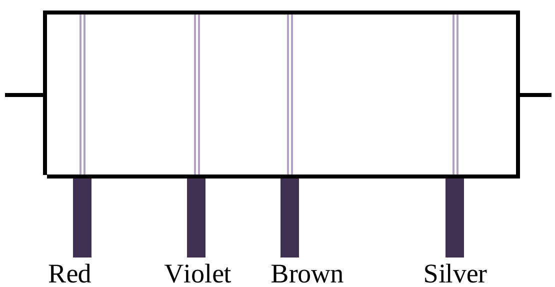


Figure 11.20

Solution
Last band is silver, therefore tolerance = ±10%.
Second from last band is Brown: therefore, number of zeros =1(1 zero).
The first band is Red. Therefore, the first digit is 2.
The second band is Violet. Therefore, the second digit is 7.
The value of the resistance will be written as:

Red	Violet	Brown	Tolerance
2	7	0	±10%

Resistance = **270 ±10%Ω**

Standard notation
The resistors have numbers and letters printed on them.

Examples

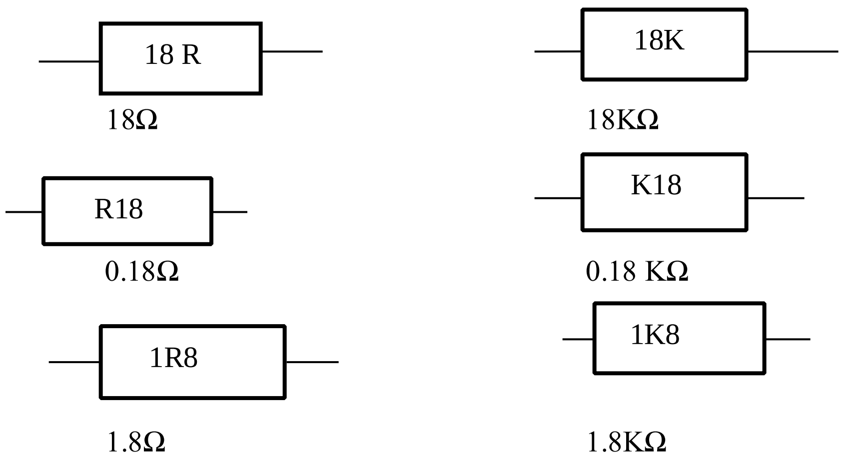


Figure 11.22 resistance code standard notation

The letters are used as tolerance.

Letter	Tolerance
F	± 1%
G	± 2%
J	± 5%
K	± 10%
M	± 20%

Examples

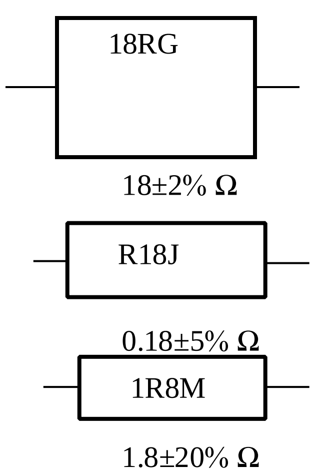


Figure 11.23 resistance code standard notation

Internal resistance of a cell

When a voltmeter is connected across a 1.5 V cell, it reads 1.5 V. This shows that chemical action within the cell causes an e.m.f. of 1.5 V.
When the cell is connected in a circuit and supplies current, the voltmeter reads 1.2 V. This is the potential difference (p.d) in the circuit. The reading on the voltmeter has dropped because the cell has resistance, like other components. This resistance is called **internal resistance, r.**

Internal resistance (r) is the resistance of a cell or battery to the current it causes. It is the resistance of the connections in the cell and some chemical effects e.g. polarization. The internal resistance is usually low, about 0.5Ω or so.

Internal resistance = $\dfrac{\text{“lost in voltage”}}{\text{current}}$

$$r = \frac{v}{I}$$

Lost in voltage, v = Ir

Electromotive force, E = potential difference, V + lost in voltage, Ir **E = V + Ir**

Worked example

The e.m.f. across the terminals of a cell is 3.0 V. If the p.d. across the cell is 2.5 V and the current flowing is 2 A, calculate the internal resistance of a cell.

Solution

E = 3 V V = 2.5 V I = 2 A r =?

Either: E = V + Ir

3 V = 2.5 V + (2 A x r)

3 V – 2.5 V = 2 A x

0.5 V = 2 A x r

$$\frac{0.5\text{ V}}{2\text{ A}} = r$$

r = **0.25 Ω**

Or: Internal resistance = $\dfrac{\text{“lost in voltage”}}{\text{current}}$

lost in voltage, v = E – V

= 3.0 V – 2.5 V

$v = 0.5\ V$

$r = \frac{V}{I}$

$r = \frac{0.5\ V}{2\ A}$

r = **0.25 Ω**

2. A battery has an e.m.f. of 12 V and an internal resistance of 0.6 Ω. What is the p.d. across its terminals when it is supplying a current of 5 A?

Solution

E = 12 V V=? r = 0.6 Ω I = 5 A

$E = V + Ir$

$V = E – Ir$

$V = 12V – (5\ A \times 0.6\ \Omega)$

11.4 Electric circuits

An **electric circuit** is a conducting path in which electrons flow or electric current takes place. An electric circuit can consist of a cell or battery, connecting wires, bulb, resistors, ammeter and voltmeter.

Circuits are grouped into two:

a. Series circuit

A **series circuit** is a circuit in which all the components are connected in one line. A series circuit has one conducting path.

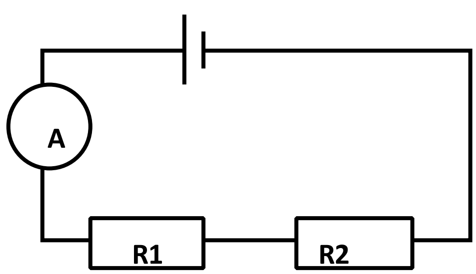


Figure 11.26 series circuit

b. Parallel circuit

A **parallel circuit** is a circuit in which components are connected in branches. A parallel circuit has more than one conducting path.

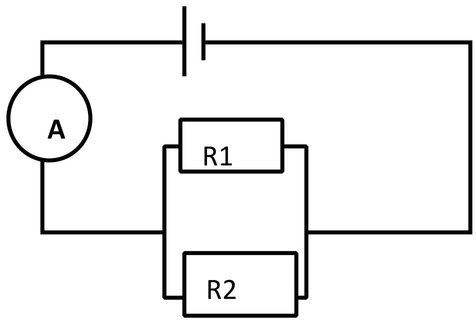


Figure 11.27 parallel circuit

RESULT

When the resistors are connected in a series circuit the resistance in the circuit is higher than the resistance when they are connected in a parallel circuit.

EXPLANATION/CONCLUSION

The total resistance of the resistors connected in a series circuit is greater than the total resistance of the resistors connected in a parallel circuit.

Current in series and parallel circuits

Current in series circuit

Current across each and every component in series circuit is the same. This current is the same as the current from the supply.

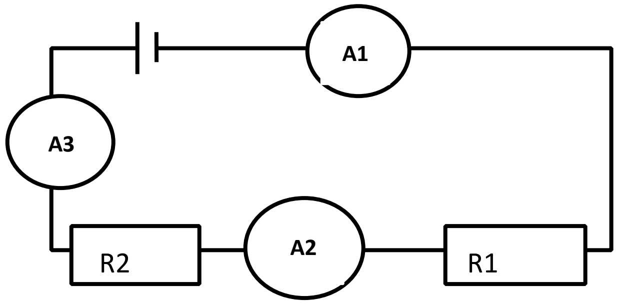


Figure 11.30 current flowing in series circuit

In this circuit, A1 = A2 = A3

Current in parallel circuit

When components are connected in a parallel circuit, the sum of the currents in a parallel circuit equals the current in series (main) circuit.

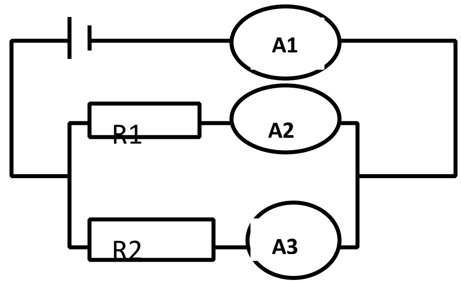


Figure 11.31 current flowing in a parallel circuit.

Sum of the current in parallel circuit = current in the main circuit

$$\mathbf{A_2 + A_3 = A_1}$$

Voltage in series and parallel circuit

Voltage in series circuit

The sum of the voltages across the components connected in series circuit equal the voltage or Pd from the supply.

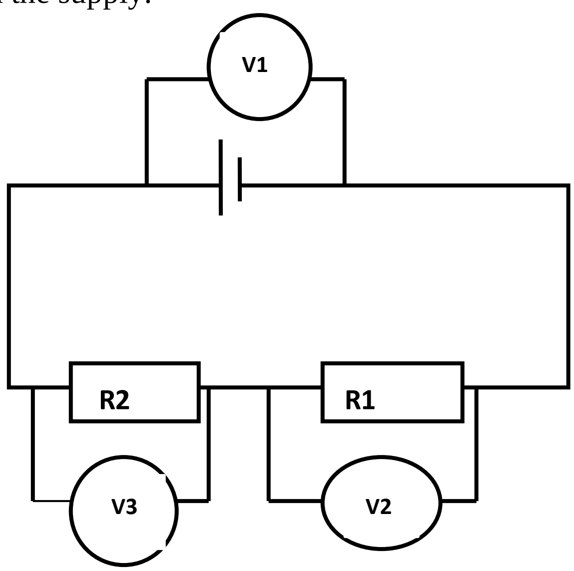


Figure 11.32 voltages in series circuit.

From the circuit shown in **Figure 11.32:**

$$\mathbf{V_2 + V_3 = V_1}$$

Voltage in a parallel circuit

Voltage across each component connected in parallel circuit is the same and equal to the supply voltage.

Net resistance of resistors connected in series and parallel circuits

Net resistance of resistors connected in series

If resistors are connected in series, they give a higher resistance than any one of the resistors by itself because the effect is the same as joining resistance wires together to form a longer wire.

The resistance of the resistance wire increases with length.

To find the total resistance of the resistors connected in series:

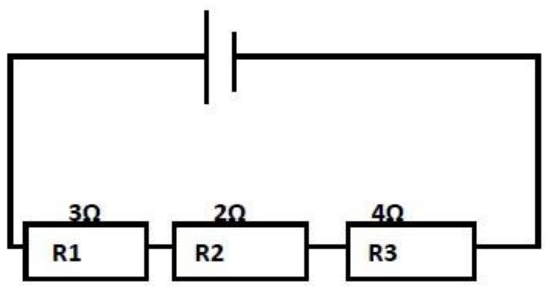


Figure 11.34 resistors connected in series.

Current through R1, R2 and R3 is the same current I since the resistors are in a series circuit.

The sum of the voltage across R1, R2, and R3 equals the voltage from the source (VT)

VT = V1 + V2 +V3………………… (i)

But	V	=	IR
	V1	=	IR1
	V2	=	IR2
	V3	=	IR3
	VT	=	IRT

Substituting in for the values of V in equation (i):

IRT = IR1 + IR2 + IR3

Dividing throughout by I, the final equation becomes:

RT = R1 + R2 + R3

Therefore, total resistance of resistors in series circuit is found by the formula:

RT = R1 + R2 + R3 + …………….. Rn

For example: The resistors 3Ω, 2Ω and 4Ω will have a total (net) resistance of 9Ω as shown below:

$$RT = 3\Omega + 2\Omega + 4\Omega$$
$$RT = \mathbf{9\Omega}$$

Net resistance of resistors connected in parallel

If resistors are combined in parallel they give a lower resistance than any one of the resistors by itself because the effect is the same as connecting a thick resistance wire. The resistance of a resistance wire decreases with an increase in thickness of the wire. Therefore, combined resistance is less than the resistance of the smallest individual resistor.

To find the combined resistance of the resistors connected in parallel:

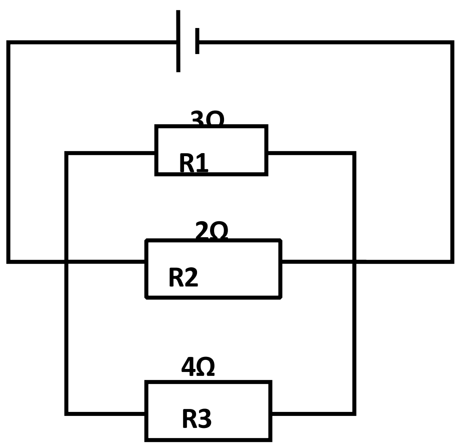


Figure 11.35 resistors connected in parallel

Voltage in parallel circuit is the same V.

The sum of the current in parallel circuit equals the current from the supply.

$$\mathbf{IT = I_1 + I_2 + I_3} \text{ ……………………… } \mathbf{(i)}$$

But $I = \frac{V}{R}$

$$I_1 = \frac{V}{R1}$$

$$I_2 = \frac{V}{R2}$$

$$I_3 = \frac{V}{R3}$$

$$IT = \frac{V}{RT}$$

Substituting for the values of I in equation (i):

$$\frac{V}{RT} = \frac{V}{R1} + \frac{V}{R2} + \frac{V}{R3}$$

Dividing throughout by V, the equation becomes:

$$\mathbf{\frac{1}{RT} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}}$$

Therefore, the total resistance of resistors in parallel circuit is given by the formula:

$$\mathbf{\frac{1}{RT} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \ldots \frac{1}{Rn}}$$

For example: If the 3Ω, 2Ω and 4Ω resistors are connected in parallel circuit, the total (net) resistance can be worked out as follows:

$$\frac{1}{RT} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$$

$$\frac{1}{RT} = \frac{1}{3\Omega} + \frac{1}{2\Omega} + \frac{1}{4\Omega}$$

$$\frac{1}{RT} = \frac{4 + 6 + 3}{12}$$

$$\frac{1}{RT} = \frac{13}{12}$$

$$RT = \frac{12}{13}$$

RT = **0.92Ω**

When two resistors are connected in parallel their effective resistance can be worked out using a formula:

$$RT = \frac{\text{the product of their resistances}}{\text{the sum of their resistances}}$$

$$\mathbf{RT = \frac{R1 \times R2}{R1 + R2}}$$

For example: 2Ω and 4Ω resistors are connected in a parallel circuit as shown in

Figure 11.36 below:

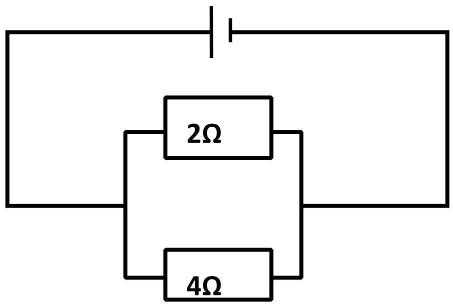


Figure 11.36

$$RT = \frac{R1 \times R2}{R1 + R2}$$

$$RT = \frac{2\Omega \times 4\Omega}{2\Omega + 4\Omega}$$

$$RT = \frac{8}{6}$$

RT = **1.33Ω**

4. A 2Ω and 4Ω resistors are connected in parallel and a 6Ω resistor is connected in series with them. A voltage across the battery is 12V.
Find:

a. The total current in the circuit.
b. The current in the 4Ω resistor.

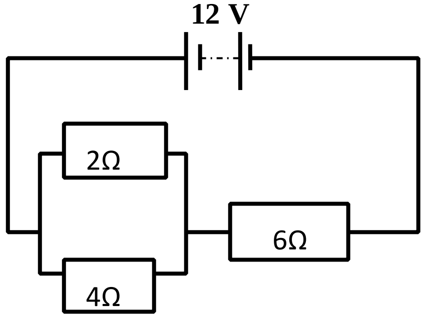


Figure 11.39

Solutions

a. $IT = \frac{V}{RT}$

$V = 12V$

$$RT = \left(\frac{R1 \times R2}{R1 + R2}\right) + R3$$

$$RT = \left(\frac{2 \times 4}{2 + 4}\right) + 6$$

$RT = 1.3 + 6$

$RT = 7.6\Omega$

$IT = \frac{12V}{7.6\Omega}$

$IT = \mathbf{1.6A}$

b. I in the 4Ω resistor

First, let us find voltage across a 4Ω resistor

V across (4Ω and 2Ω) + V across 6Ω = 12V

V across 6Ω = ITR

V across 6Ω = 1.6A x 6Ω

V across 6Ω resistor = 9.6 V

V across a 4Ω resistor = 12 V – 9.6 V = 2.4 V

I in a 4Ω resistor = $\frac{V}{R}$

$= \frac{2.4\ V}{4\Omega}$

I in a 4Ω resistor = **0.6 A**

11.5 Electric power and energy

Electric power

Power is the rate of doing work, or it is the electrical energy transferred per unit time, or it is the rate at which energy is produced.

Power = <u>work done</u>

Time taken

OR **Power** $= \dfrac{\textbf{energy used}}{\textbf{Time taken}}$

In an electric circuit, power is provided by the cell or battery. Amount of power generated by a cell or battery is the product of voltage and current flowing in the circuit.

Electrical power = voltage x current

$$\mathbf{P = IV} \text{ ………………(i)}$$

Power dissipated in a resistor of resistance R

Since P = IV

But $I = \frac{V}{R}$ (Ohm's law)

Substitute $\frac{V}{R}$ for I in equation ….(i)

$P = \frac{V \times V}{R}$

Therefore, $\mathbf{P = \frac{V^2}{R}}$ **……(ii)**

V = IR (Ohm's law)

Substitute IR for V in equation (i)

P = I x R x I

Therefore, $\mathbf{P = I^2R}$**…….(iii)**

The three equations used for calculating electrical power are:

$\mathbf{P = VI}$……………(i)

$\mathbf{P = \frac{V^2}{R}}$……………(ii)

$\mathbf{P = I^2R}$…………..(iii)

Power is measured in watts. SI unit of power is the watt (w).

Other units of power are:

1 kilowatt (Kw) = 1000W = $\mathbf{10^3}$**W**

1 megawatt (Mw) = 1 000 000W = $\mathbf{10^6}$**W**

Electrical power calculations

Worked examples

1. In an electric circuit, the pd across the battery is 3 V and the current supplied is 2 A. Calculate the power supplied by a battery in the circuit.

Solution

$V = 3V \qquad I = 2A \qquad P = ?$

$P = IV$

$P = 2A \times 3V$

$P = \mathbf{6\ W}$

Electric energy

Since power = $\frac{\text{Energy used}}{\text{Time taken}}$

Therefore, energy = power x time

E = P x t

But $P = IV$, $P = I^2R$, $P = \frac{V^2}{R}$

Therefore, electrical energy will have the following equations:

$\mathbf{E = P \times t}$……………(i)

$\mathbf{E = IVt}$…………….(ii)

$\mathbf{E = I^2Rt}$……………(iii)

$\mathbf{E = \frac{V^2t}{R}}$....................(iv)

Energy is measured in **Joules** (J).

1 Kilojoule (KJ) = 1000J = 10^3J

Worked Examples

1. An electric bulb is rated at 100 W. Calculate the energy used by the bulb in

a. 5 seconds

b. 3 hours

Solution

$P = 100\ W \qquad V = 220V$

a. Energy used in 5 s

$t = 5$

$E = Pt$

$E = 100\ w \times 5\ s$

$E = \mathbf{500\ J}$

b. Energy used in 3 hrs t = 3 hrs = 10800 s

$E = p \times t$

$E = 100\ W \times 10800\ s$

E = **1080000 J** or $\mathbf{1.08^6}$ **J** or **1080 KJ**

Cost of electricity

Electricity is supplied by the local Electricity Board. For example, in Malawi electricity is supplied by the Electricity Supply Corporation of Malawi Ltd (ESCOM). The Electricity board charges electricity in form of electrical energy used by appliances. The electrical energy is measured in kilowatt – hours by the electric energy meter.

1 kilowatt – hour is sold as 1 unit of electrical energy.

A kilowatt hour or unit of electricity is the electrical energy supplied in 1 hour to an appliance whose power is 1

Total cost of electricity = kilowatt – hours x cost per kilowatt – hour

Worked examples

1. An electrical appliance is rated at 200 W. If electrical energy costs K28.00 per kWh, what is the cost of using this heater for 8 hours at its maximum power?

Solution

P = 200 W = 0.2 kW t = 8hrs 1 kWh = K28.00

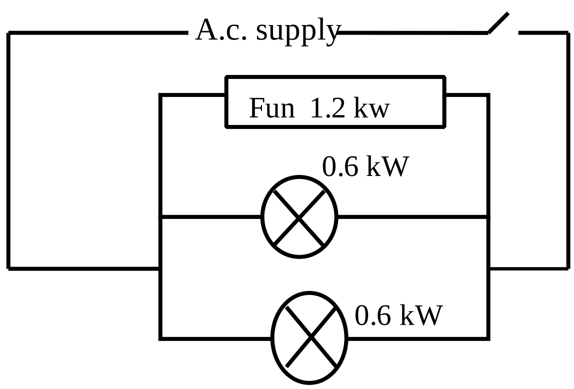
Electrical energy = p x t = 0.2 kW x 8 h

= 1.6 kWh

Total cost of electricity = 1.6 kWh x K28.00

Total cost of electricity = **K44.80**

Figure 11.46 shows appliances used in a house



If electrical energy costs K27.90 per unit (1kWh), calculate the total cost of using a fan and two bulbs for three hours per day for one week.

Solution

Total power = 1.2 kW + 0.6 kW + 0.6 kW =
2.4 kW

t = 3 h x 7 = 21 hours

E = p x t

Energy = 2.4 kW x 21 h

Energy = 50.4 kWh

Total cost = electrical energy x cost of 1 kWh

= 50.4 kWh x K27.90

Total cost = **K1406.16**

Power of the heating element

The current has the heating effect when it flows through a resistive material e.g. a coil of an electric heater or cooker. The power of the heating element can be found in the following formulas:

$$\mathbf{P = VI} \ldots\ldots\ldots\ldots\ldots \text{(i)}$$

$$\mathbf{P = \frac{V^2}{R}} \ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

$$\mathbf{P = I^2R} \ldots\ldots\ldots\ldots\ldots \text{(iii)}$$

Worked example

An electric cooker is connected to a 240 V mains. If the resistance of its coils is 15Ω, calculate its power rating.

Solution

V = 240 V R = 15Ω

$P = \frac{V^2}{R}$

$= \frac{240^2}{15}$

P = **3840 W** or **3.840 kW**

Heating elements work under different currents and voltages. Hence, they have different power ratings.

Energy transfer

The electrical energy in heating elements is released as heat energy. Therefore, heat energy lost from a heating element is gained by the surrounding material, e.g. electric heater.

In this case, we say electric current has a heating effect. This is noticed by an increase in temperature.

If there is no energy loss then,

Electrical energy = Heat energy

Electrical energy = power x time

$E = p \times t$

Heat energy = mass x specific heat capacity x change in temperature

$HE = m \times c \times \Delta T$

The equations can be related as follows:

$$\mathbf{P \times t = m \times c \times \Delta T} \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$\textbf{(i)}\ \mathbf{IVt = m \times c \times \Delta T} \ldots\ldots\ldots\ldots\ldots\ldots$$

$$\textbf{(ii)}\ \mathbf{I^2Rt = m \times c \times \Delta T}$$

Worked example

The immersion heater is used to heat water in a bath. If a heater rated at 3.6W is connected to

240V main supply, calculate

a. The resistance of the heating element.

b. The time taken for 2 kg of water in a bath to raise its temperature from 20^0C to 25^0C. (SHC of water is $4200J/kg^0C$).

Solution

a. Resistance of the heating element

$P = 3.6$ kW $= 3600$ W

$V = 240$ V

$$P = \frac{V^2}{R}$$

$$R = \frac{240^2}{3600}$$

$R = \mathbf{16\ \Omega}$

b. Time taken for 2 kg of water to raise its temperature from 20^0C to 25^0C P = 3600 W $\Delta t = (25^oC - 20^oC) = 5^0C$ m = 2 kg c = 4 200/kg^{o}C

$$Pt = m \times c \times \Delta T$$

$3600 \times t = 2 \times 5 \times 420$

$$t = \frac{2 \times 5 \times 4200}{3600}$$

t=**11.7 s**

The electrical hazards

Although electricity is very useful, it can be dangerous when it is not used safely. Therefore, electricity can be hazardous.

The major hazards associated with electricity are:

1. Electric shock

An electric shock is the passing of electric current through the body. The body becomes part of the electric circuit.

An electric shock can happen in the following situations:

a. When the body comes into contact with both wires (live and neutral wires) of an electric circuit.

b. When the body comes into contact with a metallic part that has become live (energized) through contact with an electrical conductor.

Electric shock depends on a number of factors such as the pathway through the body, the amount of current, the length of time of the exposure, wetness of the skin and presence of water (if the area is damp or dry).

2. Overheating and fire

When high current flows through the cable or appliance, there will be overheating and fire. High currents can be caused in the following ways:

a. Short circuit

A **short circuit** is the accidental touching of a live wire and a neutral wire.

At the point of short circuit, the resistance becomes very low. This allows high current to flow through the circuit. The high current can cause overheating and fire.

b. Overloading

Overloading happens when a lot of appliances are connected on one surface and all the appliances are switched on at the same time e.g. on an extension. The appliances take more current to the surface. This high current can cause overheating and fire.

Preventing electrical hazards

There are various ways of protecting people from the hazards caused by electricity.

Basic precautions

Follow some basic precautions as listed below:

- Inspect wiring of equipment before each use. Replace damaged or frayed electrical cords immediately.
- Use safe work practices every time electrical equipment is used.
- Know the location and how to operate switches or circuit breakers. Use these devices (switch or circuit breaker) to shut off equipment in the event of a fire or electrocution.
- Limit the use of extension cords; use them only for temporary operations.
- Use plugs that are equipped with circuit breakers or fuses.
- Place exposed electrical conductors behind the shields.
- Minimize the potential for water or chemical spills on or near electrical equipment. All electrical cords should have sufficient insulation to prevent direct contact with wires. It is very important to check all cords before each use, since corrosive chemicals or solvent vapors may corrode the insulation.

Circuit protection devices

Circuit protection devices are designed to automatically limit or shut off the flow of electricity in the event of a ground-fault, overloading or short circuit in the wiring system. The circuit protection devices are fuses and circuit breakers.

Fuses and circuit breakers prevent overheating of wires and components.

Fuse: A fuse is used to control the amount of current flowing in the circuit. If there is high current flowing in the circuit by accident, the fuse melts. This breaks the circuit and stops the flow of current. Hence the wire and the appliances are protected from high current, overheating and fire.

Symbol for a fuse

A fuse is found in a three-pin plug.

Three-pin plug

A three-pin plug is used to connect appliances to the mains. Three-pin plugs are used because they are safe since they have a fuse.

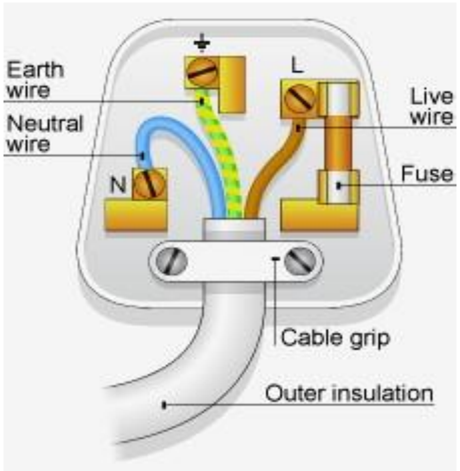


Figure 11.47 three-pin plug

Live wire

- A live wire carries ac current and voltage to the appliance
- It has alternating voltage that moves to +240V then to -240V, making the alternating current which flows backwards and forwards through the circuit.
- It gives electrical shock when touched.

Neutral wire

- A neutral wire acts as a returning path of ac current and voltage.
- It has a potential difference of O V
- It does not give an electrical shock when touched.

Earth wire

- It is a safety wire; it prevents users from getting electrical shock.
- An earth wire is grounded at one end and connected to a metallic part of an appliance at the other end. When faulty current flows, a metallic appliance becomes live. The earth wire conducts the faulty current to the ground. Hence preventing users from electric shock.

Fuse

A fuse is a safety device that prevents cables and appliances from carrying high current.

High current flowing in cables or appliances can cause overheating and fire.

When the current flowing in a cable or appliance is more than required amount, the fuse melts and breaks the circuit.

It is connected to the live wire, since it is the live wire that carries current.

Fuse rating

Fuse rating is the maximum amount of current that a fuse can allow to pass through before it melts.

To find fuse rating of a fuse:

$$\text{Fuse rating} = \frac{\text{power supplied}}{\text{Voltage from the supply}}$$

Worked example

An appliance rated at 60 W, uses a voltage of 35 V. Calculate the fuse rating of an appliance.

$$\text{Fuse rating} = \frac{\text{Power}}{\text{Voltage}} = \frac{60\text{ W}}{35\text{ V}}$$

Fuse rating = **1.7 A**

But the value of the fuse rating should not be exactly 1.7 A. There must be an allowance to allow maximum current to flow.

Circuit breaker: This is an automatic switch which if the current rises over a specified value, the electromagnet pulls the contacts apart, thereby breaking the circuit. The reset button is to rest everything. It works like a fuse, but it is better because it can be reset.

CHAPTER 12

Oscillations and waves

12.1 Oscillations or Vibrations

Oscillations or vibrations are complete upward or downward movements of an object about its fixed position (rest position or equilibrium position).

Oscillations or vibrations can also be defined as complete to and fro movements of an object about its fixed position (rest position or equilibrium position). Oscillations are produced by the vibrating systems.

Examples of vibrating systems are vibrating spring, pendulum and cantilever.

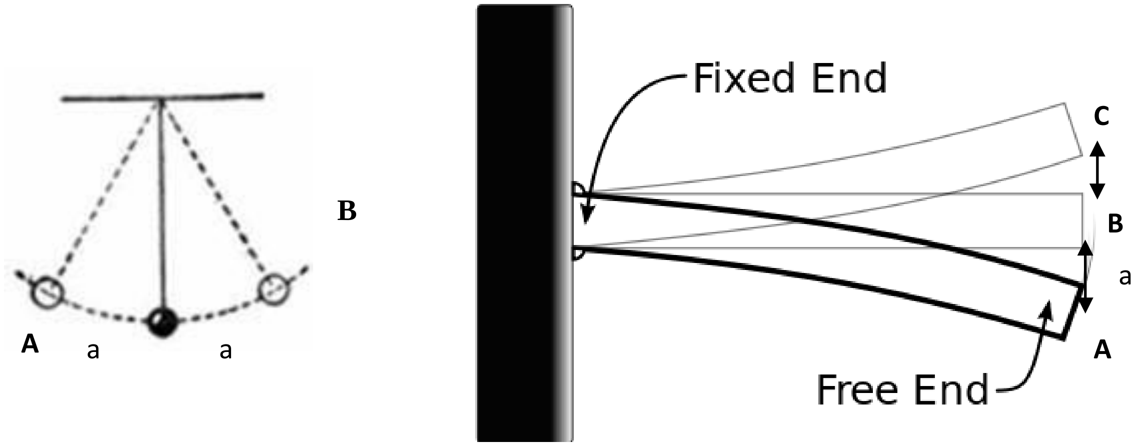


Figure 12.1 vibrating systems

a is the amplitude.
A and **C** are the extreme positions of swing or oscillation (vibration). **B** is the equilibrium or rest position.

Characteristics of oscillating systems

Oscillating systems have the following characteristics:

Amplitude (a) is the maximum displacement of an oscillating system from its resting position. In **Figure 12.1**, amplitude is the distance between **A** and **B** or distance between **B** and **C.** Amplitude is measured in metres (m) or centimeters (cm).

Displacement is the direction and distance from mean position. Displacement is measured in metres (m) or centimeters (cm).

Period (T) is the time taken for one complete oscillation or cycle to be performed. Period (T) is measured in seconds (s).

Frequency (f) is the number of complete oscillations or cycles produced in a unit time. A cycle is a complete oscillation when an oscillating system moves from a starting point **A** to **C** then back to **A** or moves from **C** to **A** then back to **C.** Frequency is measured in hertz (Hz) or cycles per second

1 cycle per second = 1 hertz

Factors affecting frequency of an oscillating system

1. For a pendulum

Experiment 12.1

AIM: To find out whether the frequency of vibration of a pendulum depends on the length of the string.

MATERIALS: A string, 50g bob, clamp stand, stop watch and ruler.

PROCEDURE:

1. Arrange the apparatus as shown below.

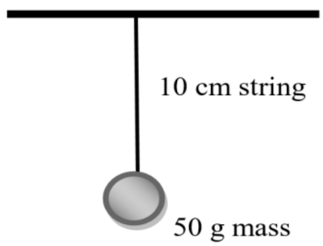


Figure 12.2

2. Pull the mass and release it to oscillate.
3. Record the time taken for 10 oscillations.
4. Record the results in **Table12.1**.
5. Repeat the experiment with length 20 cm, 30 cm, 40 cm and 50 cm.

Table 12.1

Length of a string (cm)	**Time for 10 oscillations(s)**	**Frequency = $\frac{\text{10 oscillations}}{\text{Time (s)}}$**
10		
20		
30		
40		
50		

DISCUSSION

1. Calculate the frequency for each length of a string.
2. Plot a graph of frequency against length of a string.
3. From your results and the graph, what can you conclude?
4. Other variables are kept constant.

a. Explain what this means.

b. State **two** variables that can be kept constant.

SUGGESTED RESULTS/EXPLANATIONS

1. Use the time found for 10 oscillations to calculate the frequency for each length of a string using the formula given in the table.
2. After calculating frequencies, the graph will have a shape as shown in the sketch in

Figure 12.3.

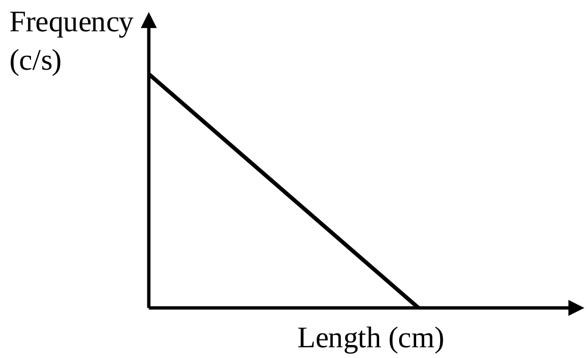


Figure 12.3

3. Frequency decreases as the length increases and vice versa. As the length increases, the string will take longer time to complete the 10 oscillations. Hence low frequency.
4. **a**. Other variables are not changed.
   b. mass of the bob and type of the string

2. For a loaded spring

Experiment 12.2

AIM: To find out whether the mass affects the frequency of oscillation of a spring.
MATERIALS: Masses (50g, 100g, 150g and 200g), g-clamp, a stop watch and a spring.
PROCEDURE:

1. Set up the apparatus as shown in **Figure 12.4**:

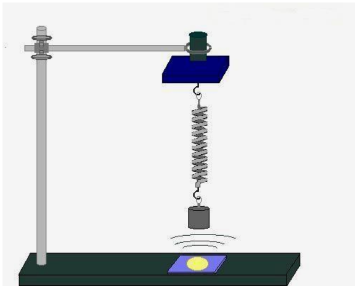


Figure 12.4

2. Pull the mass downwards and leave it to vibrate freely.
3. Recording the time taken for 10 complete vibrations.
4. Calculate the frequency.
5. Repeat the experiment for the rest of masses (100g, 150g and 200g).
6. Record the results in **Table 12.2** below:

Table 12.2

Mass (g)	Time for 10 vibrations (s)	Frequency = $\frac{\text{10 vibrations}}{\text{Time(s)}}$
50		
100		
150		
200		

DISCUSSION

1. Plot a graph of frequency against mass.
2. Using the graph, determine how the mass affects the frequency.

12.2 Waves

Oscillations or vibrations produce a wave. A wave is commonly taken as movement. We have waves on the surface of the ocean or lakes and waves in the wind.
A **wave** is a means of disturbance or oscillation that travels through a medium or vacuum, accompanied by a transfer of energy.

A **wave motion** is the transmission of energy from one place to another through a material or vacuum.

Experiment 12.5

AIM: To produce a wave.
MATERIALS: A tree and a rope.
PROCEDURE:

1. Tie a rope to the tree as shown in **Figure 12.7.**

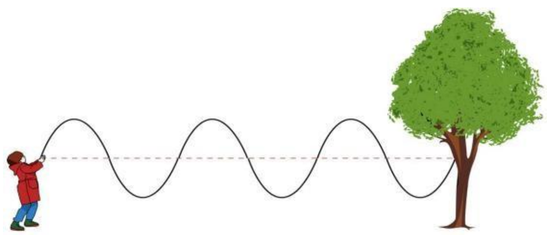


Figure 12.7

2. Jerk the rope at the other end.

RESULT
When you jerk a rope from the other end, humps and hollows are formed. These humps and hollows form a wave as shown in **Figure 12.8**.

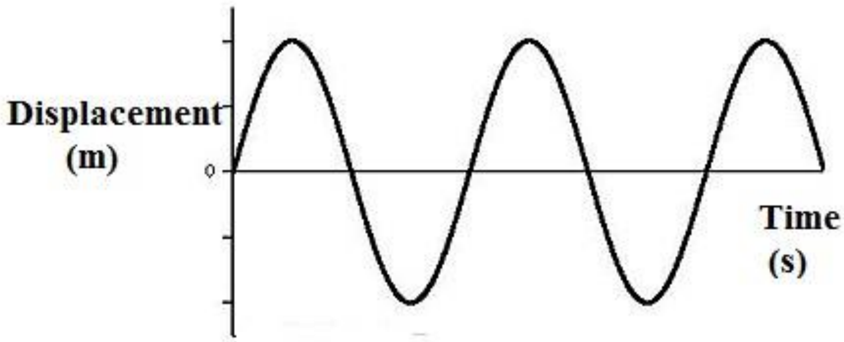


Figure 12.8 A wave

Experiment 12.6

AIM: To investigate water waves.
MATERIALS: Transparent tray (ripple tank), water and pencil (or vibrator).
PROCEDURE:

1. Fill a shallow tray (ripple tank) with water.
2. Move a pencil up and down in the water at one end of the tank or let a vibrator just touch the surface of the water and switch it on. Record the observations.

RESULT

When a pencil is moved up and down in the water at one end of the tray (ripple tank) or when a vibrator touching the water is switched on ripples move away from the disturbance caused by the pencil or vibrator.

Waves can be grouped into mechanical and electromagnetic waves.

Mechanical waves are the waves that require a medium for propagation. They cannot pass through a vacuum. Examples of mechanical waves are sound wave and water wave.

Electromagnetic waves are the waves that do not need a medium for propagation. Electromagnetic waves can pass through a vacuum. Examples of electromagnetic waves are radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, x-rays and gamma rays.

Characteristics of a wave

A wave has the following characteristics.

1. **Amplitude (a)**

Wave amplitude is the maximum displacement of a particle from its resting position. It is measured in centimetres (cm) or metres (m).

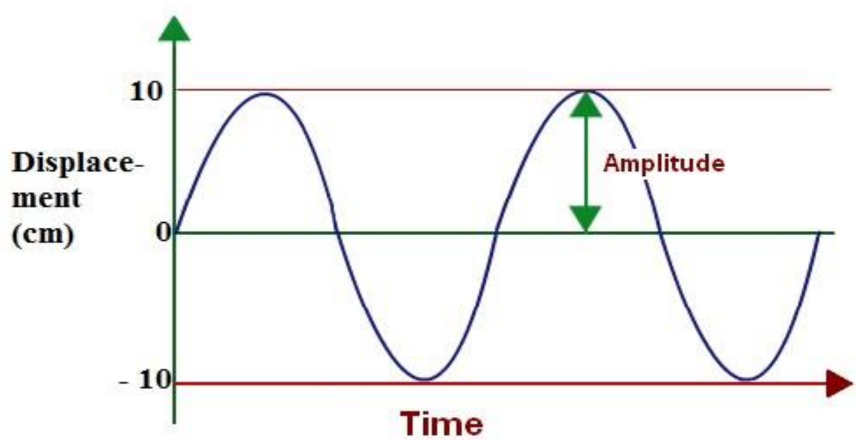


Figure 12.9 Showing amplitude of a wave

From **Figure 12.9** the amplitude of the wave is 10 cm.

2. **Frequency (f)**

Wave frequency is the number of complete oscillations or cycles produced per second.

Frequency (f) = $\frac{\text{number of complete cycles (c)}}{\text{Time in seconds (s)}}$

Frequency is measured in **hertz (Hz)** or c/s.

1 c/s = 1 Hz

For example: If the rope makes 10 complete cycles in 5 seconds, Frequency

$= \frac{10 \text{ cycles}}{5 \text{ seconds}}$

Frequency (f) = **2Hz**

3. Period (T)

Wave period is the time taken for one complete oscillation or cycle to be performed.

Period (T) = $\frac{\text{Time taken}}{\text{Number of complete cycles}}$

From the equation shown above, period (T) is the inverse of frequency (f).
Therefore,

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

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

Worked example

Figure 12.10 is a diagram showing a wave motion.

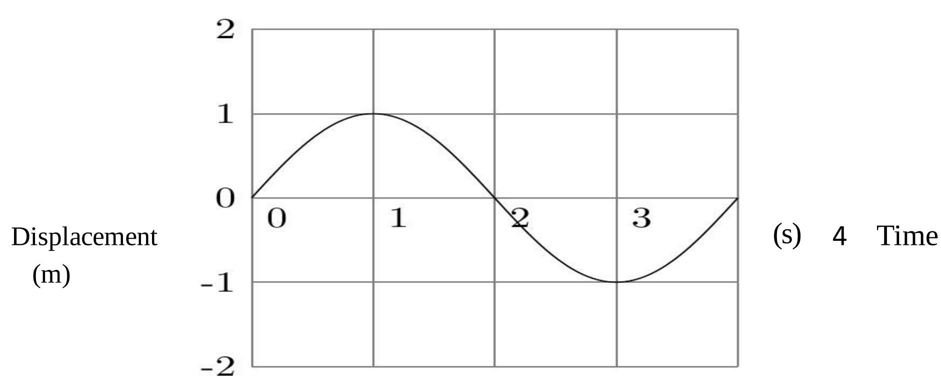


Figure 12.10

- **a.** Calculate the amplitude of the wave.
- **b.** Calculate the frequency of the wave.
- **c.** What is the period of the wave?

Solution

a. Amplitude = **1 m**

b. Frequency = $\frac{\text{Number of complete cycles}}{\text{Time taken}}$

Frequency = $\frac{1 \text{ cycle}}{4 \text{ seconds}}$

Frequency = **0.25 Hz**

c. Period (T) = $\frac{1}{f}$

T = $\frac{1}{0.25 \text{ Hz}}$

T = **4 seconds**

4. Wavelength (λ)

Wavelength is the distance between two successive particles which are at the same point after a complete oscillation in their paths and are moving in the same direction. These are the distances occupied by one complete oscillation.

Wavelength is represented by a Greek symbol called **Lambda** (□). Wavelength is measured in metres (m).

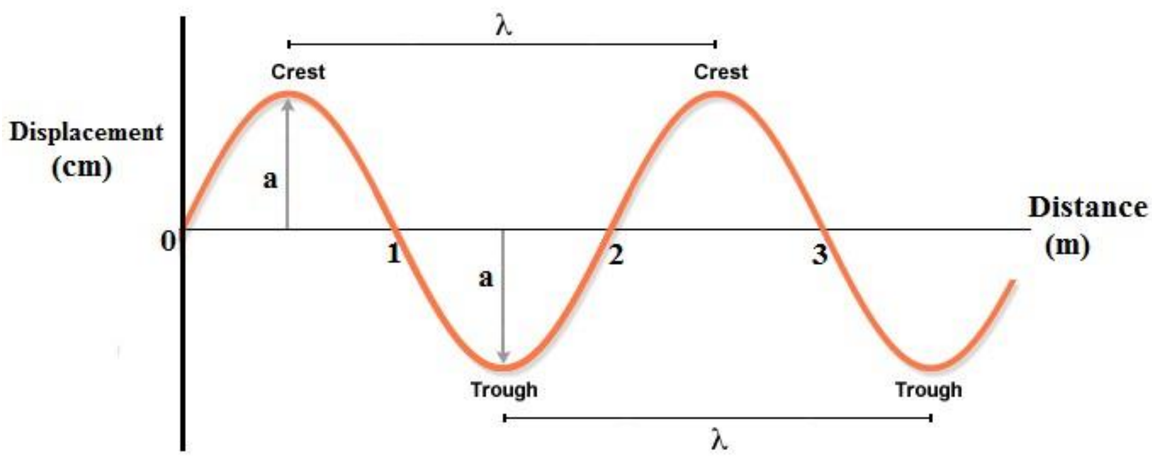


Figure 12.11 showing the wave length of the wave

The wavelength of a wave can be found by the following methods:

a. Checking the distance covered by one complete cycle.
Wavelength = distance covered by one complete cycle

In **Figure 12.11**, the distance covered by one complete cycle is 2 m. Therefore, the wavelength of a wave is **2 m**.

b. Wavelength = $\frac{\text{Total distance covered by the wave}}{\text{Number of cycles}}$

Worked example

Calculate the wavelength of a wave in **Figure 12.12**.

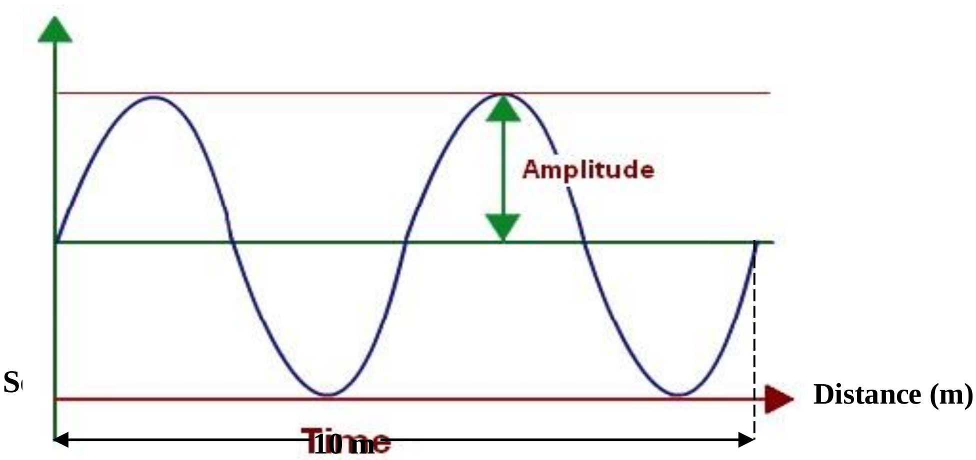


Figure 12.12

Wavelength = <u>Total distance covered</u>
Number of cycles

Wavelength = <u>10 m</u>
2 cycles

Wavelength = **5 m.**

5. Velocity

Wave velocity (speed) is the distance covered by the wave in a unit time.

Velocity = <u>distance covered by the wave</u>
Time taken

Worked example

A water wave covered a distance of 50 m in 10 seconds. Calculate its velocity.

Solution d = 50 m
t = 10 s v = d
t

v = 50 m
10 s

v = 5 m/s

6. Phase

Wave phase is the orientation of wave pulses in space with respect to the origin of the wave.

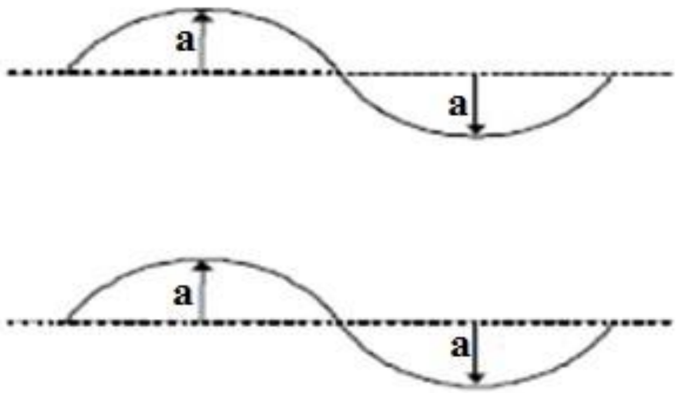


Figure 12.13(a) the waves are in phase

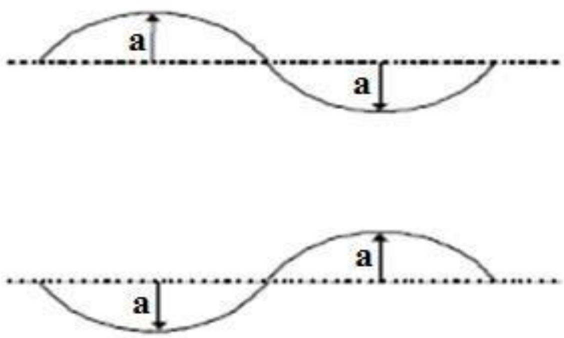


Figure 12.13 (b) the waves are out of phase

Wave front

A wave front is any line or section taken through an advancing wave which joins all points which are in the same position in their oscillations. Wave fronts are usually at right angles to the direction of the waves and can have any shape, e.g. circular and straight wave fronts.

Circular wave front can be produced by dropping a spherical object in water. The spherical object causes disturbance in water. Water forms circular patterns called **circular wave front**.

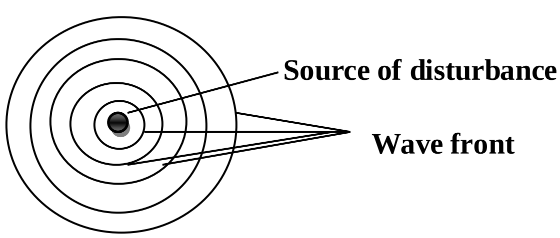


Figure 12.14 circular wave front

Straight wave front can be produced by dipping a straight edge in water. The straight edge causes disturbance in water. Water produces straight wave fronts.

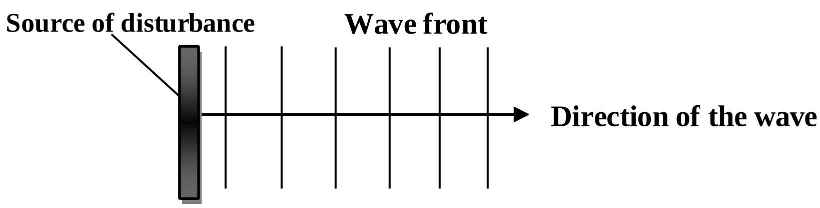


Figure 12.15 straight wave front

12.3 Types of waves

The two basic types of waves are longitudinal wave and transverse wave.

Longitudinal waves

When the end of a spring is moved backwards and forwards, the sections of the coil are pulled together and released. These sections are known as **compressions** and **rarefactions**. This produces a travelling wave effect. In this wave oscillations are backwards and forwards. The wave is called **longitudinal wave.**

A **longitudinal wave** is a wave in which the direction of the vibrating particles (oscillations) is the same as the direction of a wave itself OR it is a wave in which the displacements are parallel to the direction of a wave itself.

Compressions: These are regions of high pressure and density along a longitudinal wave where particles are squeezed.

Rarefactions: These are regions of low pressure and density along a longitudinal wave where particles are spaced.

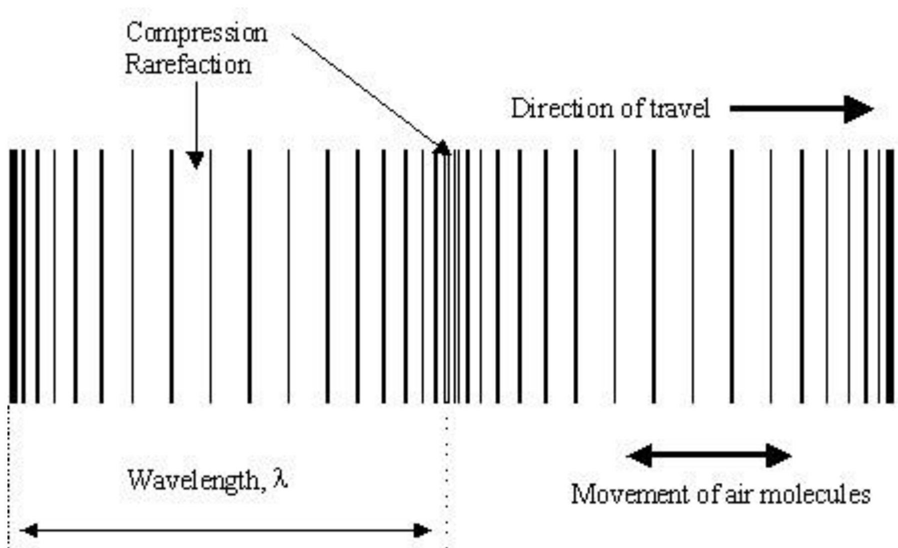


Figure 12.18 longitudinal wave

An example of a longitudinal wave is a sound wave.

Transverse waves

A transverse wave can be demonstrated by a spring as shown in **Figure 12.19**.

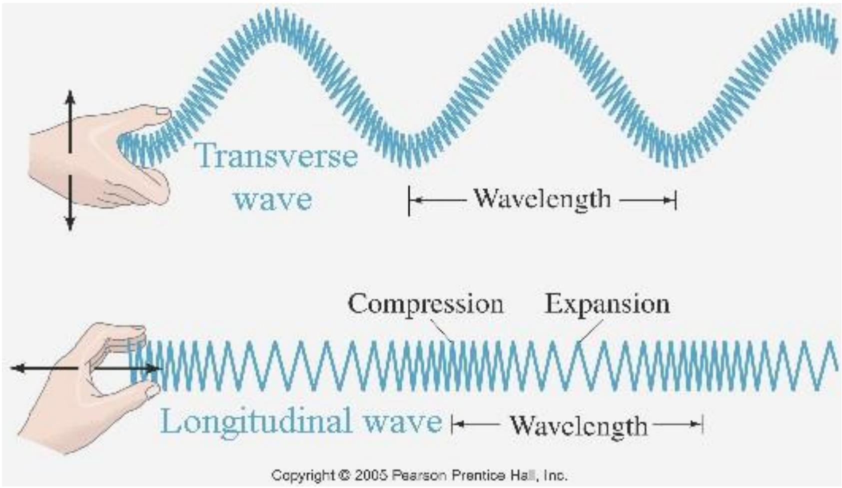


Figure 1229 Demonstrating transverse wave by using a spring

When a string is moved up and down in the direction perpendicular to its length, the particles of the rope near the end pull the next particles sideways then they pull the next particles and so on. Sideways movements are passed from turn to turn and a traveling wave effect is produced. In this way, there is a transferring of energy from one end of the string to the other.

When the oscillations are up and down or from side to side as shown in **Figure 12.19**, the wave produced is called **Transverse Wave**.

In a transverse wave the oscillations are perpendicular (at right angles) to the direction of the wave itself.

A **transverse wave** is a wave in which direction of vibrations or oscillations is perpendicular (at right angle) to the direction of propagation of the wave.

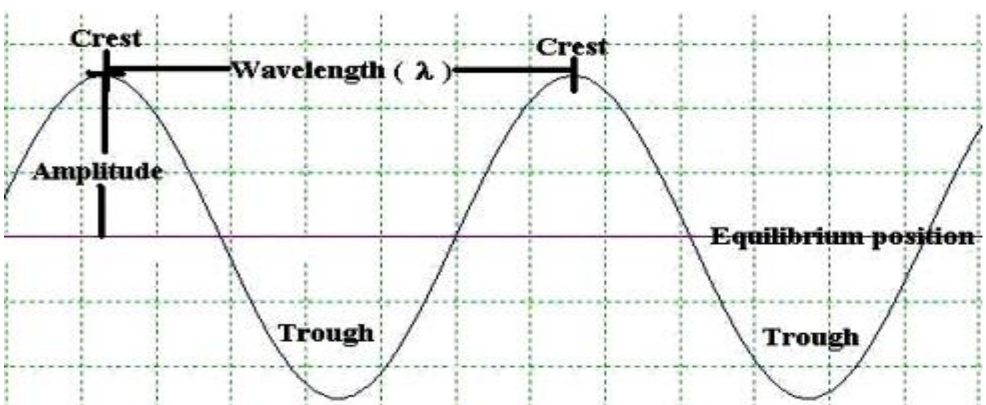


Figure 12.20 a transverse wave

Crests or **peaks:** These are points where a wave causes maximum positive displacement of the medium.
Troughs: These are points where a wave causes maximum negative displacement of the medium.
Examples of transverse waves are water wave and light wave.

NOTE: In a longitudinal wave the **wavelength** can be defined as the distance between two successive compressions or the distance between two successive rarefactions.
In a transverse wave the **wavelength** can be defined as the distance between two successive crests or the distance between two successive troughs.

12.4 Wave properties

Waves have the following properties:

a. Reflection

Experiment 12.7

AIM: To investigate wave reflection.
MATERIALS: Ripple tank, water and vibrator.
PROCEDURE:

1. Fill a shallow ripple tank with water.
2. Let a vibrator just touch the surface of the water and switch it on to create waves moving down the tank.
3. Place a horizontal metal strip at an angle to the direction of the wave. Record what happens to the wave.

When an obstacle is placed in the path of the wave it changes its direction. The wave is bounced off. This effect is called **reflection**.
Reflection is defined as the bouncing off of waves when an obstacle is placed in their path.

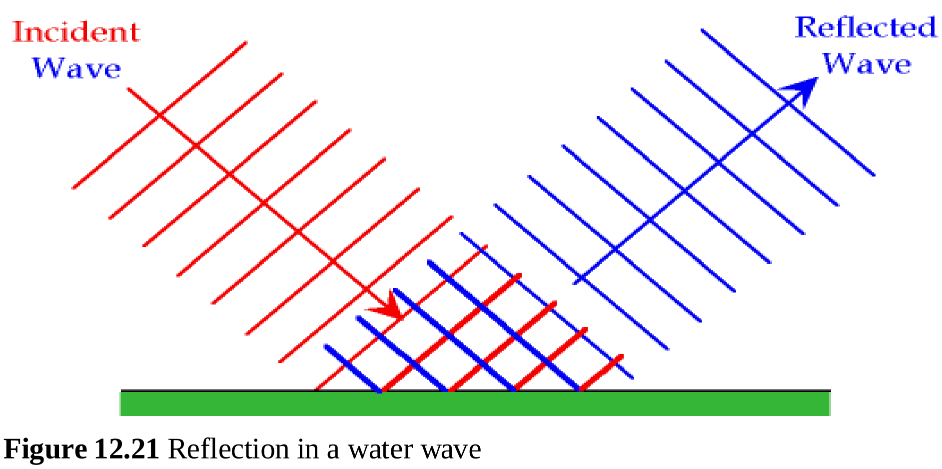


Figure 12.21 Reflection in a water wave

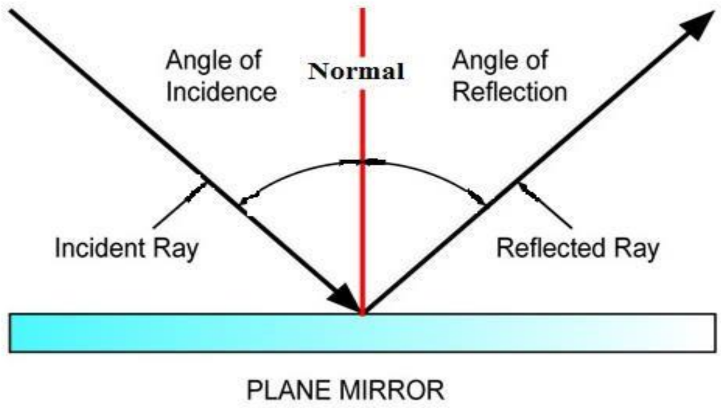


Figure 12.22 Reflection in a light wave

The laws of reflection

- **i.** The angle of incidence is equal to the angle of reflection.
  This means that the wave leaves the surface at the same angle it arrives.
  Angle of incidence (i) = angle of reflection (r).
- **ii.** The incident ray, the normal and the reflected ray all lie in the same plane. This means that all three could be drawn on the same flat piece of paper.

b. Refraction

Experiment 12.8

AIM: To investigate wave refraction.
MATERIALS: Ripple tank, water, vibrator and glass or plastic sheet.
PROCEDURE:

1. Set up a ripple tank with a piece of material that will create a shallow section in the tank.
2. Let a vibrator just touch the surface of the water in a deep region and switch it on to create waves that will travel down the tank from "deeper" end and across the shallow section.
3. Record the observations.

In **Experiment 12.8,** water waves are made to travel from a deeper region to a shallow region. In this case, the following happens:

- **i.** The wavelength decreases. In a deep region, a wavelength is greater because of high speed while in a shallow region the wavelength is shorter because of the decrease in speed.

- **ii.** The wave appears to change direction. The wave changes direction because it changes speed when traveling from a deep region to a shallow region. In a deep region, the wave travels faster and it slows down when it enters the shallow region. This apparent bending of the wave is called **refraction.**

In both regions, the frequency remains the same.

Refraction is the bending of a wave when it changes its speed or velocity.

Water waves undergo refraction or bending when they enter shallow water.
In shallow water the water waves are slowed down. In shallow water, the wave length of a water wave is reduced.

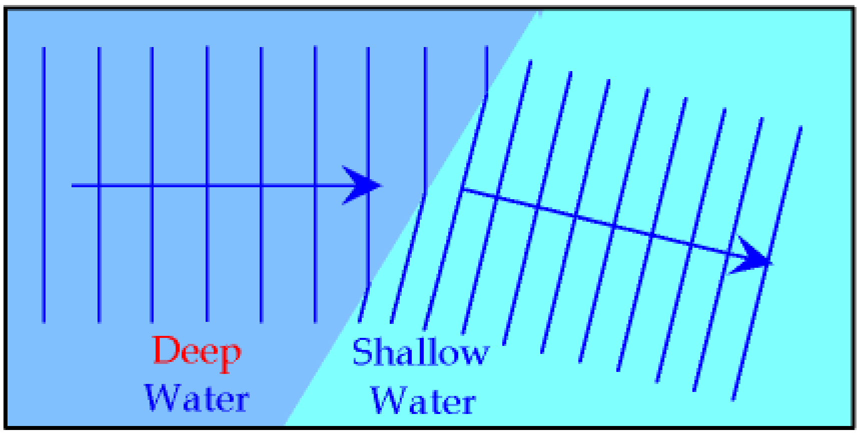


Figure 12.23 Refraction of a water wave.

A light wave undergoes refraction when it moves into a medium of different density which causes it to travel at a different speed or velocity.

When a ray of light travels from a less dense medium (e.g. air) to a denser medium (e.g. glass) it bends towards the normal because it travels with less speed in the denser medium.
When the ray of light travels from a denser medium (e.g. glass) to a less dense medium (e.g. air) it bends away from the normal because it travels with greater speed in the less dense medium.

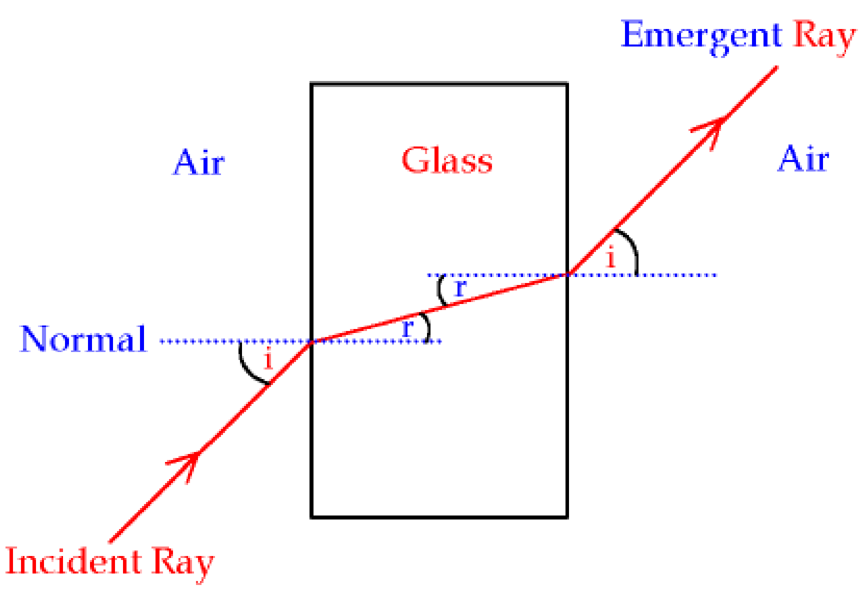


Figure 12.24 Refraction of a light wave

i = angle of incidence **r** = angle of reflection

Laws of refraction

- **i.** The incident and refracted rays are on opposite sides of the normal at the point of incidence.
- **ii.** When it comes to the incident ray, the normal and the refracted ray lie in the same plane.
- **iii.** The value of angle of the ratio of the angle of incidence to the angle of refraction is the same for light passing from one given medium into another. For example, dividing sine i by sin r, when the ray of light passes from air into glass, always produces the same number whatever the angle of incidence is.

$$\frac{\sin i}{\sin r} = \text{constant}$$

This constant is called **refractive index. Refractive index,** when referring to light, is the light-bending ability of a medium. For example, light bends more in glass than in water. This is also known as the **optical density**.

$$\frac{\sin i}{\sin r} = \text{refractive index}$$

Table 12.4 shows the refractive index of some media.

Table 12.4 Refractive index of some media

Medium	**Refractive index**
Water	1.33
Paraffin	1.44
Perspex	1.49
Glass	1.52
Diamond	2.42

Refractive index can also be calculated by dividing the speed of light in a vacuum or in air by the speed of light in a medium.

$$\textbf{refractive index} = \frac{\textbf{speed of light in a vacuum (air)}}{\textbf{speed of light in a medium}}$$

Worked examples

1. Calculate the refractive index if:

- **a.** the sin i = 65^0 and sin r = $\mathbf{40^0}$
- **b.** the speed of light in air is 3.0×10^8 m/s and its speed when it enters the water is

2.25×10^8 m/s.

Solution

a. Refractive index = $\dfrac{\sin i}{\sin r}$

Refractive index = $\dfrac{\sin 65_0}{\sin 40^0}$

Refractive index = $\dfrac{0.906}{0.643}$

Refractive index =**1.4**

b. Refractive index = $\dfrac{\text{speed of light in air}}{\text{speed of light in water}}$

Refractive index = $\dfrac{3.0 \times 10_8}{2.25 \times 10^8}$

Refractive index = **1.33**

2. The ray of light from air forms an angle of incidence of 80^0 at the surface of the glass. If the refractive index of glass is 1.5, calculate the angle of refraction.

Solution

Refractive index = $\dfrac{\sin i}{\sin r}$

$1.5 = \dfrac{\sin 80^0}{\sin r}$

$\text{Sin } r = \dfrac{\sin 80^0}{1.5}$

Sin r = 0.6565

Angle of refraction, r = $\sin^{-1} 0.6565$

Angle of refraction, r = $\mathbf{41.0^0}$

c. Diffraction

Diffraction is the spreading out of waves when passing through a slit or a gap of an obstacle.

Diffraction in a narrow gap

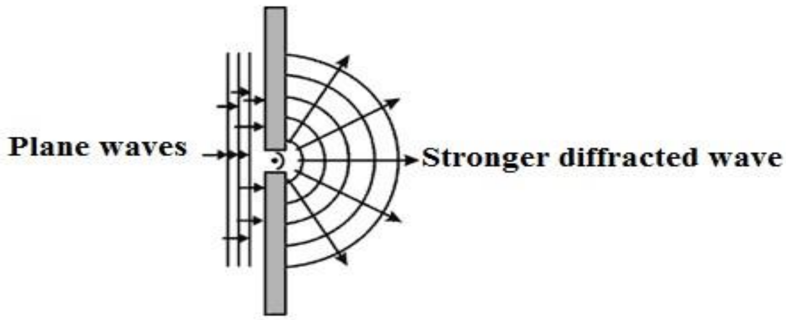


Figure 12.25 diffraction of a wave in a narrow gap

When waves pass through a narrow gap, there is more or stronger diffraction (spreading out) because the waves pass with greater pressure.

Diffraction in a wide gap

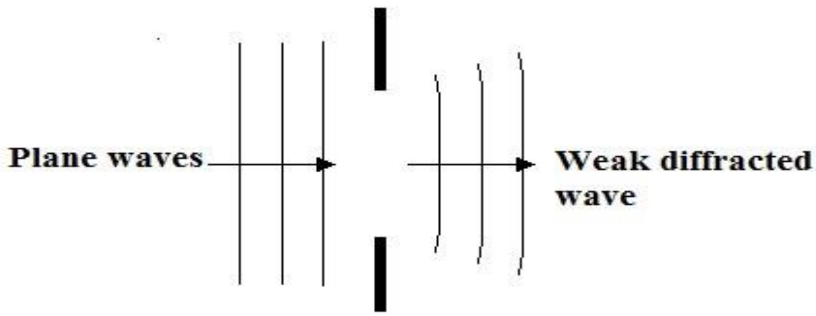


Figure 12.26 diffraction of a wave in a wide gap

When waves pass through a wide gap, there is less or weak diffraction (spreading out) because the waves pass with less pressure.

Diffraction in two slits or gaps

Figure 12.27 shows the water and light waves approaching two slits, S1 and S2 in an obstacle.

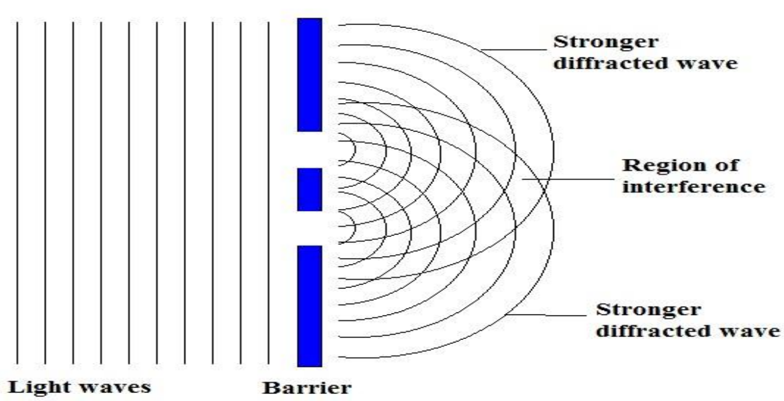


Figure 12.27 Diffraction of a wave in two slits

When a wave is diffracted in two slits, diffracted waves overlap and cause **interference.**

d. Interference

Interference is caused if two identical sets of waves travelling through the same region of water result in either reinforcing or cancelling each other.

Types of interference

i. Constructive Interference

Constructive interference is caused if two identical waves are in phase, both are moving in the same direction. The crest of one wave meets with the crest of another wave while the trough of one wave meets with a trough of another wave. These waves are always in phase, meaning they have a phase difference of 0^0. During constructive interference, the amplitude of the resultant wave is doubled.

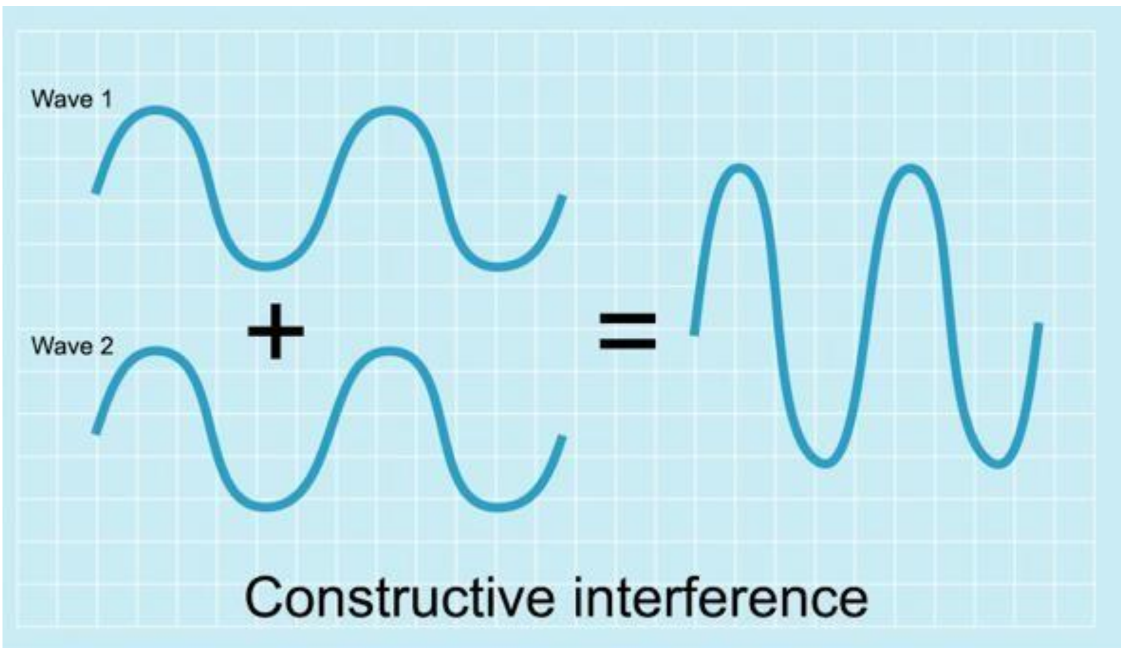


Figure 12.28 constructive interference

ii. Destructive interference

Destructive interference is caused when two identical waves move in opposite directions. When the waves meet, the crest of one wave coincides with the trough of the other wave, while the trough of the other wave coincides with the crest of the other wave. The waves are out of phase by 180^0.

This results in no wave or no movement. Hence the property is also called **Cancellation.**

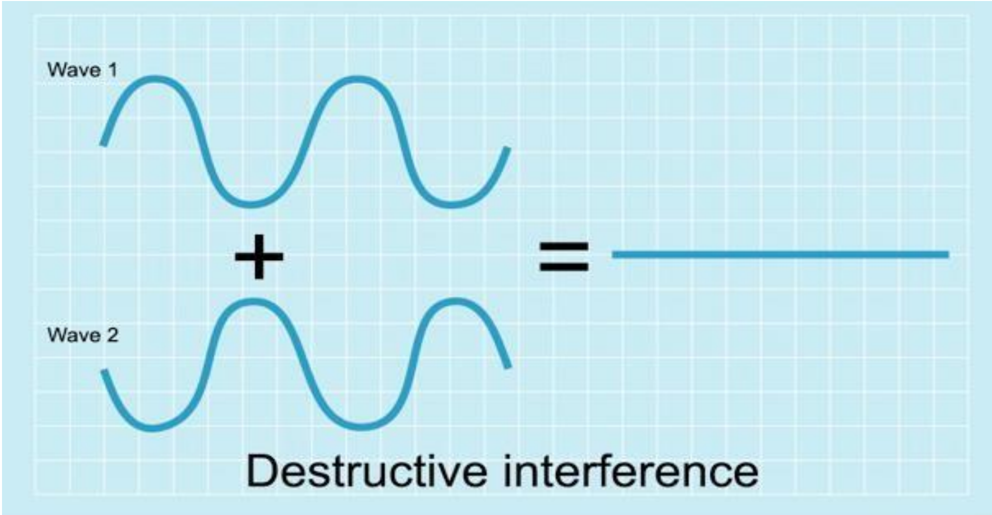


Figure 12.29 destructive interference

12.5 Wave equation

The speed or velocity, frequency and wavelength are linked by an equation called **wave equation.**
If the speed of a wave is **V** in m/s, the frequency is **f** in Hz and the wavelength is λ in m.

The wave equation becomes:

V = f x□

To derive the wave equation:

$$\text{Velocity of a complete cycle} = \frac{\text{distance covered by a complete cycle}}{\text{Time taken by a complete cycle to be performed}}$$

Distance covered by a complete cycle(d) = wavelength (λ)
Time taken for a complete cycle to be performed = Period (T)

Velocity of a complete cycle: $V = \frac{\lambda}{T}$

Which can also be written as: $V = \frac{1}{T} \times \lambda$

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

Therefore, the wave equation becomes: $\mathbf{V = f \times \lambda}$

Worked examples

1. The wave crests in a ripple tank are 3 mm apart. Calculate the speed of the wave if the frequency of the vibrator is 15 Hz.

Solution

λ = 3 mm = 0.003 m f = 15 Hz

V = f x λ

V = 15 Hz x 0.003 m

V = **0.045 m/s**

Chapter 13: Sound

13.1 Production of sound

Sound is a wave which belongs to a type of a wave called longitudinal wave. The direction of the particles is the same as the direction of the wave itself.

Production of sound

Sound waves are produced by vibrations of the vibrating systems. Examples of objects that can produce sound are loudspeaker, tuning fork, toothed wheel, siren etc.

Experiment 13.1

AIM: To show that sound is produced by vibrating objects.

MATERIALS: Person, elastic band and tuning fork.

PROCEDURE:

1. Put a finger on the throat of a person who is speaking. What do you observe?
2. Stretch an elastic band and pluck it. What do you observe?
3. Tap a tuning fork. What do you observe?

RESULTS/EXPLANATIONS

1. When you put a finger on the throat of someone who is speaking, the person starts humming. The humming can give a clue to how sound is produced.

2. If an elastic band is stretched and plucked, it will be seen vibrating and it will produce a humming sound. In this case, the elastic band represents the tissue called the vocal chords found in the throat which vibrate to produce sound.
3. When a tuning fork is tapped gently it will vibrate. Sound is produced as it vibrates.

CONCLUSION

From the above observations, it shows that sound is produced by vibrations caused by vibrating objects.

Amplitude and loudness of sound

When a loudspeaker cone vibrates, it moves forwards and backwards. The maximum distance the loudspeaker cone moves forwards and backwards is called **amplitude**. The **amplitude** of a sound wave is the maximum distance the vibrating system moves backwards and forwards from its rest position.

The amplitude of a sound wave produced increases with an increase in the amplitude of a loudspeaker cone. An increase in amplitude causes more sound energy to travel out through the air every second to the ear. Hence the sound becomes louder.

Therefore, the loudness of sound depends upon the amplitude of the wave that produces it.

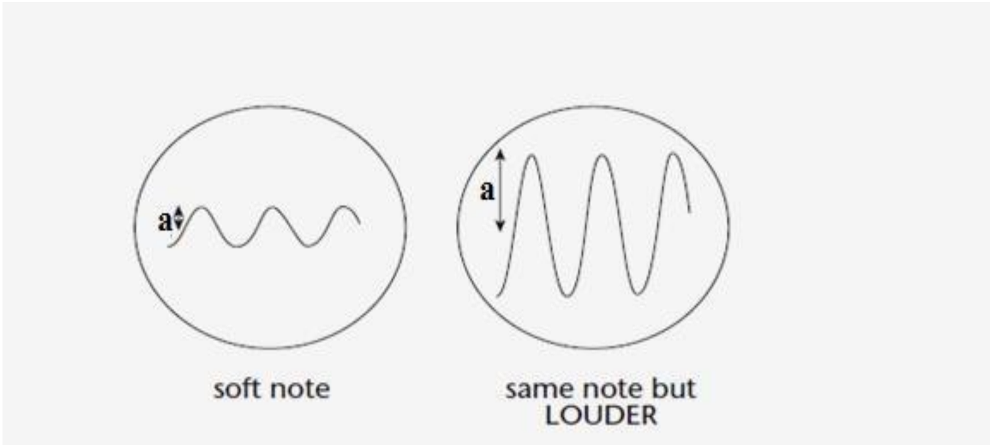


Figure 13.1 effect of amplitude of the wave on loudness of sound

Frequency and pitch of sound

Sound waves are created by vibrations or oscillations. The number of oscillations per second is called **frequency**. Frequency of a sound wave can also be considered as the number of wavelengths the wave can produce per second.

Sound waves of different frequencies sound different to the ear. Sound wave of high frequency is heard as a note said to be of high **pitch**. Sound wave of low frequency is heard as a note said to be of low **pitch**.

Sound of high frequency has a note of **high pitch** and a short wavelength. Sound of low frequency has a note of **low pitch** and long wavelength.

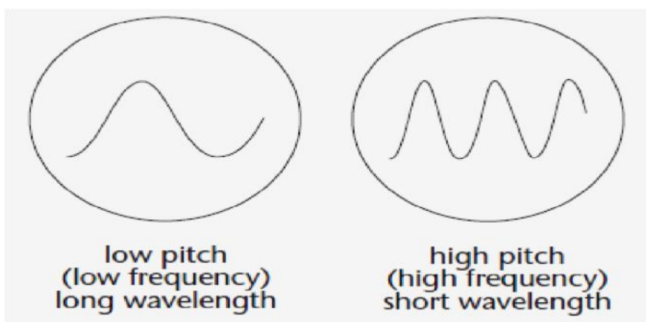


Figure 13.2 effect of frequency on the pitch of sound

Audible sound

Audible sound range is the sound of the frequency which can be detected by human ear. The frequency of audible sound ranges from 20 Hz to 20 kHz (20 000 Hz).

Ultrasonic sound

Ultrasonic sound range is the sound of frequency that cannot be detected by human ear but other animals e.g. dogs, bats and fish.

This is a sound with very high frequency of greater than 20 kHz (20 000Hz).

13.2 Free and forced vibrations

Free vibrations

When the string in **Figure 13.4** is plucked, it vibrates freely. It continues vibrating when left alone. This vibration is called **free vibration**. The frequency with which it vibrates is called **natural frequency.**

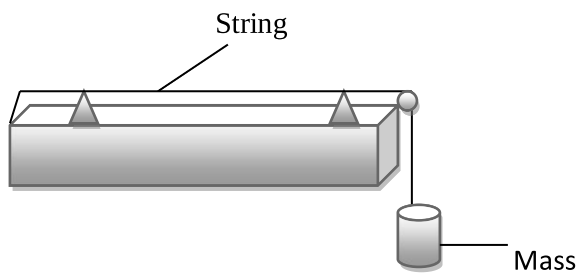


Figure 13.4 free vibrations

Examples of natural frequency are a child on a swing who has been pushed once only, a punch ball which has received just one punch, a simple pendulum and a tuning fork which has been struck.

Forced vibration

When the string in **Figure 13.4** is plucked continually its frequency is determined by the person plucking it, when the child on the swing is pushed continually its frequency is determined by the person pushing the swing. Similarly, when a boxer punches the punch-ball continually, the frequency with which the punch-ball oscillates is determined by the frequency with which the boxer punches. These objects are not vibrating with their natural frequency but they are forced to vibrate. These vibrations are called **forced vibrations**. The frequency with which these objects vibrate is called **forced frequency**.

When an object is vibrated continually it reaches its extreme position. Therefore, forced vibrations become much larger in amplitude.

Resonance

If you strike a tuning fork once and leave it to vibrate, it produces natural frequency due to natural vibration. When the vibrating tuning fork is brought closer to the air column, air column is forced to vibrate at the same frequency as the tuning fork. Therefore, the air column produces forced frequency.

When the natural frequency of the natural vibrating tuning fork equals the forced frequency of the forced vibrating air column, the resonant point is reached. This phenomenon is called **Resonance.**

Resonance takes place when a body is made to vibrate at its natural frequency by vibrations received from another vibrating source of the same frequency.

Resonance is a phenomenon (happening) that needs two vibrations:

- **a.** Forced vibration
- **b.** Natural vibration

Resonance takes place when natural frequency equals forced frequency.
“Forced vibration” frequency = “natural vibration” frequency

Demonstrating resonance by using Barton’s pendulum

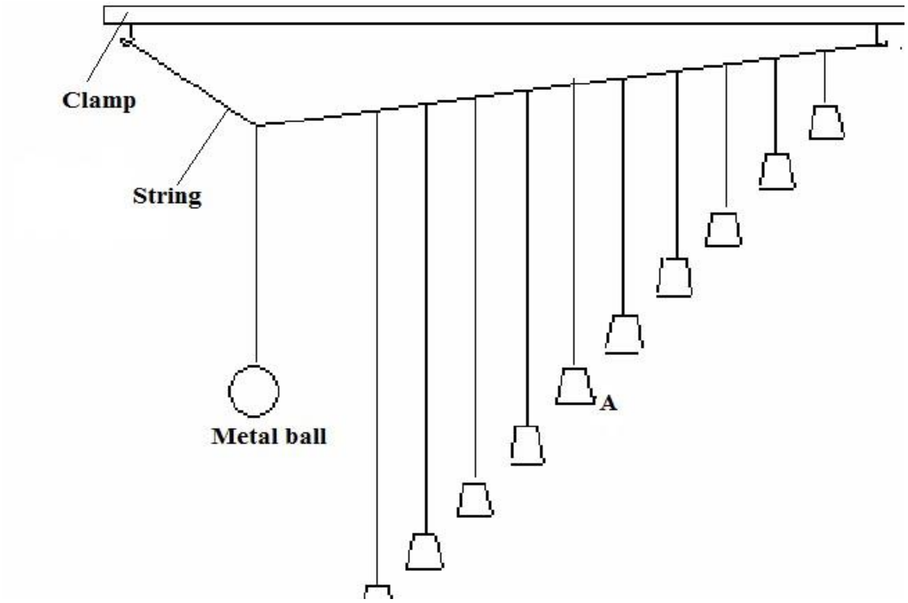


Figure 13.5 Barton’s pendulum

Every object has its own natural frequency of vibration. The object will vibrate with that frequency when it has the opportunity.

Figure 13.5 shows a stretched string to which ten pendulums of different lengths are attached. When the metal ball is set swinging, it forces all the ten bobs swinging as followers. The bob with the same length of string as the metal ball will swing with a much larger amplitude. A’s frequency equals the metal ball’s frequency because they have the same length. Therefore, A **resonates** with the metal ball.

Experiment 13.1

AIM: To investigate resonance.
MATERIALS: Resonance tube, clamp stands, tuning forks (frequencies 400 Hz, 500 Hz and 600 Hz) and water.
PROCEDURE

1. Set up an experiment as shown in **Figure 13. .**

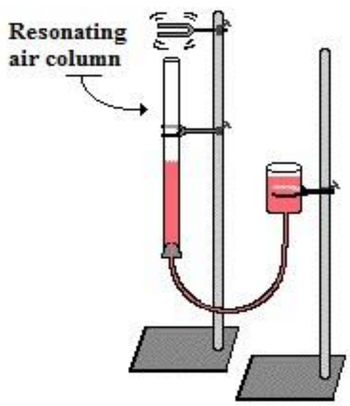


Figure13.6

2. Vibrate a tuning fork of a frequency 400 Hz.
3. Take the vibrating tuning fork and hold it over the mouth of the tube with water.
4. Vary the depth of the water in the tube until the air column is made to resonate with the turning fork. Record the length of the air column (*l*) that was required to produce resonance.
5. Repeat the experiment with other tuning forks of frequency 500 Hz and 600 Hz. Record the air column used to produce resonance in each case.
6. Record your results in **Table 13.3.**

Table 13.3

Frequency (f)	**Length of air column (*l*)**
400 Hz	
500 Hz	
600 Hz	

EXPLANATION/CONCLUSION

When the vibrating tuning fork is brought on the mouth of the tube with no air column you will not hear any sound. As the level of water is decreased and the air column is increased you will hear the sound increase. Increasing the length of air column further gives the maximum sound.

The loud sound is heard when the air column reaches a certain critical length. This is called the **position of resonance**.

The same experiment can be carried out by using a glass tube placed in a jar with water. The length of the air column is varied by raising or lowering the tube.

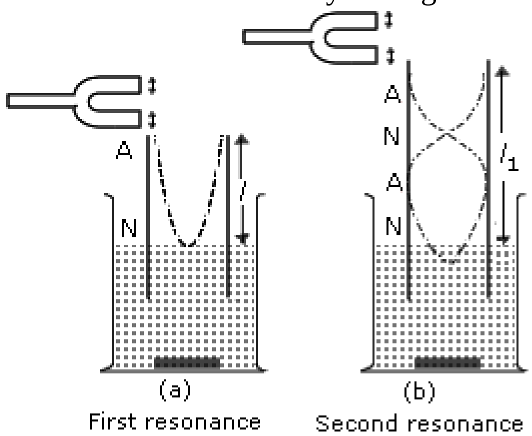


Figure 13.7 Resonance in a jar with water

Figure 13.8 shows the graph of how the amplitude of sound varies with frequency in order to reach the position of resonance.

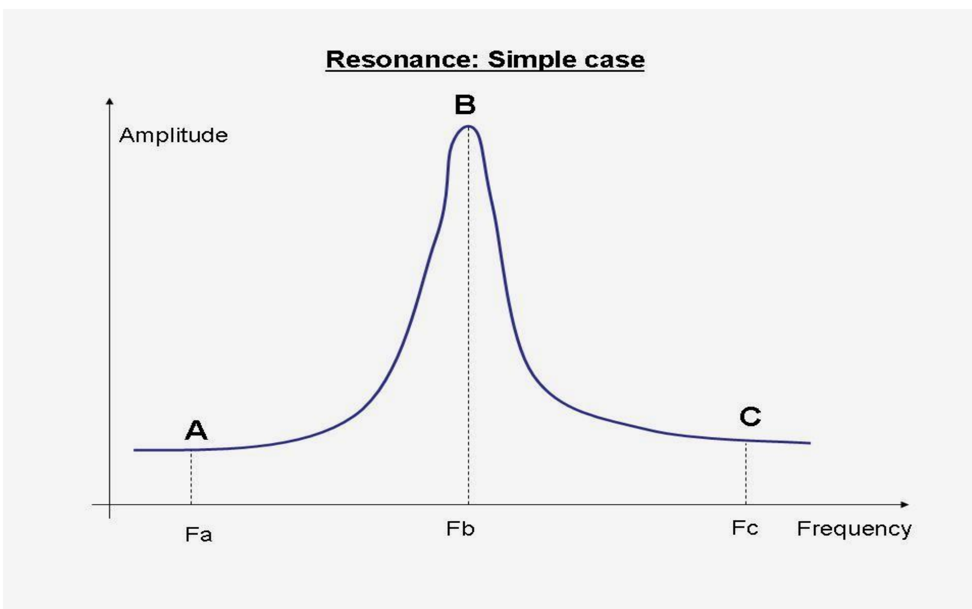


Figure 13.8 resonance graph

Fb = Resonant frequency
B = Resonant point because there is maximum amplitude of vibration

Uses of resonance

Resonance is used in the following;

- **a.** Child's swing
- **b.** Driving a car

c. Swinging bridge

d. A diver jumps up and down at the board's natural frequency when he wants to perform a very high dive. This resonance increases the amplitude of the springboard and the diver has no difficulty in reaching the required height.

Resonance can be a nuisance and dangerous. Resonance can cause breaking in swinging bridges when people are marching on it. When the natural frequency and forced frequency are equal the bridge vibrates violently.

13.3 Nature of sound waves

Propagation of sound

Sound waves are caused by vibrations.
Propagation (spreading) of sound is the way by which sound travels from side to side or from where it is produced to where it is heard.

When the bell is struck, it vibrates. The vibrations compress then stretch the air particles, as shown in **Figure 13.9.** The compressed (squeezed) air particles form a region of high pressure called **compression(C)**. The stretched (spaced) air particles form a region of low pressure called **rarefaction(R)**. The compressions and rarefactions travel forward to the ear. Air transmits a longitudinal wave. The wave is known as **sound wave**.

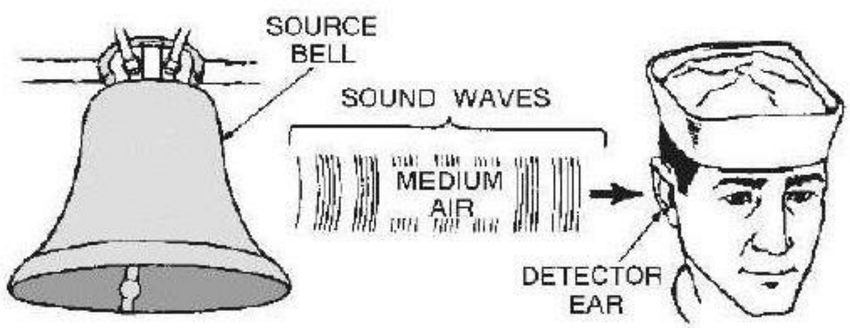
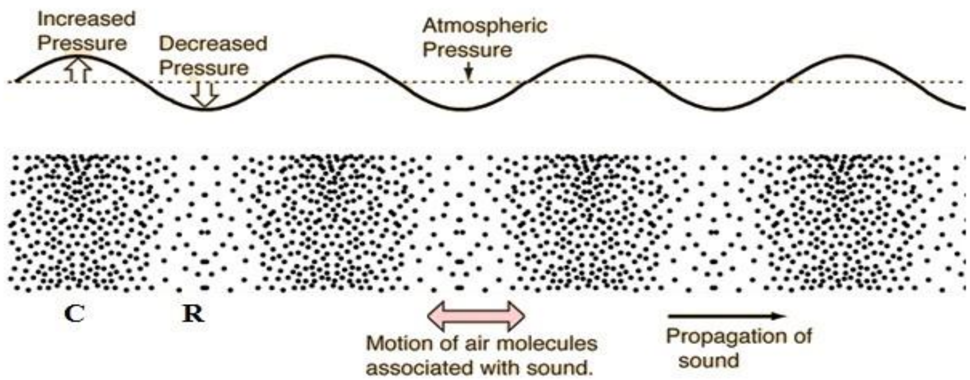


Figure 13.9 transmission of sound in air

Figure 13.10 shows how air pressure varies along the path of a sound wave.



Transmission of sound in air and in a vacuum

Figure 13.9, shows that a sound wave is transmitted in air as a longitudinal wave.
A sound wave needs a medium or material to travel through because it is a longitudinal wave and requires a material that can pass on oscillations. Sound cannot travel in a vacuum. Sound waves can travel through air, solids and liquids.

Experiment 13.2

AIM: To demonstrate that sound waves do not pass through a vacuum.
MATERIALS: Electric bell, power supply, switch , connecting wires, bell jar, cork and vacuum pump.
PROCEDURE:

1. Suspend an electric bell inside a bell jar.
2. Connect a vacuum pump to the bell jar as shown in **Figure 13.11**

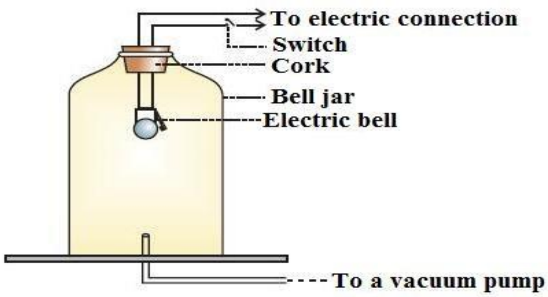


Figure 13.11

3. Close the switch before starting the vacuum pump.
   Explain your observations.
4. Start the vacuum pump.
   Explain your observations.

RESULTS/EXPLANATIONS
Before starting the vacuum pump: When the glass jar is well closed and the switch is closed, the hammer hits the gong. The sound of an electric bell is heard.
After starting the vacuum pump: When the vacuum pump is started, the sound of an electric bell becomes fainter until it cannot be heard. But the hammer can be seen striking the gong. When the air is pumped in once more, the sound of an electric bell is heard once again.

CONCLUSION
Therefore, sound waves can only be heard if there is a material or medium present to pass oscillations, so it is not possible for sound to travel through a vacuum.

Speed of sound

Speed is the distance covered per unit time. The speed of sound is mainly measured by using the reflection of sound.

Reflection of sound

Reflection of sound takes place when it strikes an obstacle, e.g. a wall or a cliff.
The reflected or bounced off sound wave is called an **echo**.
An echo can be used to measure the speed of sound in air and measure the depth of a sea.

Measuring the speed of sound using an echo

Experiment 13.3

AIM: To determine the speed of sound in air
MATERIALS: Stopwatch, toy gun, measuring tape and a high wall.
PROCEDURE:

1. Measure a distance of 100 m from the high wall by using a measuring tape.
2. Stand at a distance of 100 m (point A) from the high wall (point B).

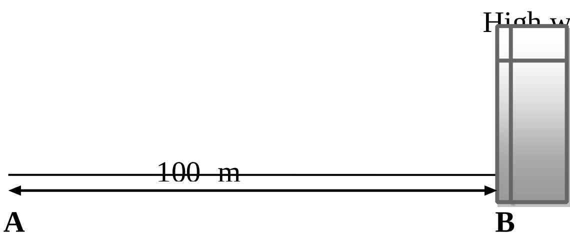


Figure 13.12

3. Fire a toy gun at point A. Start the stopwatch as soon as you fire a toy gun. Stop the stop watch as soon as you hear an echo. Record the time taken from the time the gun was fired to the time an echo was heard.

RESULTS/EXPLANATIONS

The time taken from when the sound wave was produced to when an echo was heard is **t**. The time (t) is for the distance A to B then back to A.
The distance covered is **2d**.

Therefore, the speed of sound using an echo can be estimated as follows:

$$\text{Speed} = \frac{\text{distance covered by the sound wave}}{\text{time taken}}$$

$$\text{Speed of sound} = \frac{2d}{t}$$

$$\mathbf{S = \frac{2d}{t}}$$

Note that the speed of sound without using an echo is:

$$\mathbf{S = \frac{d}{t}}$$

Transmission of sound in different media

Sound is transmitted at different speeds in different media.
The speed of sound varies considerably depending on the material through which the waves are traveling.

The following are the speeds of sound in different media or materials:

Air = 330 m/s (dry air, at 0^0C)

Water = 1400 m/s (at 0^0C)

Solid = 500 m/s

Worked examples

1. An observer sees a flash of a gun being fired and hears the sound 2.4 seconds later. If the distance from the gun to the observer is 816 m/s, calculate the speed of the sound in air.

Solution

In this situation, there is no echo being produced.

Therefore, $s = \frac{d}{t}$

d = 816 m t = 2.4 s

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

$s = \frac{816\ m}{2.4\ s}$

s = **340 m/s**

Wave equation

The speed of sound can also be found by using the wave equation:

V = f x λ

Whereby **V** is velocity (speed) in m/s, **f** is frequency in Hz and **λ** is wavelength in m.

Worked examples

1. Find the speed of the sound wave if its wavelength is 3.4 m and its frequency is 100 Hz.

Solution

λ = 3.4 m f = 100 Hz

V = f x λ

V = 100 Hz x 3.4 m

V = **340 m/s**

2. A tuning fork produces 250 cycles in 2.5 seconds. Find the wavelength of this sound if the speed of sound in the air is 340 m/s.

Solution $f = \frac{250\ cycles}{2.5\ s}$

f= 100 Hz

V= 340 m/s

λ =?

V= f x λ

$λ = \frac{V}{f}$

$λ = \frac{340\ m/s}{100\ Hz}$

λ = **3.4 m**

13.4 Factors that affect the speed of sound

The following are the factors that affect the speed of sound in a media:

a. **Direction of wind:** In air, a sound waves travels faster when it is traveling in the direction of the wind and vice versa.

b. **Temperature:** In air, the speed of sound can increase as the temperature increases without altering the pressure. The speed of sound increases with an increase in temperature when pressure is constant because the air expands and becomes less dense. Therefore, the compressions and rarefactions can easily be transmitted.
For example, the speed of sound in the air at 0^0C is 330 m/s while its speed at 25^0C is 340 m/s.

c. **Strength of intermolecular forces in a medium**
The sound is slowest in gases, more rapidly in liquids and fastest in solids because the forces become stronger. Stronger forces make particles to be tightly packed. The oscillations are passed on more rapidly in a medium with tightly packed particles.