TVET CERTIFICATE IV in Crop Production

BASIC KNOWLEDGE OF MECHANICS AND HEAT

CRPMH401

Demonstrate basic knowledge of mechanics and heat

Competence

Credits: 4

Learning hours: 40

Sector: Agriculture
Sub-sector: Crop Production

Module Note Issue date: June, 2020

Purpose statement

This module describes the skills and knowledge required to apply the knowledge of physics provided for level four. The module will allow the participant to describe, demonstrate and apply different components of physics as basis of topographical data collection, creates terraces and other related modules.

Table of Content

Learning Unit 1: Apply basic knowledge on measurement of physical quantities

Learning Outcome 1.1: Describe physical quantities

- Topic : Description of the two types of physical quantities

1.1.1: Definition of physical quantities

- ➢ Physical quantities are quantities which can be measured.
- ➢ A physical quantity can be represented by:
- ✓ Symbol of the quantity
- ✓ A numerical value for the magnitude of the quantity
- ✓ The unit of measurement

Examples of physical quantities are: mass, time, force, velocity, etc

1.1.2: Types of physical quantities

There are two types of physical quantities, which are:

- ❖ Fundamental (basic) physical quantities (which are 7)
- ❖ Derived physical quantities

A. Fundamental physical quantities

A quantity may be defined as any observable property or process in nature with which a number may be associated. This number is obtained by the operation of measurements. The number may be obtained directly by a single measurement or indirectly, say for example, by multiplying together two numbers obtained in separate operations of measurement. ***Fundamental quantities*** are those quantities that are not defined in terms of other quantities. In physics there are 7 fundamental quantities of measurements namely length, mass, time, temperature, electric current, amount of substance and luminous intensity.

1.1.3: International System (S.I) of units and symbols

In order to measure any quantity, a ***standard unit*** (base unit) of reference is chosen. The standard unit chosen must be unchangeable, always reproducible and not subject to either the effect of aging and deterioration or possible destruction.

Before 1960, there were several systems of measurements in use around the world. In 1960, an international system of units was established. This system is called the ***International System of Units*** (SI).

Table1.1: 7 Fundamental physical quantities, their SI units and symbols.

Physical quantity	Unit	Symbol
Fundamental quantities		
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol
Supplementary quantities		
Plane angle	radian	rad
Solid angle	steradian	sr

B. Derived physical quantities

Quantities which are defined in terms of the fundamental quantities via a system of quantity equations are called *derived quantities.*

Examples of derived quantities include area, volume, velocity, acceleration, density, weight and force.

Table1.2: Some derived physical quantities, their SI units and symbols.

Derived quantity	Definition	S.I. unit in terms of base units	Alternative name for S.I. unit
Area	length × length	m^2	–
Volume	$(length)^3$	m^3	–
Density	mass/volume	$kg\ m^{-3}$	–
Speed, velocity	length/time	$m\ s^{-1}$	–
Acceleration	velocity/time	$m\ s^{-2}$	–
Momentum	mass × velocity	$kg\ m\ s^{-1}$	–
Force	momentum/time	$kg\ m\ s^{-2}$	newton, N
Pressure	force/area	$kg\ m^{-1}\ s^{-2}$	pascal, Pa, $N\ m^{-2}$
Work, energy	force × distance	$kg\ m^2\ s^{-2}$	joule, J
Power	work/time	$kg\ m^2\ s^{-3}$	watt, W

Note: Among those physical quantities, we have two kinds of quantities, which are:

- Scalar quantities
- Vector quantities

Table 1.3: Difference between scalar quantity and vector quantity

Difference between scalar quantity and vector quantity	
Scalar Quantity	**Vector Quantity**
1. Scalar quantity has only magnitude, but no direction.	1. Vector quantity has both magnitude and direction.
2. Every scalar quantity is one dimensional.	2. Vector quantity can be 1-D, 2-D or 3-D.
3. Any change in scalar quantity is the reflection of change in magnitude.	3. Any change in vector quantity can reflect either change in direction or change in magnitude or changes in both.
4. Scalar quantity cannot be resolved as it has exactly same value regardless of direction.	4. Vector can be resolved in any direction using sine or cosine of the adjacent angle.
5. Any mathematical operation carried out among two or more scalar quantities will provide a scalar only. However, if a scalar is operated with a vector then the result will be a vector.	5. Result of mathematical operations between two or more vectors may give either scalar or vector. Dot product of two vectors gives only scalar; while, cross product or summation or subtraction results in a vector.
6. Few examples of scalar quantity: length, mass, energy, density, etc.	6. Examples of vector quantity: displacement, velocity, acceleration, force, etc.

1.1.4: Dimension of a physical quantity

Dimension is the product or quotient of fundamental physical quantities, raised to appropriate powers to form a derived physical quantity.

In general the dimension of any quantity *Q* is written in the form of a dimensional product,

dim $Q = L^aM^bT^cT^dI^eN^fJ^g$ where the exponents a, b, c, d, e, and g, which are generally small integers that can be positive, negative or zero, are called the **dimensional exponents.**

The dimension of a derived quantity provides the same information about the relation of that quantity to the base quantities as is provided by the SI unit of the derived quantity as a product of powers of the SI base units.

There are some derived quantities Q for which the defining equation is such that all of the dimensional exponents in the expression for the dimension of Q are zero.

This is true, in particular, for any quantity that is defined as the ratio of two quantities of the same kind. Such quantities are described as being dimensionless, or alternatively as being of dimension one.

The coherent derived unit for such dimensionless quantities is always the number one, 1, since it is the ratio of two identical units for two quantities of the same kind.

The unit of a physical quantity and its dimension are related, but not identical concepts. The units of a physical quantity are defined by convention and related to some standard;

Table 1.4: Examples of dimensions of some physical quantities

	Quantity	Definition	Formula	Units	Dimensions
Basic Mechanical	**Length**	Fundamental	d	m (meter)	L (Length)
	Time	Fundamental	t	s (second)	T (Time)
	Mass	Fundamental	m	kg (kilogram)	M (Mass)
	Area	length²	$A = d^2$	m^2	L^2
	Volume	length³	$V = d^3$	m^3	L^3
	Density	$\frac{\text{mass}}{\text{volume}}$	$\rho = \frac{m}{V}$	kg/m^3	$\frac{M}{L^3}$
	Velocity	$\frac{\text{length}}{\text{time}}$	$v = \frac{d}{t}$	m/s c (speed of light)	$\frac{L}{T}$
	Acceleration	$\frac{\text{velocity}}{\text{time}}$	$a = \frac{v}{t}$	m/s^2	$\frac{L}{T^2}$
	Momentum	mass × velocity	$p = m \cdot v$	kg·m/s	$\frac{ML}{T}$
Basic Mechanical	**Force** Weight	mass × acceleration mass × acceleration of gravity	$F = m \cdot a$ $W = m \cdot g$	N (newton) = $kg \cdot m/s^2$	$\frac{ML}{T^2}$
	Pressure	$\frac{\text{force}}{\text{area}}$	$p = \frac{F}{A}$	Pa (pascal) = N/m^2 = $kg/(m \cdot s^2)$	$\frac{M}{LT^2}$
	Energy or Work Kinetic Energy Potential Energy	force × distance $\frac{\text{mass x velocity}^2}{2}$ mass × acceleration of gravity × height	$E = F \cdot d$ $K = \frac{1}{2} mv^2$ $U = m \cdot g \cdot h$	J (joule) = N·m = $kg \cdot m^2/s^2$	$\frac{ML^2}{T^2}$
	Power	$\frac{\text{energy}}{\text{time}}$	$P = \frac{E}{t}$	W (watt) = J/s = $kg \cdot m^2/s^3$	$\frac{ML^2}{T^3}$

1.1.5: Prefixes for S.I units

Physical quantities are of wide range of magnitude. For example the mass of earth is about 6 000 000 000 000 000 000 000 000 kg while the diameter of a molecule is 0.000 000 0001m. Writing such quantities is very tedious and clumsy. Some words have been used with SI units as short-cut to writing such magnitude. These words are associated with certain magnitude. For example a word like milli stands for $\frac{1}{1000}$, kilo for 1000. Since these words are used or fixed before the SI units, they are called ***prefixes*.**

Table1.5: Some common prefixes and their symbols.

SI Prefixes					
Factor	**Name**	**Symbol**	**Factor**	**Name**	**Symbol**
10^{1}	Deca	da	10^{-1}	deci	d
10^{2}	Hecto	h	10^{-2}	centi	c
10^{3}	Kilo	k	10^{-3}	milli	m
10^{6}	Mega	M	10^{-6}	micro	µ
10^{9}	Giga	G	10^{-9}	nano	n
10^{12}	Tera	T	10^{-12}	pico	p
10^{15}	Peta	P	10^{-15}	femto	f
10^{18}	Exa	E	10^{-18}	atto	a
10^{21}	Zetta	Z	10^{-21}	zepto	z
10^{24}	Yotta	Y	10^{-24}	yocto	y

Learning Outcome 1.2: Differentiate instruments for physical quantities measurement

- Topic: Differentiation of measuring instruments

1.2.1: Definition of an instrument

An instrument is a tool or a device which can be used in order to measure the size or quantity of a given object or substance according to its standard unit.

Measurements involve comparing an unknown quantity with a known fixed unit quantity (standard unit). This measurement consists of two parts, the unit and the number indicating how many units are there in the quantity being measured.

In order to obtain various measurements, early scientists had to develop ***measuring devices***. A measuring device has ***a scale*** marked in the standard or multiple units of the quantity to be measured.

The choice of the instrument to be used depends entirely on the quantity being measured and the level of accuracy needed.

1.2.2: Instruments used for measuring length

1. **Meter rule and Tape measure**

A **ruler**, sometimes called a **rule** or **line gauge**, is a device used in geometry and technical drawing, as well as the engineering and construction industries, to measure distances or draw straight lines.

Rulers have long been made from different materials and in multiple sizes. Some are wooden. Plastics have also been used since they were invented; they can be molded with length markings instead of being scribed. Metal is used for more durable rulers for use in the workshop; sometimes a metal edge is embedded into a wooden desk ruler to preserve the edge when used for straight-line cutting. 12 in or 30 cm in length is useful for a ruler to be kept on a desk to help in drawing. Shorter rulers are convenient for keeping in a pocket. Longer rulers, e.g., 18 in (46 cm) are necessary in some cases. Rigid wooden or plastic yardsticks, 1 yard long, and meter sticks, 1 meter long, are also used. Classically, long measuring rods were used for larger projects, now superseded by tape measure, surveyor's wheel or laser rangefinders.

2. **Vernier caliper measures (thickness) small length**

A caliper is a device used to measure the distance between two opposite sides of an object. Many types of calipers permit reading out a measurement on a ruled scale, a dial, or a digital display. But a caliper can be as simple as a compass with inward or outward-facing points. The tips of the caliper are adjusted to fit across the points to be measured and then the caliper is then removed and the distance read by measuring between the tips with a measuring tool, such as a ruler.

It is used in many fields such as mechanical engineering, metalworking, forestry, woodworking, science and medicine.

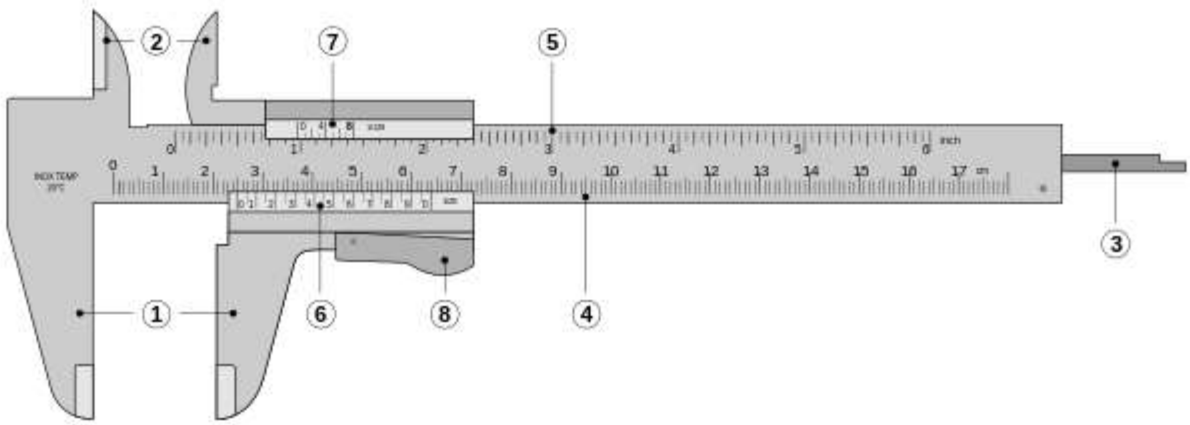


Fig.1.1: Vernier calipers

The labeled parts are

i. **Outside large jaws**: used to measure external diameter or width of an object
ii. **Inside small jaws**: used to measure internal diameter of an object
iii. **Depth probe/rod**: used to measure depths of an object or a hole
iv. **Main scale (Metric)**: scale marked every mm
v. **Main scale (Imperial)**: scale marked in inches and fractions
vi. **Vernier scale (Metric)** gives interpolated measurements to 0.1 mm or better
vii. **Vernier scale (Imperial)** gives interpolated measurements in fractions of an inch
viii. **Retainer**: used to block movable part to allow the easy transferring of a measurement

3. Micrometer screw gauge can be used for measuring small diameter

A micrometer, sometimes known as a micrometer screw gauge, is a device incorporating a calibrated screw widely used for accurate measurement of components in mechanical engineering and machining as well as most mechanical trades, along with other metrological instruments such as dial, vernier, and digital calipers.

Micrometers are usually, but not always, in the form of calipers (opposing ends joined by a frame). The spindle is a very accurately machined screw and the object to be measured is placed between the spindle and the anvil. The spindle is moved by turning the ratchet knob or thimble until the object to be measured is lightly touched by both the spindle and the anvil.

Micrometers are also used in telescopes or microscopes to measure the apparent diameter of celestial bodies or microscopic objects.

1.2.3: Instruments used for measuring volume

Measuring cylinder, Pipette and Burette

A **graduated cylinder**, also known as **measuring cylinder** or **mixing cylinder** is a common piece of laboratory equipment used to measure the volume of a liquid. It has a narrow cylindrical shape. Each marked line on the graduated cylinder represents the amount of liquid that has been measured.

Graduated cylinders are often used to measure the volume of a liquid. Graduated cylinders are generally more accurate and precise than laboratory flasks and beakers, but they should not be used to perform volumetric analysis; volumetric glassware, such as a volumetric flask or volumetric pipette, should be used, as it is even more accurate and precise. Graduated cylinders are sometimes used to measure the volume of a solid indirectly by measuring the displacement of a liquid.

Different types of graduated cylinder: 10mL, 25mL, 50mL and 100mL graduated cylinder

Fig.1.2: Different types of graduated cylinder

1.2.4: Instruments for measuring time/duration

Stop clock or stopwatch/chronometer

A **chronometer** is a specific type of mechanical timepiece tested and certified to meet certain precision standards of time.

A mechanical chronometer is a spring-driven escapement timekeeper, like a watch, but its parts are more massively built. Changes in the elasticity of the balance spring caused by variations in temperature are compensated for by devices built into it.

1.2.5: Instruments used for measuring mass

Beam balance, Spring balance, Electronic balance

A **Beam balance** (or **Beam scale**) is a device to measure weight or mass. These are also known as **mass scales**, **weight scales**, **mass balances**, **weight balances**, or simply **scales**, **balances**, or **balance scales**.

The **traditional scale** consists of two plates or bowls suspended at equal distances from a fulcrum. One plate holds an object of unknown mass (or weight), while known masses are added to the other plate until static equilibrium is achieved and the plates level off, which happens when the masses on the two plates are equal. The perfect scale rests at neutral.

A **spring scale** will make use of a spring of known stiffness to determine mass (or weight). Suspending a certain mass will extend the spring by a certain amount depending on the spring's stiffness (or spring constant). The heavier the object, the more the spring stretches, as described in Hooke's law. Other types of scales making use of different physical principles also exist.

Some scales can be calibrated to read in units of force (weight) such as newtons instead of units of mass such as kilograms. Scales and balances are widely used in commerce, as many products are sold and packaged by mass.

Mechanical scales

A mechanical scale or balance is used to describe a weighing device that is used to measure the mass, force exertion, tension and resistance of an object without the need of a power supply. Types of mechanical scale include spring scales, hanging scales, triple beam balances and force gauges.

There are actually three types of mechanical balances:

- Equal arm **balance**. ...
- Unequal arm **balance**. ...
- Spring **balance**.

Balances are different from scales in that they have a single bar resting on a pivot with two identically weighted platforms on either end of the bar. When you place a weight of known value on one platform and another object of unknown weight on the other. To find the exact weight of the unknown, you simply adjust the amount of weight on the known side of the balance. This makes it sound like there is only one type of balance, but there are more than just one. There are actually three types of balances: the equal arm balance, the unequal arm balance, and the spring balance.

Equal arm balance

The equal arm balance is named such because the distance between the pivot and each end of the bar are equidistant, or separated by an equal length from the pivot point. This pivot point, called the fulcrum, sits on the exact center of the bar. This means the fulcrum is at the center of gravity, and the balance will be "zero" when the platforms are at equal levels. This equality is achieved by having to two things of the same weight on each platform.

Unequal arm balance

As you would expect from a name like that, the fulcrum is not equidistant from the both platforms. Instead, one arm is shorter than the other. The object to be weighed is placed on the shorter end, while the known weights are moved along the longer arm until balance is obtained. A steelyard is a example in common use today. It's used in underdeveloped nations because it's inexpensive, easy to port, and the length of arms can multiply the effects of a smaller weight by a factor of 100, it is easy to use a small took for a large item.

Spring balance

The spring balance consists of a coiled spring at one end, with a hook at the other end for the object that is to be weighed. This uses physics of a springs elasticity to calculate the weight of the object. You see, the distance that the spring is stretched is proportional to the weight of the object that is being weighed.

A pointer and a graduated scale are attached to the balance to convert the distance the spring is stretched into a weight reading.

The **mechanical balance** consists, essentially, of a rigid beam that oscillates on a horizontal central knife-edge as a fulcrum and has the two end knife-edges parallel and equidistant from the center. The loads to be weighed are supported on pans hung from bearings

1.2.6: Instrument used for measuring force

A **dynamometer**, or "dyno" for short, is a device for measuring force, moment of force (torque), or power. For example, the power produced by an engine, motor or other rotating prime mover can be calculated by simultaneously measuring torque and rotational speed (rpm)

A dynamometer can also be used to determine the torque and power required to operate a driven machine such as a pump. In that case, a motoring or driving dynamometer is used. A dynamometer that is designed to be driven is called an absorption or passive dynamometer. A dynamometer that can either drive or absorb is called a universal or active dynamometer.

1.2.7: Instrument used for measuring Pressure

Pressure gauge, instrument for measuring the condition of a fluid (liquid or gas) that is specified by the force that the fluid would exert, when at rest, on a unit area, such as pounds per square inch or newtons per square centimeter.

Gauge pressure is the pressure relative to the local atmospheric or ambient pressure. The pressure is directly proportional of force and proportional of square area.

In mathematical terms, pressure can be expressed as:

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

Pressure gauges are well suited to measuring the three different types of pressure.

- Absolute Pressure Gauges.
- Gauge Pressure Measuring Devices.
- Differential Pressure Gauges.

There are two basic pressure types: absolute and gauge, distinguished by what pressure they are compared to, which is called the reference pressure. Gauge pressure's reference is ambient atmospheric pressure. Absolute pressure's reference is an absolute vacuum.

Pressure measurement is the analysis of an applied force by a fluid (liquid or gas) on a surface. Pressure is typically measured in units of force per unit of surface area. ... A manometer is a good example, as it uses the surface area and weight of a column of liquid to both measure and indicate pressure.

Table 1.6: Some other examples of measuring instruments and their corresponding physical quantities:

Instrument	Quantity
Theodolite	measuring angles in the horizontal and vertical planes
wattmeter	electrical power
wind vane	wind direction
voltmeter	electric potential, voltage
seismometer	seismic waves (for example, earthquakes)
spectrometer	properties of light
sphygmomanometer	blood pressure
pH meter	pH (chemical acidity/basicity of a solution)
alcoholmeter	alcoholic strength of liquid
ammeter	electric current
anemometer	wind speed
barometer	air pressure
calorimeter	heat of chemical reactions
ellipsometer	refractive index, dielectric function, thickness of thin films
dumpy level	horizontal levels, polar angle
electrometer	electric charge
etc	

Note: We will see how to use some of these instruments in details in learning outcome 4

Learning Outcome 1.3: Differentiate errors for physical quantities measurement

- Topic: Identification of the types of errors in measurement

1.3.1: Definition of an error

Error is the difference between the actual value and calculated value of any physical quantity.

1.3.2: Sources of errors in measurement of physical quantities

All measurements of physical quantities are uncertain and imprecise to some limit. There are three sources of errors.

- Negligence or inexperience of a person.
- Faulty apparatus.
- Inappropriate method or technique.

A **measurement** is an observation that has a numerical value and unit.

When you measure an object, you compare it with a standard unit. Every measurement must be expressed by a number and a unit. The Oxford Dictionary explains the term **measure** as: "Estimate the size, amount or degree of (something) by using an instrument or device marked in standard units or by comparing it with an object of known size".

In order for a measurement to be useful, a standard measurement must be used.

Standard measurement is an exact quantity that people agree on to be used for comparison or as a reference to measure other quantities.

We have three kinds of standards: International standard, Regional standard and National standard.

The science of measurement is called **metrology**. It has three branches to know: Legal metrology, Industrial metrology and Material testing.

1.3.3: Types of errors and their prevention

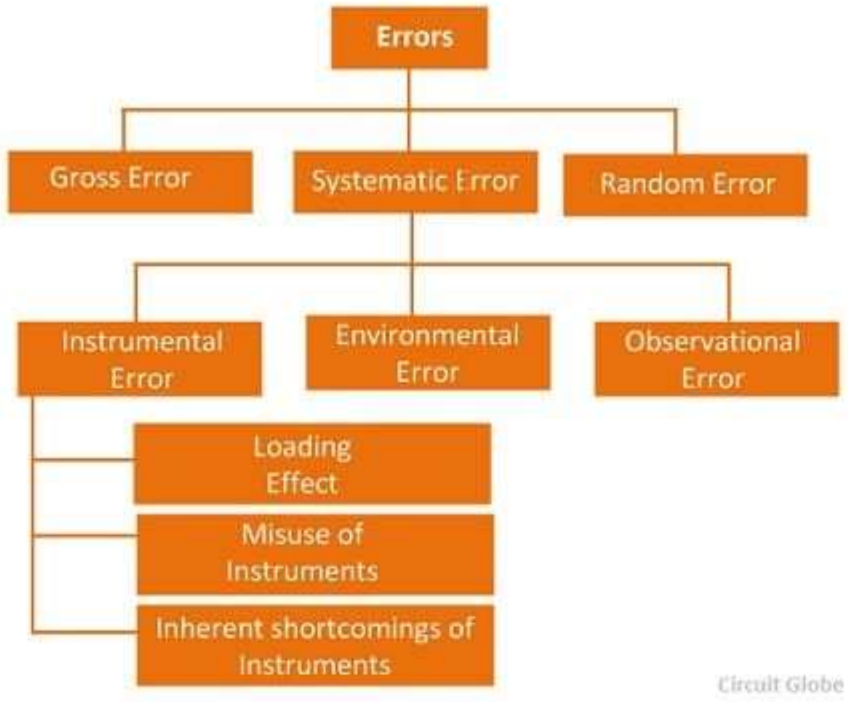


Fig 1.3: Types of errors

1. **Gross Errors**

The gross error occurs because of the human mistakes. For examples consider the person using the instruments takes the wrong reading, or they can record the incorrect data. Such type of error comes under the gross error. The gross error can only be avoided by taking the reading carefully.
For example – The experimenter reads the 31.5ºC reading while the actual reading is 21.5Cº. This happens because of the oversights. The experimenter takes the wrong reading and because of which the error occurs in the measurement.
Two methods can remove the gross error.
These methods are:

- The reading should be taken very carefully.
- Two or more readings should be taken of the measurement quantity. The readings are taken by the different experimenter and at a different point for removing the error.

Experimental errors are inevitable. In absolutely every scientific measurement there is a degree of uncertainty we usually cannot eliminate. Understanding errors and their implications is the only key to correctly estimating and minimizing them.
The experimental error can be defined as: "the difference between the observed value and the true value" (Merriam-Webster Dictionary). The uncertainties in the measurement of a physical quantity (errors) in experimental science can be separated into two categories: ***random*** and ***systematic***.

2. **Random errors**

Random errors fluctuate from one measurement to another. They may be due to: poor instrument sensitivity, random noise, random external disturbances, and statistical fluctuations (due to data sampling or counting).
A random error arises in any measurement, usually when the observer has to estimate the last figure possibly with an instrument that lacks sensitivity. Random errors are small for a good experimenter and taking the mean of a number of separate measurements reduces them in all cases.

3. **Systematic errors**

Systematic errors usually shift measurements in a systematic way.

They are not necessarily built into instruments. Systematic errors can be at least minimized by instrument calibration and appropriate use of equipment.
A systematic error may be due to an incorrectly calibrated instrument, for example a ruler or an ammeter. Repeating the measurement does not reduce or eliminate the error and the existence of the error may not be detected until the final result is calculated and checked, say by a different experimental method. If the systematic error is small a measurement is accurate.
If you do the same thing wrong each time you make the measurement, your measurement will differ systematically (that is, in the same direction each time) from the correct result.
There are three main causes of error: **human, instrument** and **environment**.

- ❖ **Human error (Observation error)** can be due to mistakes (misreading 22.5cm as23.0cm) or random differences (the same person getting slightly different readings of the same measurement on different occasions**).**

For example:

1. The experimenter might consistently read an instrument incorrectly, or might let knowledge of the expected value of a result influence the measurements (Bias of the experimenter).
2. Incorrect measuring technique: For example, one might make an incorrect scale reading because of parallax error (reading a scale at an angle).
3. Failure to interpret the printed scale correctly.

- ❖ **Instrument errors** can be systematic and predictable (a clock running fast or a metal ruler getting longer with a rise in temperature). The judgment of uncertainty in a measurement is called the absolute uncertainty, or sometimes the raw error.

For example:

i. Errors in the calibration of the measuring instruments.
ii. Zero error (the pointer does not read exactly zero when no measurement is being made).
iii. The instrument is wrongly adjusted.

- ❖ **Environmental Errors**

These errors are due to the external condition of the measuring devices. Such types of errors mainly occur due to the effect of temperature, pressure, humidity, dust, vibration or because of the magnetic or electrostatic field. The corrective measures employed to eliminate or to reduce these undesirable effects are:

- The arrangement should be made to keep the conditions as constant as possible.
- Using the equipment which is free from these effects.
- By using the techniques which eliminate the effect of these disturbances.
- By applying the computed corrections.

Although random errors can be handled more or less routinely, there is no prescribed way to find systematic errors.
One must simply sit down and think about all of the possible sources of error in a given measurement, and then do small experiments to see if these sources are active.
The goal of a good experiment is to reduce the systematic errors to a value smaller than the random errors.
For example a meter stick should have been manufactured such that the millimeter markings are located much more accurately than one millimeter.

- ❖ **Accidental errors**

Accidental errors are those which remain after mistakes. And systematic errors have been eliminated and are caused by a combination of reasons beyond the ability of the observer control.
Accidental errors are caused randomly (unknown and unpredictable changes) in an experiment are called as accidental errors. They are also known as random errors.

Accidental errors can be reduced by selecting instrument with small least count

Absolute and Relative Errors (Uncertainties)

- **Absolute Error**

Absolute error is a measure of how far 'off' a measurement is from a true value or an indication of the uncertainty in a measurement. For example, if you measure the width of a book using a ruler with millimeter marks, the best you can do is measure the width of the book to the nearest millimeter. You measure the book and find it to be 75 mm. You report the absolute error in the measurement as 75 mm +/- 1 mm. The absolute error is 1 mm. Note that absolute error is reported in the same units as the measurement.

Alternatively, you may have a known or calculated value and you want to use absolute error to express how close your measurement is to the ideal value. Here absolute error is expressed as the difference between the expected and actual values.

Absolute Error = Actual Value - Measured Value

For example, if you know a procedure is supposed to yield 1.0 liters of solution and you obtain 0.9 liters of solution, your absolute error is 1.0 - 0.9 = 0.1 liters.

- **Relative Error**

You first need to determine absolute error to calculate relative error. Relative error expresses how large the absolute error is compared with the total size of the object you are measuring. Relative error is expressed as a fraction or is multiplied by 100 and expressed as a percent.

Relative Error = Absolute Error / Known Value

For example, a driver's speedometer says his car is going 60 miles per hour (mph) when it's actually going 62 mph. The absolute error of his speedometer is 62 mph - 60 mph = 2 mph. The relative error of the measurement is 2 mph / 60 mph = 0.033 or 3.3%.

In some other cases it is easier to work with absolute rather than relative errors (and vice-versa), so be familiar with both.
These errors can be reduced by about an order of magnitude (± 1 minute to ± 0.1 minute) when the error is limited by precision.
As a general rule, record all readings on analogue scales to 0.1 or 0.2 of the smallest division.

Not to do so may seriously impair the quality of your results.

- **Approximation errors**

The approximation error in some data is the discrepancy between an exact value and some approximation to it. An approximation error can occur because:

1. The measurement of the data is not precise due to the instruments. (e.g., the accurate reading of a piece of paper is 4.5 cm but since the ruler does not use decimals, you round it to 5 cm.)
2. Approximations are used instead of the real data (e.g., 3.14 instead of π).

In the mathematical field of numerical analysis, the numerical stability of an algorithm indicates how the error is propagated by the algorithm.

- **Percentage errors**

Percent error is the difference between estimated value and the actual value in comparison to the actual value and is expressed as a percentage. In other words, the percent error is the **relative error** multiplied by 100.

The formula for percent error is:

PE = (|Estimated value-Actual value|/ Actual value) × 100

1.3.4: Accuracy and Precision

The terms **accuracy** and **precision** are often misused.

Experimental precision means the degree of exactness of the experiment or how well the result has been obtained. Precision does not make reference to the true value; it is just a quality attribute to the repeatability or reproducibility of the measurement. *Accuracy* refers to correctness and means how close the result is to the true value. Accuracy depends on how well the systematic errors are compensated. Precision depends on how well random errors are reduced.

Accuracy is the degree of veracity ("how close to true") while precision is the degree of reproducibility ("how close to exact").

Accuracy and precision must be taken into account simultaneously. All measurements have a degree of uncertainty: no measurement can be perfect!

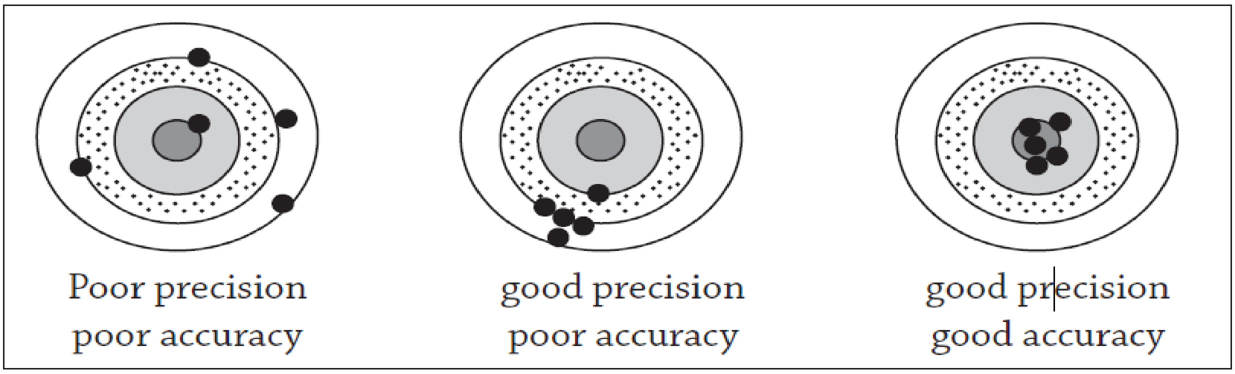


Fig 1.4: Accuracy and precision

A measurement system is called **valid** if it is both **accurate** and **precise**.

Uncertainty depends on both the accuracy and precision of the measurement instrument. The lower the accuracy and precision of an instrument, the larger the measurement uncertainty is.

Often, the uncertainty of a measurement is found by repeating the measurement enough times to get a good estimate of the standard deviation of the values.

Physical measurements are never exact but approximate because of error associated with the instruments (limitations of the measuring instrument) or which arise when using them (the conditions under which the measurement is made, and the different ways the operator uses the instrument).

For example, it is possible to have readings taken with great precision which are not accurate i.e. using an inaccurate instrument of high sensitivity (precision).

For example, if the instrument being used has a zero error which has not been taken care of, the measurements read from it are consistently affected by the zero error. Similarly, it is possible to have readings which are accurate but not very precise. This occurs if one uses an accurate instrument of low sensitivity (precision).

Example of measurement using a ruler

Using a ruler with 0.5cm marking, we might measure this eraser to be 5.5cm long.

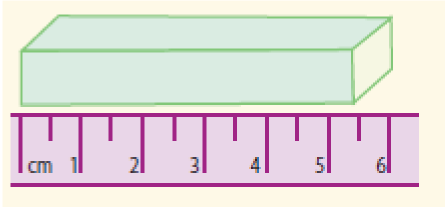


Fig.1.5:Measuring the length by using ruler

- ✓ I f we used a more precise ruler, with 0.1cm markings, then we find the length to be 5.4cm.
- ✓ I f we used a micrometer that measured to the nearest 0.01cm, we may find that the measured length is 5.41cm.

The Limit of Accuracy of a Measuring Instrument are ± 0.5 of the unit shown on the instrument's scale. It is important to assess the **uncertainty in measurements**. One way to do this is to repeat measurements and average the results.

The maximum deviation from the average is one way to assess uncertainty (although not the best way). In the following measurements, measure each case at least three times and take an average.

Then record the number like the following example: Measured times: 5.6s, 6.0s, 6.2s**;**

Average: 5.9s

Experimental time: **5.9 ± 0.5s.**

Learning Outcome 1.4: Determine physical quantities

- Topic1: Measuring/calculation of the length using meter rule and vernier caliper

Measurements involve comparing an unknown quantity with a known fixed unit quantity (standard unit). This measurement consists of two parts, **the unit** and **the number** indicating how many units are there in the quantity being measured.

In order to obtain various measurements, early scientists had to develop ***measuring devices/instruments***. A measuring device has *a scale* marked in the standard or multiple units of the quantity to be measured.

1.4.1: Measurement of the Length

I. Measurement of the Length by using meter rule/meter stick

Length is measured in ***meters***. One meter is the distance between the two marks on a standard platinum-iridium bar kept at Paris (France).

Although the meter is the standard unit of length, it is sometimes too big to measure some distances and too small to measure others. We therefore need other larger and smaller units related to the meter to carry out some measurements.

Commonly encountered multiples and sub-multiples of length include the kilometer (one kilometer is equal to one thousand meters) and the millimeter (one millimeter is equal to one thousandth of a meter).

Activity1

To observe the scale of meter rule

Materials: A meter rule

Steps

1. Hold a meter rule provided to you and note its calibration. What does each division represent?
2. Discuss the calibration of a meter rule with your colleagues in your class.

Straight distances which are less than one meter in length are generally measured using ***meter rules***. Meer rules are graduated in ***millimeters (mm)***.

Each division on the scale represents 1 mm unit (see figure below).

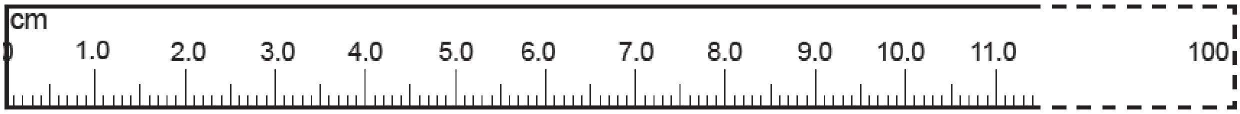


Fig.1.6: A metre rule

Activity 2

To demonstrate how to use a meter rule

Materials: A meter rule, a block of wood

Steps

1. Place the meter rule in contact with the block as shown in Fig. below. The zero mark on the scale is placed at the edge of the object.
2. Position your eyes vertically above at the other end of the block as shown in Fig. below
3. Suggest the reason for this.
4. Read the measurement and record it down in your exercise book.

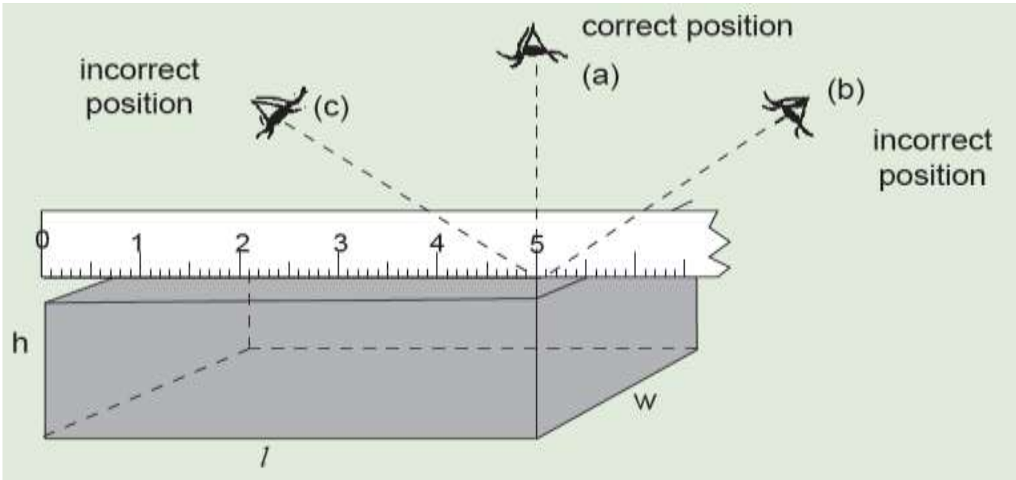


Fig.1.6: Reading a meter rule

5. Repeat the steps this time measuring the width (w) and height (h) of the block.
6. Record your reading in tabular form as shown in table below

Table 1.7: Form used for measuring length

Length (cm)	Width (cm)	Height (cm)

Note: It is not always necessary to start measuring at the zero mark of the meter rule as shown in above Fig. You may use any two points on the scale, make your readings and obtain the required length by subtraction.

II. Measurement of the Length by using Vernier callipers

Activity

To observe the parts of a vernier caliper

Materials: vernier calliper

Steps

1. Look at a vernier calliper provided. Name the parts and describe their functions.
2. Observe its horizontal and rotating scales, its jaws and knobs.
3. Discuss with your group members how it measures length.

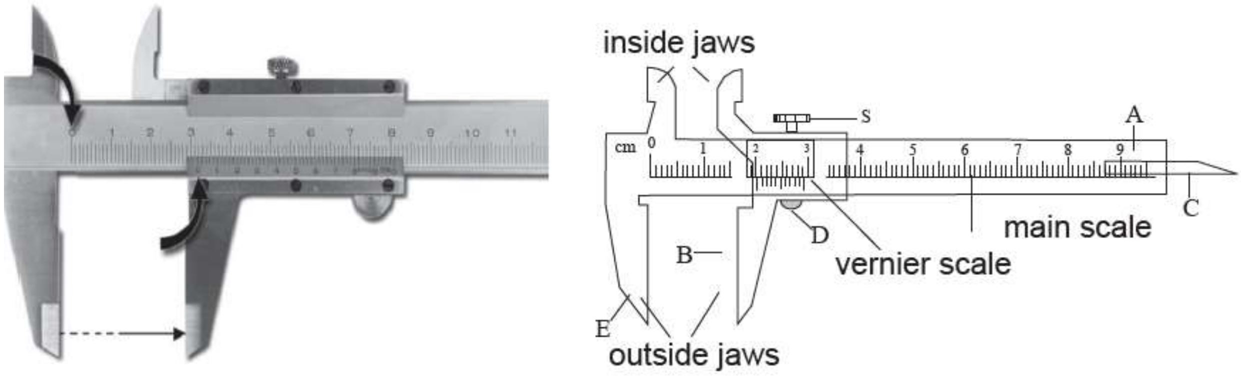


Fig.1.7: Vernier caliper and its parts

The calliper consists of a steel rigid frame A, onto which a linear scale is engraved. This scale is called the ***main scale*** and it is calibrated in centimeters and millimeters. It has a fixed jaw E at one end and a sliding jaw *B* centrally aligned by a thin flat bar *C*. The spring-loaded button *D* is used to prevent the sliding jaw from moving unnecessarily. The sliding jaw carrying a vernier scale can move along the main scale and can be fixed in any position along the main scale by screw *S*.

The outside jaws are used to take external length measurements of objects. The inside jaws are used to take internal length measurement of an object. The sliding flat bar *C* is used to find the depth of blind holes.

Using a vernier scale

Least count of a vernier caliper

Activity

To observe and analyse the scale on a vernier calliper

Materials: Vernier calliper

Steps

1. Take a vernier callipers and observe its scale. How many divisions are there between 0 and 1, 4 and 5?
2. In your group, find out what each division represents. What is the name given to the value?

The vernier scale has a length of 9 mm. It is divided into ten equal divisions. Therefore, each division has a length of 0.9 mm. The difference between 1 division on the main scale and 1 division in the vernier scale is (1– 0.9) mm =0.1 mm. The smallest reading called the *least count (LC)* that can be read from vernier callipers is 1 mm – 0.9 mm = 0.1 mm or 0.01 cm .

The second decimal value in a reading is obtained by identifying the mark on the vernier scale which coincides with a mark on the main scale called the ***vernier coincidence*** *(VC)* and multiplying it with the least count i.e 0.01 cm.

Second decimal value = (VC × LC).

How to read the vernier calipers scale

Activity 1

To read and record the reading on a vernier caliper

Materials: cylindrical object, vernier calliper

1. Place the object to be measured between the outside jaws as shown in Fig below. Slide the jaw until they touch the rod.

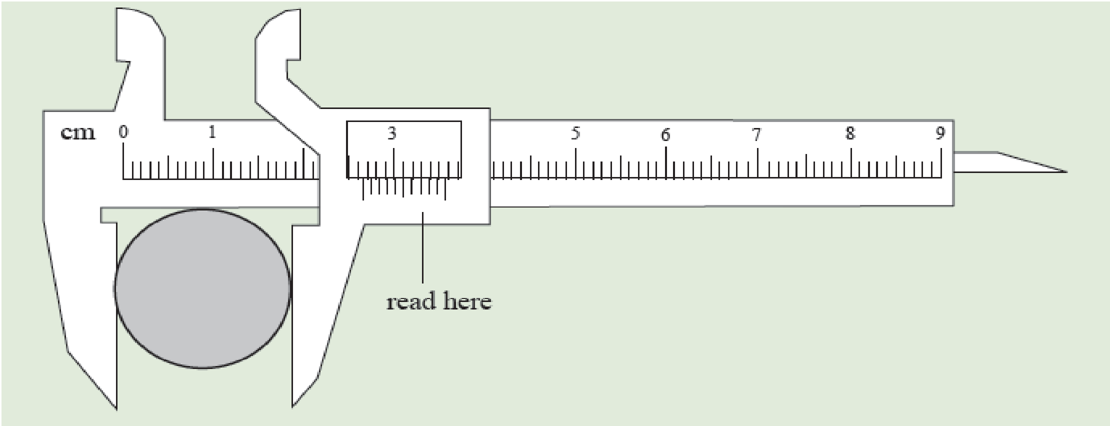


Fig.1.8: Measurement of external diameter using vernier calipers

2. Record the readings on the main scale and the vernier scale. The main scale reading is the mark on the main scale that is immediately before the zero mark of the vernier scale.
3. Multiply the vernier scale reading by 0.01 cm.
4. Add the main scale reading (in cm) and the vernier scale reading (in cm) to get the diameter of the rod.

For instance, for the vernier shown in above Fig, the main scale reading (MSR) is 2.6 cm. However, to get the second decimal value, we make use of the vernier scale. The vernier scale mark that coincides exactly with a main scale mark gives the vernier coincidence (VC).

In this case, the 6^{th} division coincides with the main scale division.

Therefore, the external diameter of the cylindrical object is

MSR + (VC × LC) = 2.6 cm + (6 × 0.01) cm

= 2.66 cm.

Activity 2

To measure the internal diameter of a test tube using a vernier caliper

Steps

1. Insert the inside jaws of a vernier callipers into the test tube.
2. Move the sliding jaws until the jaws just touch the inside walls of the test tube as shown in Fig. below
3. Take and record the readings on the main scale and the vernier scale. Use these readings to determine the internal diameter of the test tube.

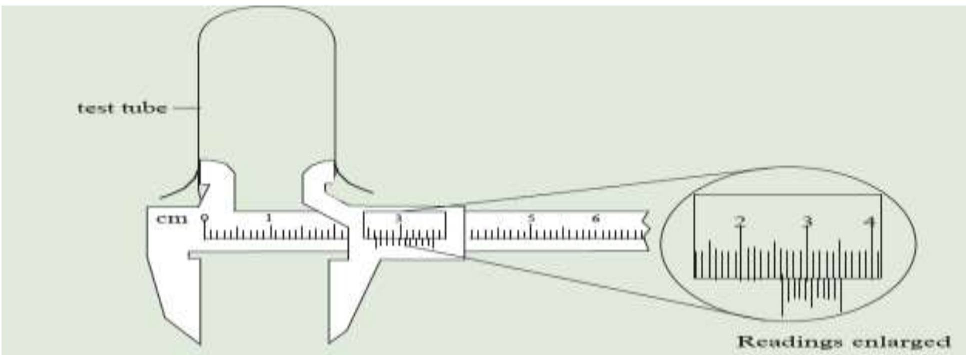


Fig.1.9: Measurement of internal diameter using vernier callipers.

We can determine the diameter of the test tube shown in above Fig. as follows:

The internal diameter of the test tube = MSR + (VC × LC) = 2.6 cm + (2 × 0.01) cm

= **2.62 cm**

Example 1

What are the readings shown by the vernier callipers in Fig. (a) and (b)?

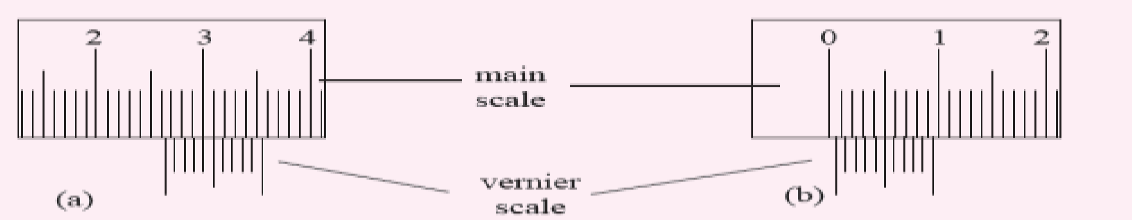


Fig.1.10: Vernier calliper readings

Solution

(a) Main scale reading = 2.6 cm

Vernier scale reading = 0.04 cm

Reading = **2.64 cm**

(b) Main scale reading = 0.00 cm

Vernier scale reading = 0.05 cm

Reading = **0.05 cm**

Exercise

What are the readings shown on the calipers in Fig. (a) and (b)?

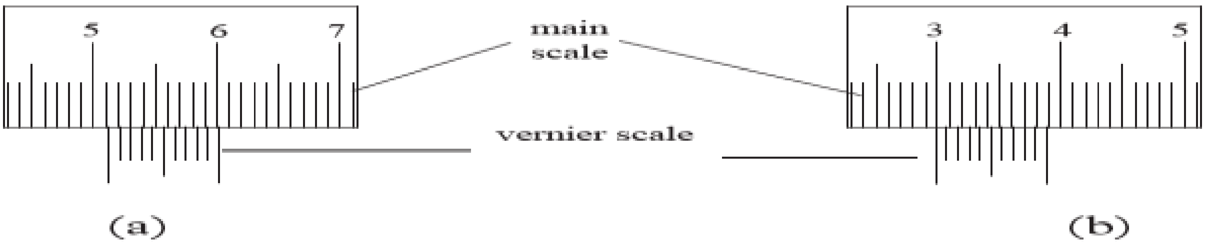


Fig.1.11 Vernier calliper reading

III. Measurement of the Length by using Micrometer screw gauge

- Topic 2: Measuring/calculation of the length using micrometer screw gauge

Activity

To observe the parts of micrometer screw gauge

Materials: a micrometer screw gauge

Steps

1. Look at the micrometer screw gauge provided
2. Observe its horizontal and rotating scales.
3. Observe its jaws and practice how to open and close them slightly,

A micrometer screw gauge is an instrument for measuring very short length such as the diameters of wires, thin rods, thickness of a paper etc. It was first made by an astronomer called ***William Gascoigne*** in the 17th century.

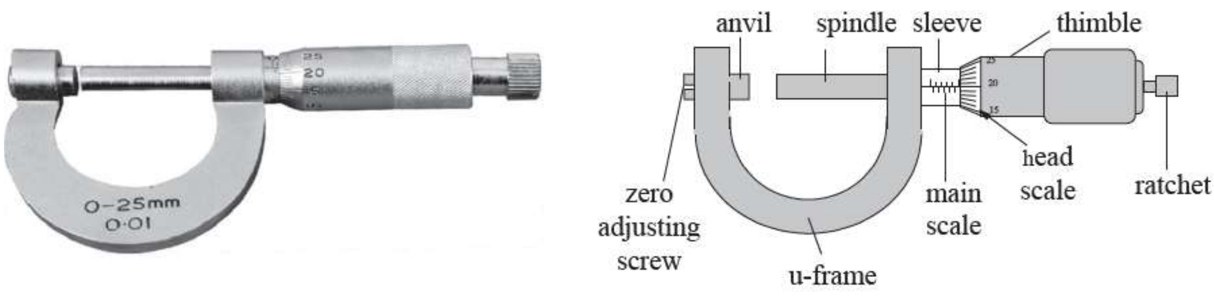


Fig.1.12: Micrometer screw gauge and its Parts

A micrometer screw gauge consists of the following:

- **U-frame** which holds an ***anvil*** at one end and **a *spindle*** at the other end.
- ***Sleeve***, which has a linear ***main scale (sleeve scale)*** marked in millimeters or halve millimeters.
- ***Thimble*,** which has a circular rotating scale that is calibrated from 0 to either 50 or 100 divisions.

This scale is called the ***head scale (thimble scale)*.** When the thimble is rotated, the spindle can move either forward or backwards.

- ***Ratchet*** which prevents the operator from exerting too much pressure on the object to be measured.
- ***Zero adjusting screw*** that is used to clear zero errors.

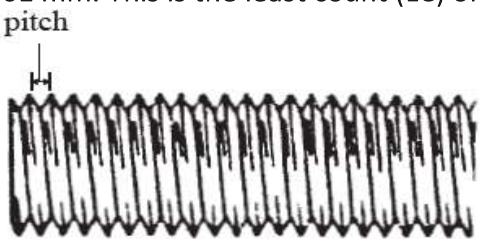
Reading a micrometer screw gauge
How to use and determine the reading on the micrometer screw gauge
Activity
To analyze the scale on micrometer screw gauge

Materials: a micrometer screw gauge
Steps

1. Take a micrometer screw gauge given to you and observe its sleeve and thimble scales.
2. Now, take a keen look on a thimble scale. How many divisions are between 0 and 100? or 0 and 50?
3. Discuss in your group how to find the value represented by each division?

The movement of the thimble is controlled by a screw of known **pitch** as shown in Fig above .

There are two common types of pitches on the thimble namely: 1 mm and 0.5 mm.
When the pitch is 1 mm, the thimble has 100 divisions called ***head scale divisions*.** In this case each division represents 0.01 mm. This is the least count (LC) of this screw gauge.



$$LC = \frac{1\ \text{mm}}{100} = 0.01\ \text{mm}.$$

Fig.1.13: the pitch of a thimble.

Similarly, if the pitch is 0.5 mm the thimble has 50 division. Each divisions represents 0.01 mm, i.e.

$$LC = \frac{0.5\ mm}{50} = 0.01\ mm$$

The thimble reading called ***the head scale coincidence*** **(HSC)** is the value of the mark on the thimble that coincides with the horizontal line on the sleeve. Main scale reading is taken by considering the reading of a mark on the fixed scale that is immediately before the sleeve enters the rim of the head scale.
The linear main scale on the sleeve is calibrated in millimeters or half millimeters. The micrometer screw gauge is operated by turning the thimble until the object whose measurement is required just touches the anvil and the spindle.
The ratchet is then rotated to press the object gently between the anvil and the spindle. When the correct pressure has been exerted on the object, a clicking noise is heard indicating that the reading can now be taken. See Fig. below

Fig.1.14: Thimble divisions.

In Fig. (a), the least count = 0.01 mm.

The micrometer screw gauge reading

= MSR + (HSC × LC)

= 4.0 m + (80 × 0.01) mm

= **4.80 mm.**

In Fig. (b), LC = 0.01 mm.

The micrometer screw gauge reading

= MSR + (HSC × LC)

= 4.5 + (30 × 0.01) mm

= **4.80 mm.**

Example 1

A micrometer screw gauge has a thimble scale with 100 divisions and screw pitch of 1.00 mm. Find the length of one division (least count) on the thimble scale.

Solution

100 divisions have a length of 1.00 mm

∴1 division has a length of

$$\frac{1.00\ mm}{100}$$

Activity

To determine the diameter of a ball bearing using a micrometer screw gauge

Materials: a ball bearing, micrometer screw gauge

Steps

1. Clean the faces of the spindle and the anvil to remove any dirt.
2. Close the gap between the anvil and the spindle to check for zero error. In case of any error, remove it by rotating the zero adjustment screw clockwise or anticlockwise as the case may demand. Alternatively you may note the error as a negative or a positive value and add it to or subtract it from the final reading accordingly.
3. Turn the spindle to open a suitable gap for holding the ball bearing in between the anvil and the spindle.
4. Close the spindle to the correct tightness (see figure below).
5. Take the readings on the main scale and the thimble scale and record them down in your exercise book.

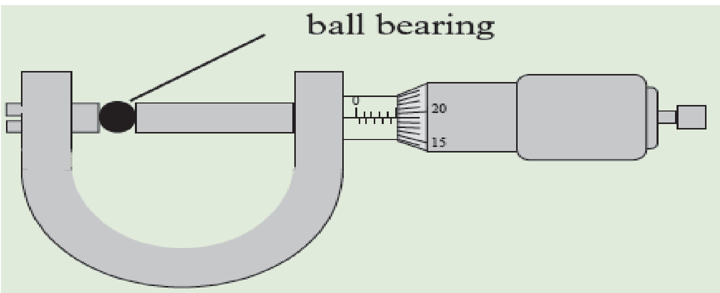


Fig.1.15: Using a micrometer screw gauge

6. Repeat the activity by taking two more measurements. Obtain the average value.

7. Multiply the thimble scale reading by 0.01 mm.
8. Add the main scale reading (in mm) and the thimble scale reading (in mm) to get the diameter of the ball bearing.

Example

What is the diameter of the ball bearing shown in Fig. below

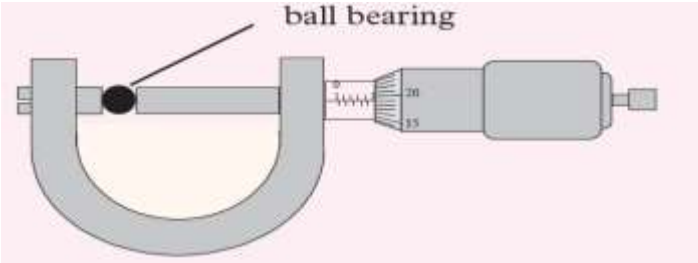


Fig.1.16: Determining diameter of a ball bearing

Solution

Main scale reading = 5.0 mm

Head scale coincidence = 19 divisions

Head scale reading = 19 × 0.01 = 0.19 mm

Full reading = 5.0 + 0.19 = 5.19 mm

The diameter of the ball bearing is 5.19 mm

Exercises

1. State the value of the readings shown by the micrometer screw gauges in Fig (a) and (b)

Fig.1.17: micrometer screw gauges reading

2. Draw a micrometer screw gauge showing the following reading if the screw pitch is 0.5 mm.
   (a) 18.56 mm (b) 2.36 mm (c) 5.72 mm
3. Repeat Question 2 above for a micrometer screw gauge of pitch 1 mm.

1.4.2: Measurement of time and area/surface

- Topic 3: Measuring/determining the time and area

  1. **Measurement of time**

Activity

To describe the concept of time

Materials: stopwatch, playing ground

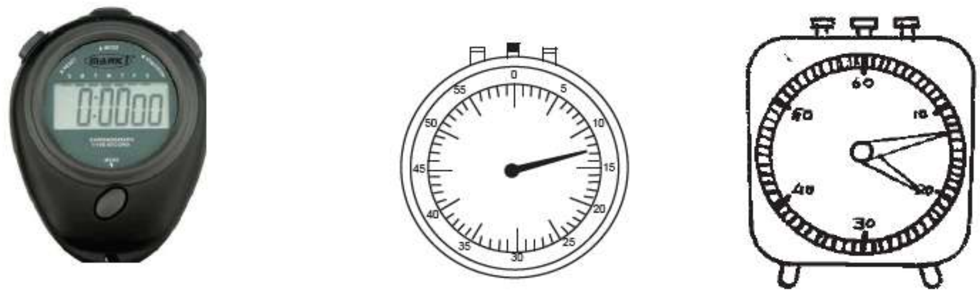
Steps

1. Ask your partner to run from one end of the field to the other as you time the event.
2. Let him/her also time as you ran the same distance. Compare the times you took. Who took the shortest time? Explain.
3. Discuss with your partner what you think time is, its SI unit, symbol and how to use the stopwatch.

From the above Activity, you should have established that time is a measure of duration taken by an event. The SI unit of time is the **second** and its symbol is ***s***

Stopclocks and watches

All living things have an inbuilt biological clock which seems to control the rhythm of their life cycle. For example, the cock will crow only at specific time intervals. Regardless of where we are located or what we are doing, we are always aware of the idea of passage of time. This passage of time is noticed in many ways, for example by the heartbeat, the sun, seasons, etc. The measurement of time is based on rhythm.
Time is measured using either analogue or digital watches and clocks (Fig. below). Analogue watches and clocks (Fig. (b) and (c)) are controlled by oscillations of a balance wheel and hairspring or electrical oscillations of a quartz crystal.



(a) A digital stopwatch (b) a stopwatch (c) a stop clock

Fig.1.18: Stop watches and a stop clock

Table1.8: Units of time and their relationships with the seconds.

Unit	Symbol	Comparison with SI unit
1 hour	h	3 600 s
1 minute	min	60 s
1 second	s	1 s
1 millisecond	ms	0.001 s
1 microsecond	µs	0.000 001 s

Example

How many seconds are there in 1 week?

Solution

1 week = 7 days
1 day = 24 h
1 week = 7 × 24 ×60 × 60
= 604 800 s
1 h = 60 min
1 min = 60 s

Digital stopwatch can measure very small time intervals. It can display, hours, minutes, seconds and milliseconds.

Using a digital stopwatch

Timing the reading of words
Activity
To measure and record the time taken to read words
Materials: stopwatch

Steps

1. Start the stopwatch and time how long it takes your partner to read a certain sentence e.g.
- Stop environmental pollution!
- Our environment is our livelihood!
- HIV/AIDS is incurable!
- Avoid unprotected sex!
2. Stop the watch, reset and repeat the activity about four times. Find your average time for reading the sentence.

You should have observed that the longer the sentence, the longer the time taken to read it. The average time for reading a sentence is more accurate than each individuals time recorded for the same event.

Activity
To time the heart beat
Materials: stopwatch

1. Place your palm on the side of your chest and feel your heartbeat.
2. Start the stopwatch.
3. By feeling and counting your heartbeats, determine the number (n) of heartbeat in 60 s.
4. Determine the time interval between your two heartbeats as 60 / n .

When breathing normally, you should obtain 72 heart beats in one minute (60s). Hence the interval between your two heart beat should be 60 s / 72 = 0.833 s.

Example

The heart of an obese student was beating at 85 beats per minute. Find the time interval for one beat. What can you advice the person (Hint: the normal heartbeat rate is 72 beats per minute).

Solution

85 beats takes 60 seconds

1 beat will take?

$1 \times 60\ s / 85 = 0.706\ s$

The time for one heartbeat is 0.706 s. The person should visit a doctor for checkup.

Exercises

1. Define the term time and state its SI unit.
2. A wheel of a car rotating uniformly makes 400 revolutions in one minute.
3. Describe an experiment to measure the time interval for one heartbeat

How long will the wheel take to make one revolution?

2. Measurement of area

Activity

To define area and its unit of measurement.

Materials: a ruler, a square solid, a rectangular solid

Steps

1. Measure the lengths and widths of the square and rectangular solids and record down their measurements.
2. For each item, multiply the two dimensions measured in step 1. What value do you obtain?
3. Discuss in your group, what area is and its SI unit.
4. Discuss how to determine the areas of regular and irregular solids.

In your discussion, you should have learnt that **area is the measure of the extent of a surface**. The ***SI unit*** of area is ***square meter (m^2)***. Area is a derived quantity.

Table 1.9: Unit of area, its symbol and its relationship with the SI unit of area (m^2).

Unit	Symbol	Comparison with m^2
1 square kilometre	km^2	1 000 000 m^2
1 square metre	m^2	1m^2
1 square centimetre	cm^2	0.000 1 m^2
1 square millimetre	mm^2	0.000 001 m^2

Examples

1. Convert 97.5 mm^2 into m^2

Solution

1 000 000 mm2 =1 m2

$$97.5\ mm^2 = \frac{97.5\ \times 1}{1000000}$$

= **0.0000975 or 9.75 ×10^{-5} m^2**

2. Convert 100 cm^2 into m^2

Solution

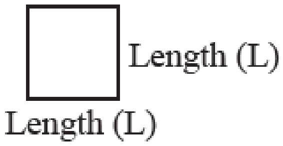
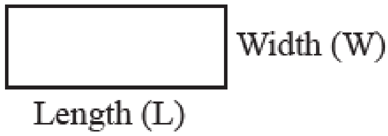
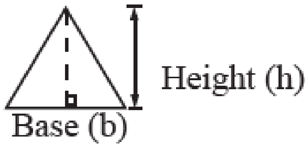
1 m^2 = 10 000 cm^2

$$100\ cm^2 = \frac{100}{10000} = \frac{1}{100} = 0.01\ m^2$$

Area of regularly shaped objects

The area of regularly shaped objects may be obtained by measuring the relevant dimension(s) and then applying the appropriate formula.

Table1.10: Some formulas used in the measurement of area.

Name	Shape	Formula (Area)
Square		$A = L \times L$
Rectangle		$A = L \times W$
Triangle		$A = \frac{1}{2}(b \times h)$
Circle		$A = \pi r^2$

Examples:

The dimensions of the top of a small coffee table are 40 cm by 30 cm. Calculate the area of the top of the table in (a) m^2 (b) mm^2

Solution

(a) Area $= L \times W$ or $A = 40\text{ cm} \times 30\text{ cm}$

$= 40\text{ cm} \times 30\text{ cm}$

$= 1\,200\text{ cm}^2$ $\quad = \frac{40}{100}\text{ m} \times \frac{30}{100}\text{ m}$

$\therefore A = \frac{1200}{10\,000} = 0.12\text{ m}^2$ $\quad = 0.12\text{ m}^2$

(b) Area $= L \times W$ or $A = 40\text{ cm} \times 30\text{ cm}$

$= 40\text{ cm} \times 30\text{ cm}$ $\quad = (40 \times 10)\text{ mm} \times (30 \times 10)\text{ mm}$

$= 1\,200\text{ cm}^2$ $\quad = 400 \times 300\text{ mm}^2$

$= 1\,200 \times 100\text{ mm}^2$ $\quad = 120\,000\text{ mm}^2$

$= 120\,000\text{ mm}^2$

Exercises

1. A cylinder has a diameter of 4.2 cm. How many times would a thread of 132 cm be wound around the cylinder?
2. A page of a book measures 14.5 cm × 21.4 cm. What is its area in square millimeters?
3. The diameter of a cylindrical pencil is 9 mm. Calculate the cross-sectional area in square centimeters.

1.4.3: Measurement of volume

- Topic 4: Measuring/determining the volume of some regular and irregular shapes and the volume of liquids

Activity

To define volume and state its SI units

Materials: beaker, water

Steps

- Discuss with your members what volume is and its SI units. What are the other smaller and larger units that are used to measure volume?
- Now, pour water into the beaker and read the level of water. What does the reading represent? Explain.

From the above Activity, you should have established that Volume is the amount of space occupied by a substance. The reading obtained when water is poured in the beaker represents the volume of water. The SI unit of volume is ***cubic meters (m^3).*** Like area, volume is also a derived quantity.

Table1.11: The SI unit of volume and its relationship with other units of volume and capacity.

Unit	Symbol	Comparison with m^3
1 cubic kilometres	km^3	1000 000 000 m^3
1 cubic metres	m^3	1 m^3
1 cubic centimetres	cm^3	0.000 001 m^3
1 litre	*l*	0.001 m^3
1 millilitre	ml	0.000 001 m^3

Example

A car uses 1 liter of petrol to cover a distance of 13 km. How long, in meters, would such a car cover with 30 cm^3 of petrol?

Solution

1 liter = 1 000 cm^3

1 km = 1 000 m

13 km = 13 000 m

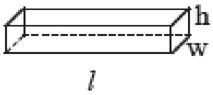
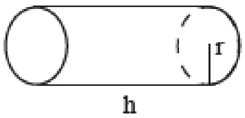
1 000 cm^3 covers 13 000 m

With 30 cm3, it would cover 13 000 × 30/ 1 000 = 390 m

a) Volume of regular shaped solids

The volume of a regularly shaped solid may be determined by measuring the required dimensions and then applying the appropriate formula.

Table1.12: some solids and the formulae to find their volumes

Name	Shape	Formula
Cuboid		$V = l \times w \times h$
Sphere		$V = \frac{4}{3}\pi r^3$
Cylinder		$V = \pi r^2 h$

b) Volume of liquids

Activity

To calculate a volume of a liquid in a container

Materials: rectangular container, a cylindrical container, water

Steps

1. Pour some water into a rectangular container as shown in Fig. below (a). Measure length, *l* breadth, *b* and height, *h* and calculate the volume of liquid inside the container.
2. Repeat the activity using the same amount of the liquid with a cylindrical container as shown in Fig. below (b).

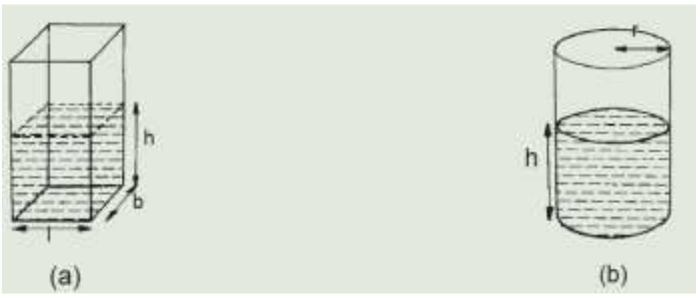


Fig.1.19: volume of liquid in container

3. Measure the radius *r* and the height *h* then determine the volume of the liquid using the appropriate formulas.
4. Compare the two volumes to see if they are the same.

From Activity here above, you should have established that the volume of water in a rectangular container is equal to the cylindrical container i.e

$$V = l \times b \times h = \pi r^2 h$$

Instruments for measuring volume of liquids
Activity
To identify instruments for measuring volume
Materials: measuring cylinder, burette, pipette, reference books, internet

1. Identify the unit marked on each instrument
2. Discuss with your group members how you would use each instrument to measure volume of liquid.
3. Now, take each instrument provided at a time and study their scales carefully.

From the above Activity, you should have discovered that instruments for measuring volume include measuring cylinders, burettes and pipettes. These instruments are already calibrated (marked) in the units of volume (cubic centimeters, cm^3) or capacity (milliliters, m*l*).

i. **Measuring cylinder**

Measuring cylinders hold different volumes or capacities. They have a scale marked either in cm3 or m*l*. (1 cm3 = 1 m*l*). They measure the contained column of the liquid. It is for this reason that they are graduated from zero upwards.

How to use a measuring cylinder

Pour some coloured water into a measuring cylinder. Observe the shape of the liquid surface. Sketch the shape of the liquid surface. What do you notice? You will notice that the liquid surface is curved. The curved liquid surface is called ***meniscus***. Read the level of the bottom of the meniscus with your eyes at the horizontal level (Fig. below).

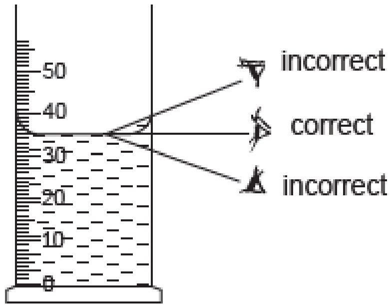


Fig.1.20: How to use a measuring cylinder

ii. **Burette**

A burette consists of a long graduated glass tube fitted with a tap which opens and closes easily. Burettes are mostly used when a known volume of a liquid is to be run off. The scale is graduated in cm3 or m*l* and runs from zero downwards since the volume required is run off from the bottom (Fig. below).

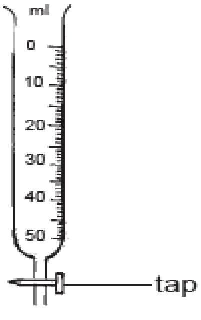


Fig.1.21: A burette

How to use a burette

- ✓ Pour a liquid into the burette with the help of a funnel.
- ✓ Make sure that the level goes well beyond the zero.
- ✓ Open the tap and allow the level to come to the zero mark. (This is to ensure that even the lower part of the tap is filled with the liquid).
- ✓ Run off the required volume of the liquid by opening the tap.

iii. **Pipette**

Pipette like a burette, it is used to run off known volume of a liquid. There are two types of pipettes commonly used in school laboratories. They are: ***graduated pipette*** **and** ***one mark pipette*** (Fig. below).

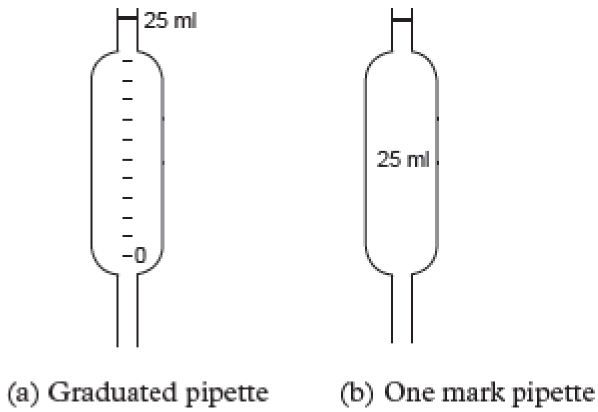


Fig.1.22: Types of pipettes

The graduated pipette can deliver various amounts of known volumes of a liquid. The one mark pipette delivers only one known volume of a liquid, e.g. 25 m*l* for a 25 m*l* pipette.

How to use a one mark pipette

- ➢ Dip a 25 m*l* pipette in a beaker containing clean water.
- ➢ Suck in the water to a level above the mark.
- ➢ Close the mouth of the pipette with your thumb and slowly allow the liquid level to drop to the one mark.
- ➢ Run off the liquid into a measuring cylinder.
- ➢ Compare the volume delivered by the pipette and the volume read from the measuring cylinder.
- ➢ The two volumes should be the same.

c) Volume of solids by displacement method

Activity

To determine the volume of a regularly shaped solid using a measuring cylinder

Materials: meter rule, marble, measuring cylinder, water

Steps

1. Measure the diameter *r* of the marble using a meter rule and calculate its volume V1 using the formula

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

2. Partly fill a measuring cylinder with water and record the initial volume of the water V1. Carefully lower the marble into the water in the measuring cylinder (see Fig. below). Record the new volume of the water V2.

3. Find the volume of the water displaced, (V2 – V1). Compare this volume with the volume of the marble calculated using the formula.

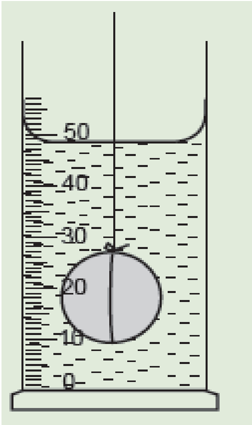


Fig.1.23: Volume by displacement method

You will notice that:

The volume of the displaced water = volume of the marble.

The activity shows that solids displace their own volume of the liquid. The method of finding the volume of a solid by displacing a liquid is called *displacement method*.

Activity

To determine the volume of an irregularly shaped solid using a Eureka can

Materials: Eureka can, irregular stone, water, measuring cylinder

Steps

1. Fill a Eureka can with water until some of it over flows through the spout.
2. Once the overflow stops, put the measuring cylinder at the mouth of the spout.
3. Tie the irregular solid with a string and lower the solid carefully into the can. Make sure the solid is completely immersed.
4. Collect and measure the volume of the water displaced (Fig. below).

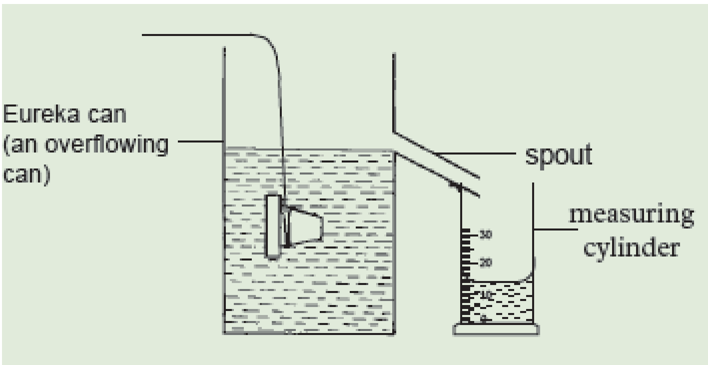


Fig.1.24: Measuring volume using a Eureka can

Then the volume of the solid is equal to the volume of the water displaced.

Exercices

1. Define volume and state its SI unit.
2. A tank full of a liquid has a volume of 0.6 m^3. Find the volume of the tank in:
   (a) litres **(b)** cm^3 **(c)** m*l*
3. A metal block measures 5 cm by 4 cm by 10 cm. Calculate:
   (a) The volume of the block.
   (b) The number of blocks each measuring 2 cm by 1 cm by 5 cm that have the same volume as that of the metal block.
4. A beaker of radius 5 cm contains water to a height of 10 cm.
   (a) What is the volume of the water in the beaker?
   (b) When a stone is completely immersed in the beaker, water rises to a height of 19 cm. What is the volume of the stone?

1.4.5: Measurement of mass

- Topic 5: Measuring the mass

1. **Instruments used for measuring mass**

✓ Beam balance
✓ Spring balance
✓ Electronic balance

Activity

To compare masses using non-standard measures

Materials: a brick, a jug full of water

Steps

1. By lifting a brick and a jug full of water each at a time, determine which is heavier.
2. Let your group member repeat the activity.
3. Compare your findings. Did all of you make the same judgment on which is heavier?
4. What is the disadvantage of using such a method to measure mass?
5. What would be the remedy?

From the above Activity , you must have noted that, one cannot be accurate when determining how heavy an object is using non standard measures like hands. This calls for the need to use a standard measure. Mass is the amount of matter in a substance. Its SI unit is ***kilogram (kg).*** The standard kilogram is the mass of a block of platinum iridium alloy kept at the office of weights and measures in Paris. Other masses are measured by comparing them directly or indirectly with this mass.

Table1.13: Relationship between the SI unit of mass (kg) and other larger and smaller units of mass.

Unit	Symbol	Comparison with kg
1 tonne	t	1 000 kg
1 kilogram	kg	1 kg
1 gram	g	0.001 kg
1 milligram	mg	0.000 001 kg

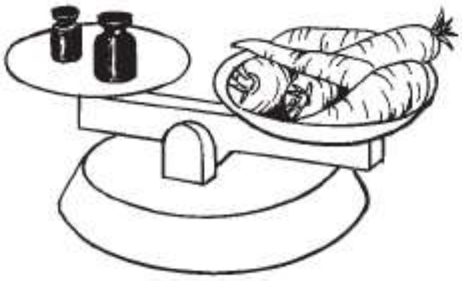
Example
Convert 39.6 mg into kilograms
Solution

$$1\text{ mg} = \frac{1}{1000}\text{ g} = \frac{1}{1\,000\,000}\text{ kg}$$

$$\text{Therefore, } 39.6\text{ mg} = \left(\frac{1}{1\,000\,000} \times 39.6\right)\text{ kg}$$

$$= 0.000\,039\,6\text{ kg}$$

There are many kinds of balances used for measuring mass (Fig. below).



a) beam balance (b) traditional pan balance (c) electronic balance

Fig.1.25: Different types of balances

i. Beam balance

In the laboratory, the mass of an object can be measured using a ***beam balance*** and a set of standard masses (Fig. below).

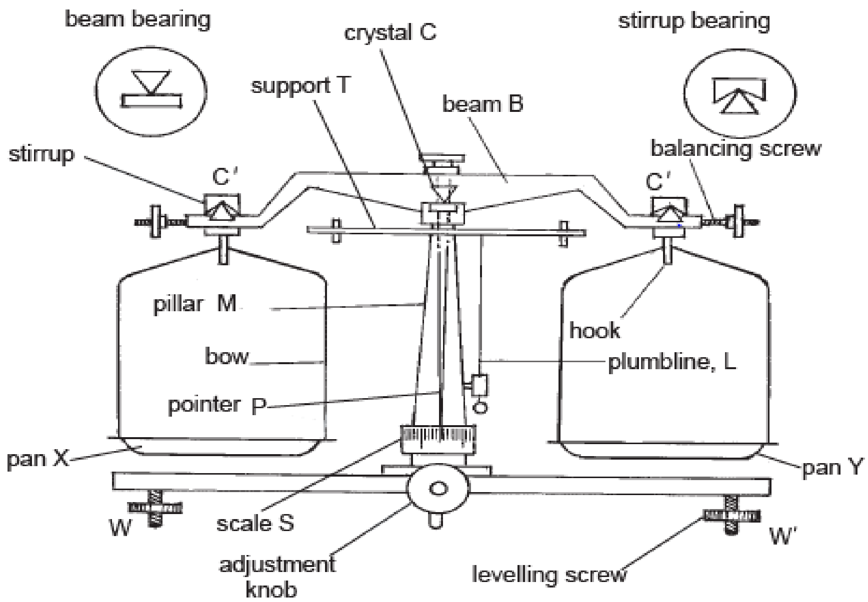


Fig.1.26: A beam balance

The beam balance has an arm B and two containers (X and Y). The first container holds the load while the other container holds the metal that has a fixed weight. The beam is zeroed before using. This involves making sure that the pointer P is at the middle of the scale S and the plumbline L is just touching pillar M. This is done by adjusting the screws W and W' respectively. When the beam balances, the masses on the scale-pans are equal. The mass to be measured is placed on one scale-pan which is then balanced by using known or standard masses on the other scale pan. After weighing, the beam is gently lowered so that it rests on the support T, which takes the load off the delicate wedges.

Table1.14: Difference between mass and weight

Mass	Weight
Quantity of matter in a body.	Pull of gravity on a body.
SI unit is kilogram (kg).	SI unit is newton (N).
Constant everywhere.	Changes from place to place.
Scalar quantity.	Vector quantity.
Measured using a beam balance.	Measured using a spring balance.

ii. Spring balance

The ***spring balance*** is a device used to measure *weight*, i.e. the downward force exerted by a mass undergoing acceleration due to gravity. As the name suggests, the main component of a spring balance is a spring. In a traditional style spring balance (see the illustration below), the spring is mounted in a frame. One end of the spring is fixed to the top of the frame. A hook located below the frame is attached to the other end of the spring. A ring or a second hook at the top of the assembly allows it to be hung from a suitable fixed point (typically an overhead beam or metal framework). The item to be weighed is then suspended below the balance using the hook, which causes the spring to be stretched. The amount by which the spring is stretched will depend upon the weight of the item.

Fig. 1.27: a spring balance

A pointer attached to the spring moves up and down in the centre of the frame as the spring stretches and contracts. Each side of the frame is marked with a graduated scale. Typically, the graduations on one side denote *weight* (in *Newtons* or *pounds-force*), while those on the other side denote *mass* (in *grams* or *kilograms*).

When no load is attached to the scale, the spring is at rest and the pointer should align with zero. Once a load is added, the spring will stretch by an amount that is proportional to the applied force, and the pointer will move downwards. The force (i.e. the weight of the load) and the mass corresponding to it can be determined by reading the graduated scale on each side of the frame at the position where the pointer comes to rest.

According to Hooke's law, the force ***F*** (in Newtons) exerted on a spring by stretching it is the product of the distance ***X*** (in metres) by which the spring is extended beyond its normal length (i.e. the length of the spring when no force is acting upon it) and a constant value ***k*** called the *spring constant*. Hooke's law can be stated algebraically as:

$$F = kX$$

The value of the spring constant will depend on the spring.

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

Although a spring balance is primarily intended for measuring force (i.e. weight), it may be possible to calibrate it to accurately measure mass in a known location (using the local value of gravitational acceleration). Whether measuring mass or weight, however, there are a couple of things that should be noted when using a spring balance. First of all, the spring will have a tendency to "bounce" to a greater or lesser degree, depending on its spring constant (which is essentially a measure of how stiff the spring is). This means that when a load is first added to the spring balance, the pointer will oscillate around its final position for a brief time before coming to rest. The scale should not be read until the pointer has settled down.

The second thing to realise is that the elasticity of the spring can change. It can vary slightly with temperature, for example. Most spring balance manufacturers stipulate that accuracy is only guaranteed within a specified temperature range. More importantly, the spring may be stretched over time due to repeated use, or more quickly if excessive force is applied to it. This will lead to incorrect results being obtained, so the spring balance should be periodically tested using known weights. In some cases, it may be possible to recalibrate the balance.

We have already said that mass and weight are two different things. Weight is the *force* exerted on an object by a gravitational field. We can think of the weight ***W*** of an object as a downwards-acting *force vector*, the magnitude of which is a *scalar* (one-dimensional) quantity. The vector in this case has two components, one being the mass ***m*** of the object, and the other being the magnitude of the local gravitational acceleration ***a***. In order to find the weight of an object, we can use Newton's second law of motion, which describes the relationship between the *mass* of an object and the *force* required to *accelerate* it. This essentially states that the force ***F*** acting on an object is equal to its mass *m* multiplied by its acceleration ***a***. In algebraic terms, this is expressed as:

$$F = ma$$

Since the force we are interested in here is the weight of an object, we can rewrite this as:

$$W = m.g$$

What we really want to know is the mass ***m*** of an object, **g** is the acceleration due to gravity, so we will rearrange this:

$$m = \frac{W}{g}$$

Sometimes, we don't actually need to weigh something to find its mass. If we know the density *ρ* and volume *V* of a material, for example, we can calculate its mass *m* using the following formula:

$$m = \rho V$$

- Topic 6: Measuring/Calculation of density and pressure

1.4.6: Calculation of density

Definition of density
Activity
You were introduced to density in Primary 5.

1. Remind your partner the meaning of density.
2. Discuss with your partner the SI units of density based on the definition.

Density is defined as **mass per unit volume**. From the definition, the formula for calculating density is as follows:

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

The derived SI unit for density is kilogram per cubic meter, kg/m^3, also written as kg/m^3. Density may also be measured in grams per cubic centimeter,
g/cm^3, or g/cm^3. The relationship 1 000 kg/m^3 = 1 g/cm^3 is used for conversion of units of density.
The symbol for density is the Greek letter ρ read as Rho, while mass and volume are abbreviated (m) and (V) respectively. Using these symbols, the formula for density is ρ = $\frac{M}{V}$

Table 1.16: Different substances have different densities

Substance	Density in kg/m^3	Density in g/cm^3	Substance	Density in kg/m^3	Density in g/cm^3
Aluminum	2 700	2.70	Sand (varies)	2 600	2.60
Brass (varies)	8 500	8.50	Steel (varies)	7 800	7.8
Copper	8 930	8.93	White spirit	850	0.85
Glass (varies)	2 600	2.60	Zinc	7 100	7.10
Gold	19 300	19.3	Iron	7 500	7.50
Ice (at 0°c)	920	0.92	Invar	8 000	8.00
Lead	11 300	11.3	Cork	180	0.18
Mercury	13 600	13.6	Air	1.293	0.001 293
Methylated spirit	800	0.80	Hydrogen	0.899	0.000 089 9
Platinum	21 500	21.50	Pure water	1000	1.0

Example1
An object of volume 0.004 23 m3 has mass 36 kg. Determine its density in kg/m^3.
From table 1.18, identify the substance from which the object is made.

Solution
(a) ρ = m/V
= 36 kg/ 0.00432 m3 = 8 510.6 kg/m3.

(b) The object is made from brass.

Example2
The density of mercury is 13.6 g/cm^3. What volume will have a mass of 200 g.

Solution
ρ = 13.6 g/cm^3
m = 200 g

We know that ρ= mV therefore $V = \frac{m}{\rho} = \frac{200}{13.6}$ = **14.7 cm^3**

Example3

What mass of gold has a volume of 2.5 cm^3? (Take the density of gold as 19.3 g/cm^3).

Solution

Density of gold = 19.3 g/cm^3, Volume (V) = 2.5 cm^3

$\rho = m/V \Rightarrow m = \rho \times V$

$= 19.3 \times 2.5$

= 48.25 g

If the density of an object is greater than the density of water, the object sinks in the water. For example, a stone is denser than water.

If density of an object is less than the density of a liquid, the object floats in the liquid.

A piece of cork is less dense than water; the cork floats on water.

Exercices

1. What is the mass of air in a room measuring 5 m × 10 m × 10 m? (Take the density of air to be 1.293 kg/m^3).
2. An aquarium measuring 1 m by 0.8 m by 0.5 m is filled with water of density 1 000 kg/m^3. Calculate the mass of water contained in the aquarium.
3. The volume of methylated spirit is 0.8 g/cm^3. Calculate the volume of 20 grams of the liquid.
4. The following figure shows alongside shows an irregular object of mass 56 g immersed in water. Given that the volume of water in the measuring cylinder was 10.0 cm^3, calculate the density of the object in g/cm^3.

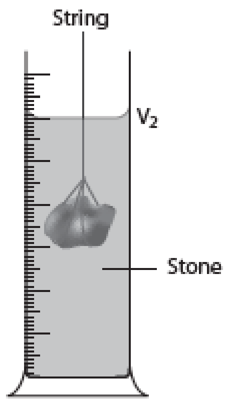


Fig.1.28 : Volume of irregular object

1.4.7: Measurement of Pressure

i. Definition and units of pressure

Pressure (symbol "*p*") is the force acting normally per unit area applied in a direction perpendicular to the surface of an object. **Gauge pressure** is the pressure relative to the local atmospheric or ambient pressure. The pressure is directly proportional of force and proportional of square area.

In mathematical terms, pressure can be expressed as:

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

The pressure within a fluid (gas or liquid) is a scalar quantity—that is, it has magnitude but no particular direction associated with it in space.

Pressure arises from two fundamentally different kinds of sources: **ambient** and **localized**.

1. **Ambient sources of pressure** are usually a gas or a liquid in which an entity is immersed, such as a human being on the surface of the earth or a fish in a stream or lake. Life forms are generally insensitive to ambient pressures and become aware of the source of that pressure when currents become strong enough that the fluid exerts a non-uniform localized pressure on the life form, such as when the wind blows.
2. **Localised pressure** sources are usually discrete objects, such as the finger pressing on the wall, or the tyres of a car pressed against the pavement. A liquid or gas can become the source of a localized pressure if either of them is forced through a narrow opening.

ii. Unit of pressure

The unit is the **pascal** and is named after Blaise Pascal, the eminent French mathematician, physicist, and philosopher noted for his experiments with a barometer, an instrument to measure air pressure.

The name Pascal was adopted for the SI unit Newton per square meter in 1971.

The **Pascal** (symbol: **Pa**) is the SI derived unit of pressure. It is a measure of force per unit area, equivalent to **l Pa ≡ 1 N/m2 ≡ 1 kg/(m·s**^{2}**).**

The Pascal is perhaps best known from meteorological barometric pressure reports, where it occurs in the form of **hectopascals** or **millibar**(**1*hPa* ≡ 100 *Pa* ≡ 1 *mbar***). ***barye ≡ 1 µbar = 1 dyn/cm***^{2}

The standard atmosphere (atm) of pressure is approximately equal to air pressure on earth above mean sea level and is defined as:

In 1985, the International Union of Pure and Applied Chemistry (IUPAC) recommended that standard atmospheric pressure should be harmonized to **100,000 Pa = 1 bar = 750 Torr**.

Another unit for pressure measurement is **millimeters of mercury**

(.**1 *mmHg* = 9.80669*Pa***)

We use a **manometer** to measure pressure in liquids and a **barometer** to measure air pressure.

iii. Static fluid pressure

The pressure exerted by a static fluid depends only upon the **depth of the fluid**, **the density of the fluid**, and the **acceleration of gravity**.

The pressure in a static fluid arises from the weight of the fluid and is given by the expression:

$P_{staticfluid} = \rho f \times g \times h$

Where ρ is the density of fluid; g is acceleration of gravity; and h is depth of fluid.

The pressure from the weight of a column of liquid of area A and height h is: Weight/Area

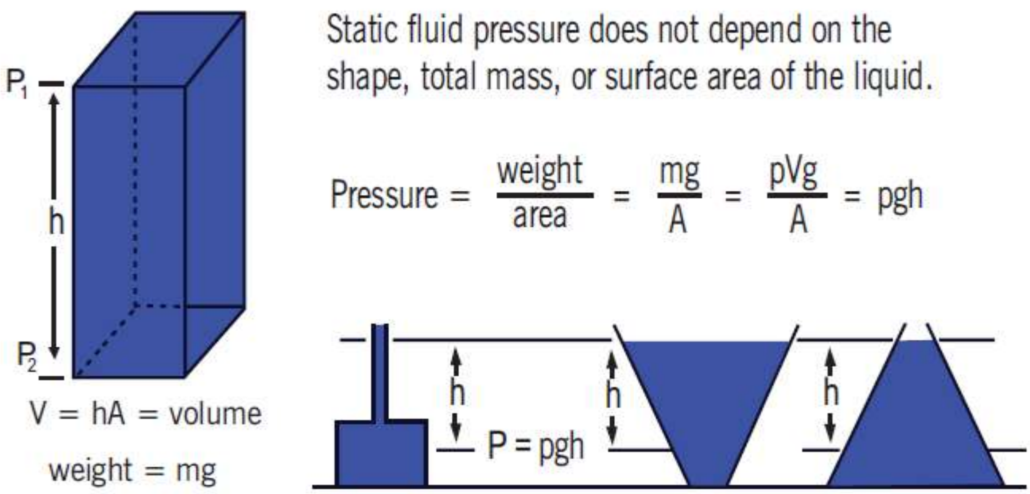


Fig. 1.29: Pressure in liquid

The most remarkable thing about this expression is what it does not include. The fluid pressure at a given depth does not depend upon the total mass or total volume of the liquid.

The above pressure expression is easy to understand for the straight, unobstructed column, but not obvious for the cases of different geometry which are shown.

Because of the ease of visualizing a column height of a known liquid, it has become common practice to state all kinds of pressures in column height units, like mmHg. Pressures are often measured by manometers in terms of a liquid column height.

Therefore Pressure at a depth h, ***P = ρgh***

iv. Atmospheric pressure

Measuring atmospheric pressure

The atmospheric pressure is the weight exerted by the overhead mass of air on a unit area of surface.

It can be measured with a mercury barometer, consisting of a long glass tube full of mercury inverted over a pool of mercury:

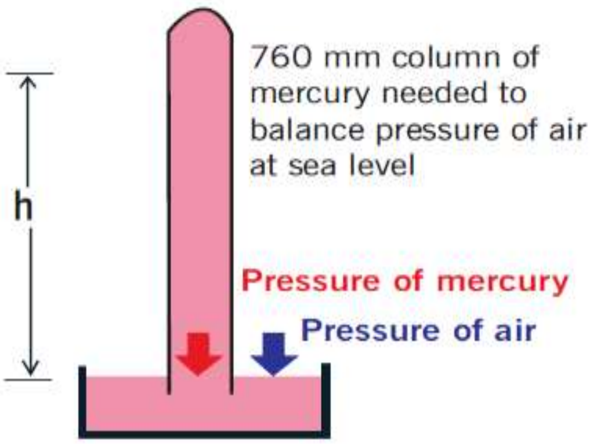


Fig. 1.30: Mercury barometer

When the tube is inverted over the pool, mercury flows out of the tube, creating a vacuum in the head space, and stabilizes at an equilibrium height, h over the surface of the pool. This equilibrium requires that the pressure exerted on the mercury at two points on the horizontal surface of the pool, (inside the tube) and (outside the tube), be equal.

The pressure at the point inside the tube is that of the mercury column overhead, while the pressure at that point is that of the atmosphere overhead. We obtain, from measurement of h,

P = eHg gh

Where $\rho Hg = 13.6\ gcm^{-3}$ is the density of mercury and $g = 9.8ms–2$ is the acceleration of gravity. The mean value of h measured at sea level is 76.0 cm, and the corresponding atmospheric pressure is 1.013 × 105 $kg\ m^{-1}\ S^{-2}$ in SI units.

The most commonly used pressure unit is the atmosphere (atm) ($1atm = 1.013 \times 10^5\ Pa$) the bar (b) ($1\ b = 1 \times 10^5\ Pa$), the millibar (mb) ($1\ mb = 100\ Pa$) and the torr. ($1\ torr = 1\ mm\ Hg = 134\ Pa$) The use of millibars is slowly giving way to the equivalent SI unit of hectoPascals.

The mean atmospheric pressure at sea level is given equivalently as; $P = 1.013 \times 10^5\ Pa = 1013hPa = 1013mb = 1\ atm = 760torr.$ R is the mean height of the atmosphere from the surface of earth.

Exercises

1. Which of the following equations is not correct?
   a) Force = mass x acceleration
   b) Density = $\frac{volume}{mass}$
   c) Pressure = density x acceleration x height
   d) Pressure = $\frac{Force}{Area}$

2. The static fluid pressure at any given depth depends on:

a) the total mass

b) the surface area

c) the distance below the surface

d) all of the above

3. A substance has mass of 3kg submitted by acceleration of $9m/s^2$.

a) Find the force in Newton.

b) What is the pressure of it on a square of 4m for a side?

4. (a) Define pressure and state its SI unit.

(b) Find the pressure in Pa of force, F = 45N and applied on a triangle of base of 5m and height of 3m.

5. Calculate the Pressure on the surface when a force of 30N acts on area of 0.2m2.

6. a) Define pressure and state the S.I unit in which pressure can be expressed.

b) A brick of mass 3kg measures 6cm by 4cm by 3cm.

(i) What is the greatest pressure it can exert when placed on a flat surface.

(ii) What is the least pressure it can exert?

7. A book of mass 500g is lying on a table. Its cover measures25cm by 29cm. What pressure does it exert on the table?

Learning Unit 2: Apply basic knowledge of kinematics and dynamics

Introduction

Mechanics: is the study of the action of forces on objects and motion. The knowledge of mechanics has led to development of many motion related objects including vehicles, planes, ships, trains etc, that have made our movement from one place to other faster and easier.

No matter what your interest in science or engineering, mechanics will be important for you - motion is a fundamental idea in all of science. Mechanics can be divided into 2 areas - kinematics, dealing with describing motions, and dynamics, dealing with the causes of motion

The Basic Mechanics textbook covers force and motion, work and energy, and fluid mechanics as applied in industrial maintenance. It explains principles of operation for simple machines, such as the lever, inclined plane, wheel and axle, pulley, and screw.

Learning Outcome 2.1: Characterize a body in motion

2.1.1: Uniform Rectilinear Motion

- Topic 1: Characteristize a body in motion in Uniform Rectilinear Motion

Activity

To identify different kinds of motion

Steps

1. Observe and describe to your partner the following types of motions of bodies in terms of direction (Fig. below).

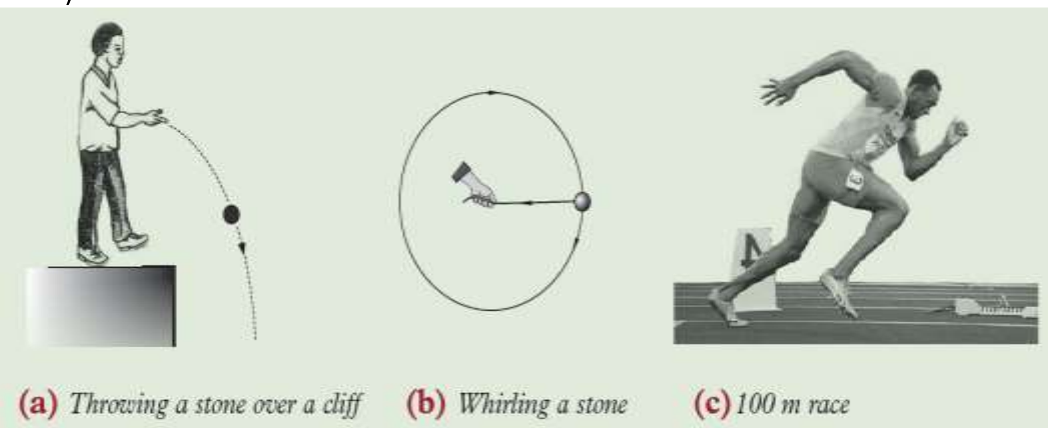


Fig 2.1: Different types of motion

2. Share your ideas in a class discussion on what linear motion is.
3. Involve your physics teacher to clarify your discussion.

In our daily lives, we come across various objects moving from one point to the other. The objects are said to be in motion. People, animals and machines are from time to time involved in motion in different directions. Motion in a straight line is called **linear motion**(see Fig. (c)) above

In this unit, we are going to study linear motion. We shall pay attention to the time taken, distance covered, speed, velocity and acceleration of the motion and their relationships.

There are two types of linear motion namely: uniform motion and non-uniform motion.

A. **Uniform motion**

When a body moves in a straight line, then we say that it is executing **linear motion**.

When a body moves in a straight line, then the linear motion is called **rectilinear motion**. This motion is also called **Uniform rectilinear motion** (velocity is constant means no acceleration)
In this unit, we are going to study linear motion. We shall pay attention to the time taken, distance covered, speed, velocity and acceleration of the motion and their relationships.

In this motion, the speed of the moving body remains the same or constant.
Difference between distance and displacement

a) Distance and displacement

Activity

To compare the lengths of a straight line and a curved one

Materials: playing ground, tape measure

Steps

1. Mark points A and B on the playing ground far way from each other.
2. Starting from point A, make full strides towards point B in a straight line. How many strides do you get?
3. Now, let your partner repeat step 2. Compare the number of your strides with those of your partner. Did you get the same number of strides? Explain.
4. Repeat the activity but this time taking any curved path from point A to B. Between the straight and the curved paths, which one is longer ?
5. Now, measure the total length from points A to B using a surveyor tape measure. What length do you get? What is the SI unit of length?
6. Discuss with your partner what distance and displacement are and their SI units.

In your discussion, you should have noted the following:

Distance

Distance is the total length of the path followed by an object, regardless of the direction of motion. It is a scalar quantity and measured in units of length. The SI unit of distance is the meter (m). Long distances may be measured in kilometers (km) while short distances may be measured in centimeters (cm) or millimeters (mm).

It should be noted that in determining the distance between two points, the direction at any point along the path is not considered. The direction along the path may keep on changing or remain constant (see the figure below) .

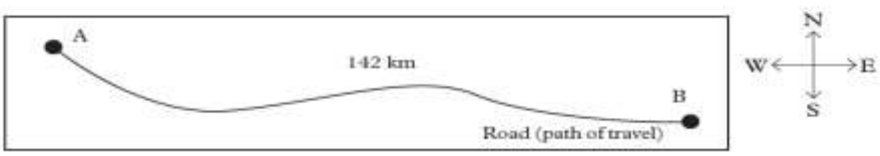
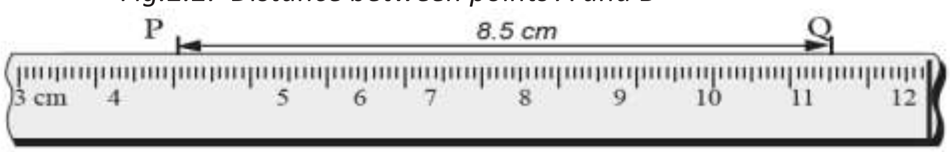


Fig.2.2: Distance between points A and B



Displacement

Displacement is the object's overall change in position from the starting to the end point. It is the shortest distance along a straight line between two points in the direction of motion. The *SI unit* of displacement is the ***meter*** **(m).**

To fully describe displacement, you need to specify how far you have travelled from where you started and in what direction you have travelled. For example, point A is 100 kilometres Northwest of point B. In diagrams, an arrowhead indicates the direction of motion .

Displacement is a **vector quantity.**

displacement = distance in a stated direction from a reference point

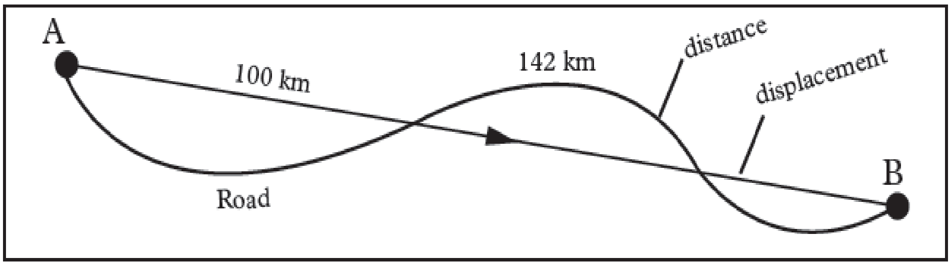


Fig.2.3: Displacement between points A and B is 100 km

A **trajector**y is the path /curve described by an object (projectile) moving through air or space under the influence of forces such as gravity, upthrust and weight.

Table 2.1: Difference between Distance and Displacement

Sr. no.	Distance	Displacement
01	Distance is the length of the path travelled by a body while moving from an initial position to a final position.	Displacement is the shortest distance between the initial position and the final position of the body.
02	Distance is a scalar quantity.	Displacement is a vector quantity.
03	Distance measured is always positive.	Displacement can be positive or negative depending on the reference point.
04	The total distance covered is equal to the algebraic sum of all the distances travelled in different directions.	The net displacement is the vector sum of the individual displacements in different directions.
05	There is always a distance covered whenever there is a motion.	Displacement will be zero if the body comes back to its initial position.
06	Unit: metre (m)	Unit: metre (m)

Difference between speed and velocity

The ***distance moved by a body per unit time is called speed.*** In this motion, direction is not considered. Thus,

Speed = $\frac{distance}{time} = \frac{x}{t}$

The SI unit of speed/velocity is meters per second (**m/s**). Other units of speed such as kilometers per hour (km/h) and centimeters per second (cm/s) are also in common use.

When a body covers equal distances in equal time intervals, it is said to move with ***uniform speed***.

Example1: What is the speed of a racing car in meters per second if the car covers 360 km in 2 hours?

Solution

$$\text{Speed} = \frac{\text{distance moved}}{\text{time taken}} = \frac{360 \text{ km}}{2 \text{ h}} = 180 \text{ km/h}$$

OR

$$\text{Speed} = \frac{\text{distance moved}}{\text{time taken}} = \frac{360 \times 1\,000 \text{ m}}{2 \times 3600} = 50 \text{ m/s}$$

Instantaneous speed

As you travel in a car or bus, you notice that the speedometer of the car keeps on showing different values of speed. The speed at any given instant in your journey is called instantaneous speed.

Average speed

Quite often, the speed a body moving between two points keep on varying. Such a body is said to be move with ***non-uniform* speed**. The equivalent constant speed that the body would move at to cover the same distance in the same time is called **average speed.**

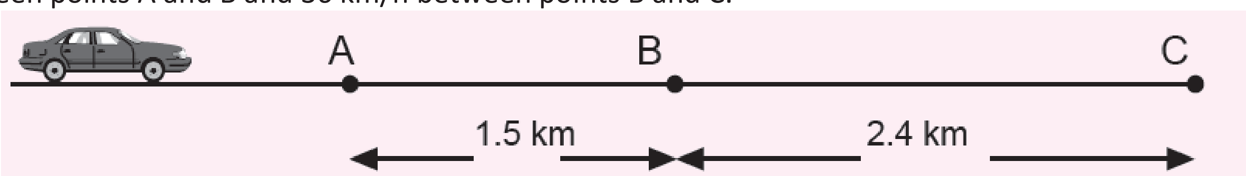
Average speed of a body is the total distance covered by the body over the total time taken i.e.
Average speed = Total distance moved/ Total time taken
Note:
Instantaneous speed of an object should not be confused with the average speed. We can use an example of a car travelling between two points A and B to differentiate the two. The average speed of a car is the total distance AB the car travels over the total time it takes to cover the distance whereas instantaneous speed is the varying speed shown by speedometer of the car at different instants along the distance AB.

Table 2.2: Difference between Speed and Velocity

Speed	**Velocity**
Speed is the distance covered by a body in unit time.	**Velocity** is the displacement covered by a body in a unit time.
It is a scalar quantity.	It is a vector quantity.
It Determines "How fast an object is moving"?	It determines "In which direction an object is moving"?
It indicates the rapidity of objects.	It indicates both the rapidity and position of the object.
It is the rate of change of distance.	It is a rate of change of displacement.
It cannot be negative.	The velocity of moving Objects can be negative, positive or can be zero.

Example 2

A car moving along a straight road ABC as shown in Fig. below maintains an average speed of 90 km/h between points A and B and 36 km/h between points B and C.



Calculate the:

(a) Total time taken in seconds by the car between points A and C.

(b) Average speed in meters per second of the car between points A and C.

Solution

(a) $$\text{Average speed} = \frac{\text{Total distance}}{\text{Time taken}}$$

$$\text{total time between A and B} = \frac{\text{Total distance}}{\text{Average speed}}$$

$$= \frac{1.5}{90}\text{ h} = \frac{1.5}{90} \times 60 \times 60\text{ s} = 60\text{ s}$$

$$\text{Total time between B and C} = \frac{2.4}{36} \times 60 \times 60\text{ s} = 240\text{ s}$$

$$\text{Total time between A and C} = 60\text{ s} + 240\text{ s} = 300\text{ s}$$

(b) $$\text{Average speed} = \frac{\text{Total distance}}{\text{Time taken}}$$

$$= \frac{(1.5 + 2.4) \times 1\,000\text{ m}}{300\text{ s}}$$

$$= 13\text{ m/s}$$

The speed of a body in a specified direction is called velocity or velocity is the rate of change of distance in a particular direction. Therefore,

Velocity = distance moved in a particular direction/ time taken

Velocity is also defined ***as the displacement covered per unit time*** or ***the rate of change of displacement.*** i.e.

$$\text{Velocity} = \frac{displacement}{time}$$

The SI unit of velocity is **meters per second (m/s).**

In some cases, the velocity of a moving body keeps on changing. In such cases, the average velocity of the body is considered.

Average velocity = total displacement/ time taken

When stating or describing the velocity of an object, the direction of velocity should always be indicated. In doing so, we state direction say north, south, upwards, downwards, etc. A negative sign in a value of velocity is commonly used to indicate movement in the reverse direction.

Note: Just as distance and displace despite their similarities, so do speed and velocity. For instance, if we say the car is travelling 50 km/h towards north of Kigali, then we are talking about velocity. Remember that the only aspect that differentiates speed and velocity is the component of direction.

When velocity in a particular direction is constant, the velocity is referred to as ***uniform velocity***.

Table2.3: Displacement of a car and the corresponding time taken.

Displacement (m)	0	4	8	12
Time taken (s)	0	2	4	6

The velocity after every two seconds is 2 m/s, hence velocity of the car is uniform.

Example 3

A car travelled from town A to town B 200 km east of A in 3 hours. It then changed direction and travelled a distance of 150 km due north from town B to town C in 2 hours.

Calculate the average:

(a) Speed for the whole journey.

(b) Velocity for the whole journey.

Solution

(a) Average speed $= \frac{\text{total distance}}{\text{time taken}} = \frac{(200 + 150)\text{ km}}{(3 + 2)\text{ h}}$

$= \frac{350}{5}\left(\frac{\text{km}}{\text{h}}\right)$

$= 70\text{ km/h}$

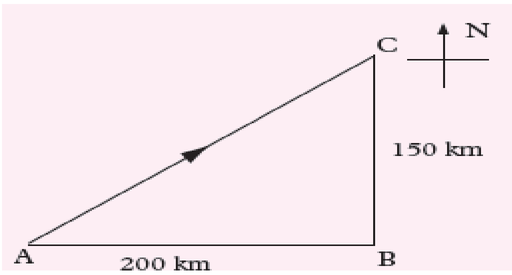
(b) Average velocity $= \frac{\text{displacement, AC}}{\text{time taken}} = \frac{\sqrt{200^2 + 150^2}\text{ km}}{3 + 2\text{ h}}$

$= \frac{250}{5\text{ h}}\text{ km}$

$= 50\text{ km/h}$, Direction is from A to C

In m/s $= \frac{50\ 000\text{ m}}{3\ 600\text{ s}}$

$= 13.89\text{ m/s}$



The answer in b) for the displacement AC

Equations of motion of a body in Uniform Rectilinear Motion (URM)

Distance covered by a body = speed × time taken

$X = Vxt + x_0$, $X = Vt$, $x_0 = 0$ m

$$V = \frac{X - x_0}{t - t_0},\ V = \frac{X}{t},\ t_0 = 0\sec,\ x_0 = 0m$$

Time taken by a body = $\frac{Distance}{Speed}$, $t = \frac{X}{V}$

Where: **X**: distance, **V:** Speed/Velocity, X_0**:** initial distance, **t**: time, t_0 : initial time

Graphs of linear motion

a) Distance – time graphs of a body in URM

Activity

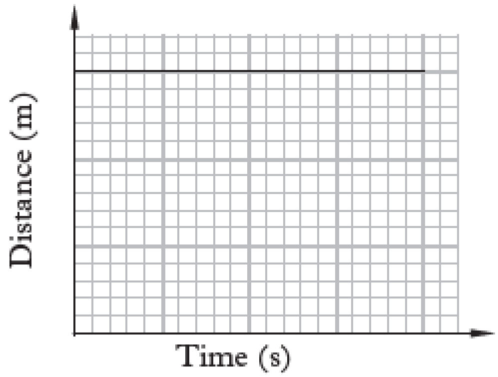
To draw and interpret a distance-time graph

Materials: graph papers, pencil, ruler

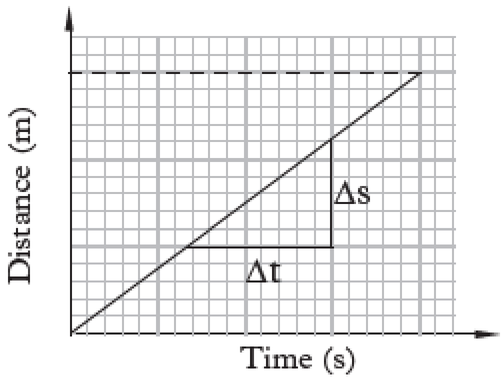
Steps

1. Sketch distance-time graphs for two bodies: one at rest and the other moving at a constant velocity.
2. Discuss and interpret each graph in your group.
3. Draw and analyze graphs of bodies whose speed is increasing or decreasing with time.
4. Suggest what the gradient represents in a distance-time graph.

Therefore, you should have obtained Fig. (a) and (b) for the body at rest and one moving at a constant velocity respectively.



(a) Body at rest



(b) Moving body with constant velocity

Fig. 2.4: (a) and (b): Distance-time graph

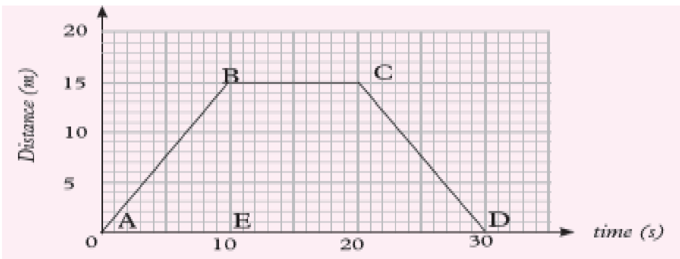
The graph in Fig. (a) shows that the distance covered by the body is not changing with time. The body is therefore at rest (stationary).

The graph in Fig. (b) shows that the distance covered by the body is increasing with time.

The **gradient** of the graph is Δs / Δt and represents the **speed** of the object. Thus, the graph represents the motion of the body moving with constant (uniform) speed.

Example

The figure below shows a distance-time graph for a motorist. Study it and answer the questions that follow.



(a) How far was the motorist from the starting point after 10 seconds?

(b) Calculate the average speed of the motorist for the first 10 seconds.

(c) Describe the motion of the motorist in regions (i) BC (ii) CD

Solutions

(a) By reading directly from the graph, distance travelled in 10 s = 15 m.

(b) Slope of the graph = speed of the motorist.

Slope = change in distance/ change in time = (15 – 0)m /(10 – 0)s = 1.5 m/s

(c) (i) In the internal BC, distance is not changing but time changes, hence the body is at rest (stationary).
(ii**)** In the internal CD, the motorist is moving at a constant speed towards the starting point.

b) Displacement-time graphs of a body in URM

Activity

To draw and interpret a displacement time graph

Materials: graph papers, pencil, ruler

1. In groups of three, discuss and sketch the displacement-time graph for a body:
   (a) Whose displacement changes uniformly with time.
   (b) At rest.
   (c) Whose rate of changes of displacement is not constant.
2. In your group analyze and interpret the displacement-time graph in 1(a), (b) and (c).
3. Compare your graphs with those of other groups in a class discussion.

In order to describe the displacement of a body, a **reference point** is considered. The reference point is the point when the body is at zero displacement as shown in Fig. below. The body may be moving tow the left or right from the reference point.

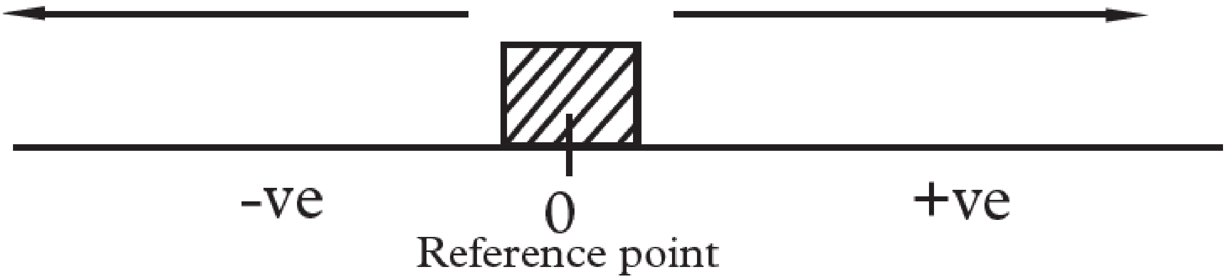


Fig.2.5 : Moving object

Let us consider a body moving in such a way that its displacement changes uniformly with time. Depending on the direction taken, two graphs can be drawn as shown in Fig. (a) and (b).

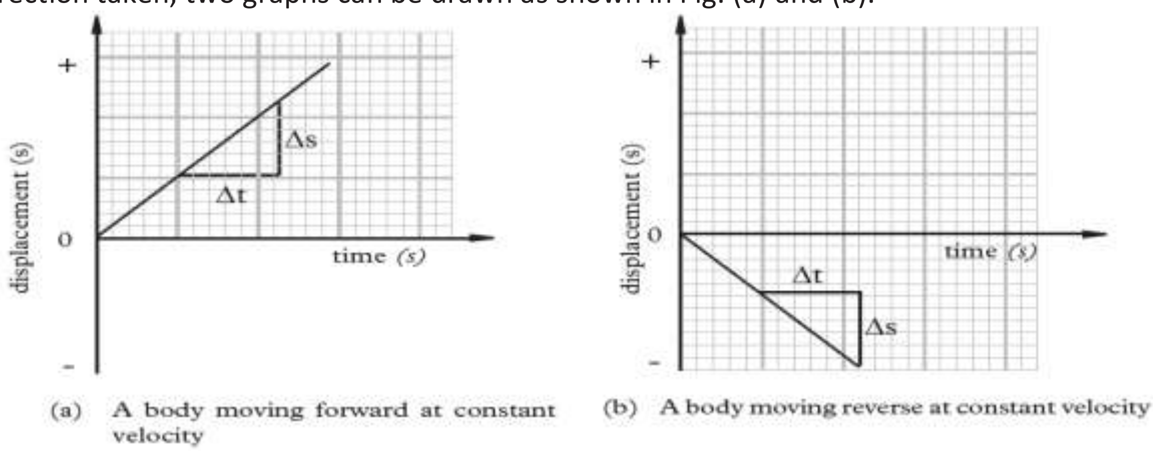


Fig.2.6 : Displacement-time graphs for moving constant velocities objects

As we have seen already, the gradient Ds/Dt of a displacement-time graph gives the velocity of the body. Thus, in Fig. above (a), the body is moving forward at constant velocity while in Fig. above (b), the body is moving in the reverse (opposite direction) at constant velocity.

c) Speed-time graphs of a body in URM

a) Object at rest

At rest, the objet covers no distance since there is no movement. Therefore, the speed of the object is zero as shown in Fig. below

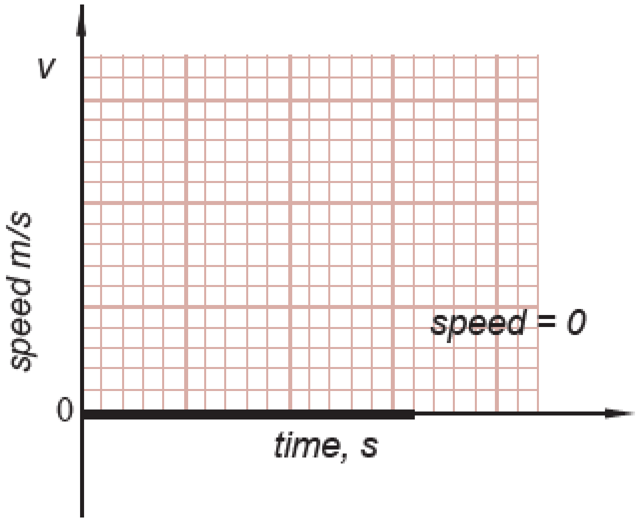


Fig. 2.7: Speed-time graph for a body at rest

The gradient in a speed time graph gives us:

Change in speed / Change in time = acceleration.

In this case (when the object is stationary), the gradient is zero and so acceleration is zero.

b) A body moving with uniform (constant) speed/velocity

The Figure below shows the motion of a body moving with the uniform speed.

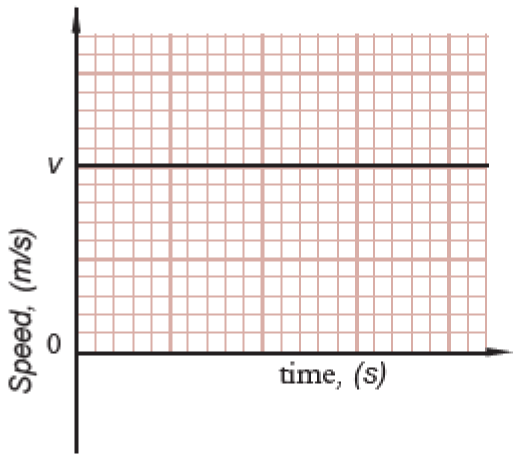


Fig.2.8 : Speed-time graph for a body in uniform speed

Gradient = 0

Acceleration in this case is zero i.e
a = 0 m/s^2

B. **Non-uniform or uniform accelerated motion**

In this motion the speed of an object changes at a constant rate, a good example is the free fall.
In general, we have:

- Uniform accelerated rectilinear motion (velocity increases with time)
- Uniform decelerated rectilinear motion (velocity decreases as the time increases)
- Topic 2: Characterize a body in Non-uniform motion

2.1.2: Uniform Accelerated Rectilinear Motion (UARM)

1. **Acceleration of a moving object**

Activity

To determine the rate of change of velocity with time

Materials: A long tape, carbon disk, a runway, ticker-tape timer, a trolley

Steps

1. Pass a long tape under the carbon disc of the ticker-tape timer and attach it to a trolley. Place the trolley on a horizontal runway. Ensure that the runway is friction compensated as in Fig. below.

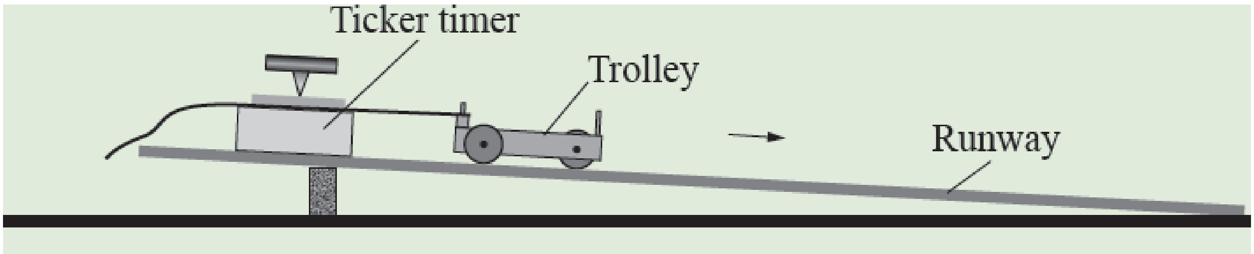


Fig.2.9 :To determine uniform velocity using a ticker-tape timer.

2. Now, increase the angle of inclination using the wooden block until the trolley is seen to be moving with increasing speed down the runway.
3. Release the trolley and start the ticker-timer. What do you notice about the separation of adjacent dots on the tape?
4. Brainstorm with your members how the dots on ticker-tape will look like when the speed of trolley is reducing with time.
5. What quantity is used to refer to the change of velocity with time? Suggest its SI units.

It can be seen that the separation of the dots increases with time as shown in the Fig. below. Since the time between two successive dots is 0.02 s, the time between each 5 spaces length is 0.10 s.

Fig. 2.10: Ticker-tape for an accelerating body

This shows that the velocity of the trolley is not constant but changing with the time.
When the velocity of a body changes with time it is said to be ***accelerating.***
Acceleration is defined as ***the rate of change of velocity*** i.e.

Acceleration = $\frac{velocity}{time}$

The SI unit of acceleration is ***meters per square second*** or ***m/s²***

If the acceleration of a body is 4 m/s^2, it means that its velocity is increasing by 4 m/s every second. When the velocity of a body decreases, it is said to be decelerating or retarding.

Equations of motion of a body moving in uniform decelerated rectilinear motion

$X = \frac{1}{2}at^2 + v_0 t + x_0$, $X = \frac{1}{2}at^2 + v_0 t$, $x_o = 0$ m

V= at +v_0, $a = \frac{V - v_0}{t - t_0}$

$t = \frac{V - v_0}{a}$

Where:

X: distance

a:acceleration

t: final time

v_o: initial velocity

V: final velocity

x_0: initial distance

t_o: initial time

Graphs of a body in Uniform Accelerated Rectilinear Motion (UARM)

1. **Distance - time graph**

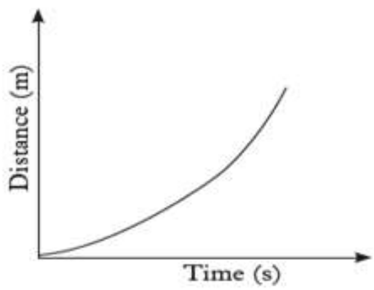


Fig.2.11: Speed increases with time

In this Figure,the gradient (representing speed) is increasing, implying that the object is accelerating. Examples of real life settings where such motion is exhibited include:

- A body rolling down an inclined plane.
- A car accelerating uniformly from rest.

2. **Speed time graph of a body in UARM**

A body moving with non-uniform speed (body accelerating)

When a body moves with uniform acceleration, its speed changes by equal amounts in equal interval time. The speed-time graph for a body whose speed changes uniformly is a straight line as shown in Fig. follows.

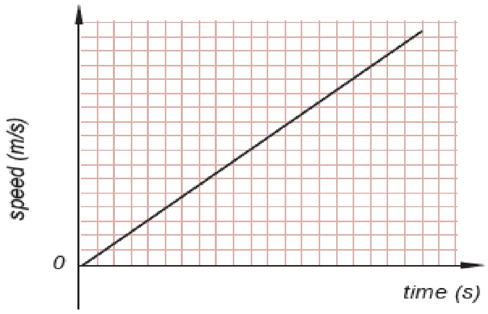


Fig.1.12: Speed-time graph

3. Velocity – time graphs of a body in UARM

A velocity-time graph tells us how the speed and direction of an object changes with time. Where there is no change in direction, a velocity–time graph looks the same as a speed-time graph. On a velocity – time graph, the gradient of the line is numerically equal to the acceleration. The gradient tells us how much extra speed is gained every second.

A body moving with steady acceleration from rest

Consider a car that started from rest and increased its velocity regularly. Its velocity-time graph is shown in Fig. bolow

Fig.2.13 : Velocity-time graph for uniform acceleration.

The gradient of velocity time graph represents the acceleration i.e.

Gradient = $\frac{\boldsymbol{Change\ in\ velocity}\ (\Delta V)}{\boldsymbol{change\ in\ time}\ (\Delta t)} = \boldsymbol{Acceleration}$

The rate of change of velocity (acceleration) is uniform, hence the graph is a straight line.
Consider a body moving with velocity in time as shown in the table below.

Table 2. 4: Values of velocity (m/s) and time taken (s)

Velocity (m/s)	0	5	10	15
Time taken (s)	0	2	4	6

The velocity increases by 5 m/s for every 2 seconds. Thus, the body is said to be accelerating uniformly at 2.5 m/s^2.

Example1

A car accelerates from rest to a velocity of 20 m/s in 5 s. Thereafter, it decelerates to a rest in 8 s. Calculate the acceleration of the car (a) in the first 5 s, (b) in the next 8 s.

Solution

(a) Acceleration $= \dfrac{\text{change in velocity}}{\text{time taken}}$

$= \dfrac{\text{final velocity} - \text{initial velocity}}{\text{time taken}}$

(rest means velocity is zero)

$= \dfrac{(20 - 0 \text{ m/s}}{5 \text{ s}}$

$= 4 \text{ m/s}^2$

(b) Acceleration

$\dfrac{\text{final velocity} - \text{initial velocity}}{\text{time taken}}$

$= \dfrac{(0 - 20) \text{ m/s}}{8 \text{ s}}$

$= \dfrac{-20 \text{ m/s}}{8 \text{ s}} = -2.5 \text{ m/s}^2$

or deceleration of 2.5 m/s^2

2.1.3: Uniform Deceleration rectilinear Motion (UDRM)

Topic 3: Characterize a body in Uniform Accelerated Rectilinear Motion (UARM)

I. Acceleration of a moving object in UDRM

Deceleration or retardation is negative acceleration. This is usually shown with a negative sign before the value e.g $- 4 \text{ m/s}^2$, deceleration at 4m/s^2.

When the rate of change of velocity with time is constant, the acceleration is referred to as ***uniform acceleration*.**

II. Equations of motion of a body moving in uniform decelerated rectilinear motion

$X = -\frac{1}{2}at^2 + v_0 t + x_0$, $X = -\frac{1}{2}at^2 + v_0 t$, $x_0 = 0$ m

V= at +v_0, $a = \dfrac{V - v_0}{t - t_0}$

$t = \dfrac{V - v_0}{a}$

Here acceleration is negative i.e there is decrease in velocity

III. Distance - time graph of a body in UDRM

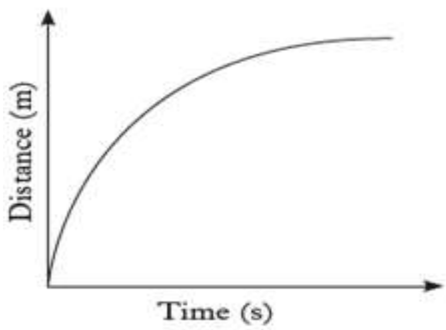


Fig.2.14: speed decreases wit time

In Fig. (b), the speed of the object is decreasing, implying that the object is decelerating. Examples of real life setting where such motion is exhibited include:

- A body thrown vertically upward.
- A body rolling uphill an inclined plane.
- A car decelerating uniformly.

IV. **Velocity- time graph of a body decelerating uniformly (UDRM)**

Consider a car moving at a particular velocity. If the brakes are applied such that it decelerates uniformly to rest, its velocity time-graph is as shown in Fig. below

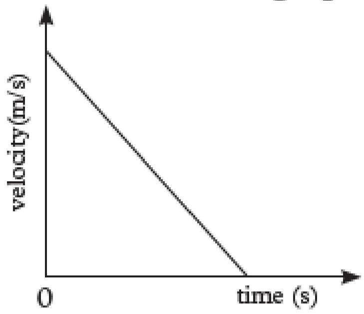


Fig.2.15: Velocity-time graphs for uniform deceleration

Example

Fig. below shows a graph of speed against time for the motion of a car travelling from Musanze to Muhanga.

Determine:

(a) The acceleration of a car in the first 4 s.

(b) The distance travelled in the first 4 s.

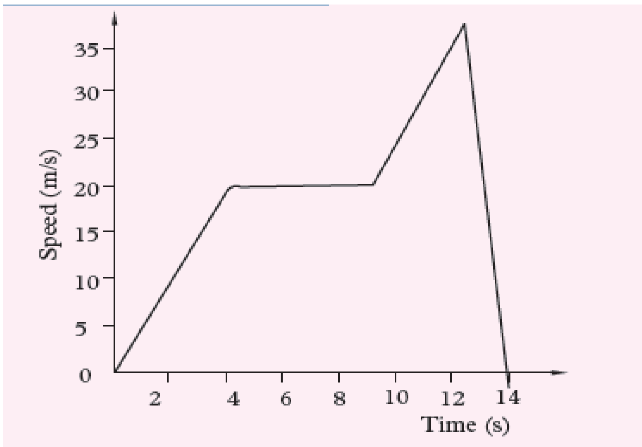


Fig.2.16 : Speed - time graph

Solution

(a) Acceleration = **change in speed / change in time taken** = Δs / Δt = 20 m/s / 4s = 5 m/s^2

(b) Distance travelled = Area under the graph = 1 / 2 a × $time^2$ (s) + v_0 × time

V0 = 0 m / s

Distance = 1 / 2 × 5^2× 4

= 50 m

Exercises

1. Sketch the following graphs.
   - **(i)** The speed-time graph for a body moving with uniform speed.
   - **(ii)** The distance-time graph for a body moving with uniform speed.
2. The figure below Fig. (a) shows the distance-time graph for body A while Fig. (b) shows the speed-time graph for body B.

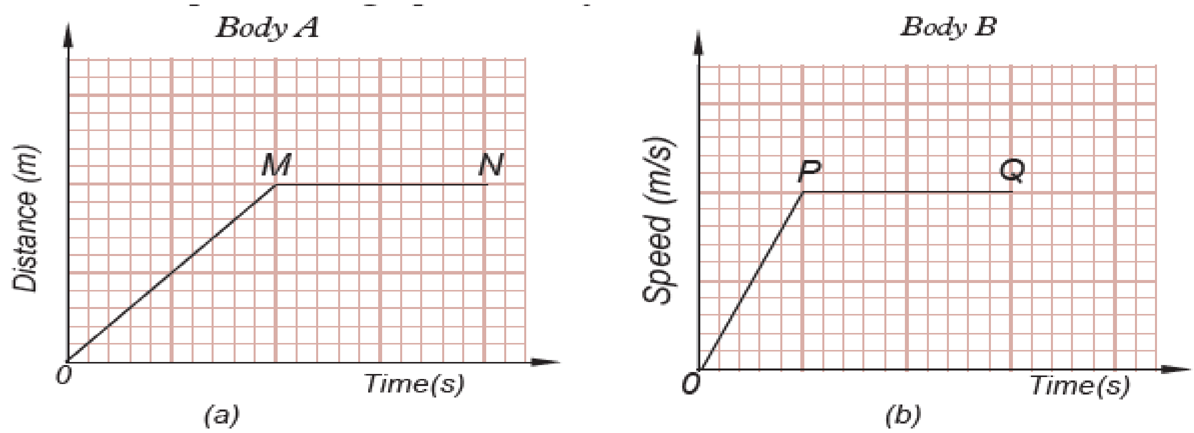


Fig.2.17: Distance-time graphs

Describe fully the motion of the bodies in the following regions:

(a) OM **(b)** MN **(c)** OP **(d)** PQ

Example

Table 2.5: Data collected to study the motion of cylist.

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

(a) Plot a graph of velocity (y-axis) against time (x-axis).
(b) Use your graph to determine the acceleration of the cyclist in the first four seconds

Solution

(a)

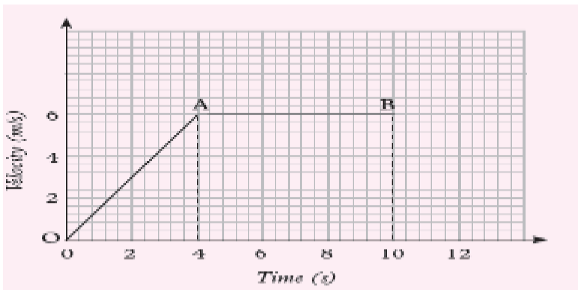


Fig.2.18 : Velocity-time graph

(b)

Acceleration = slope of the graph

= Change in velocity / Change in time

= (6 – 0) m/s / (4 – 0) s = 6 m/s 4 s
= 1.5 m/s^2

EXERCISES

1. A bus changes its speed from 180 m/s to rest in 10 s. Calculate the:

a. Deceleration of the bus
b. Displacement of the bus

2. (a) Sketch a velocity-time graph for a car moving with uniform acceleration from 10 m/s to 30 m/s in 20 s.

(b) The graph in the figure below shows the motion of a body falling freely under gravity.

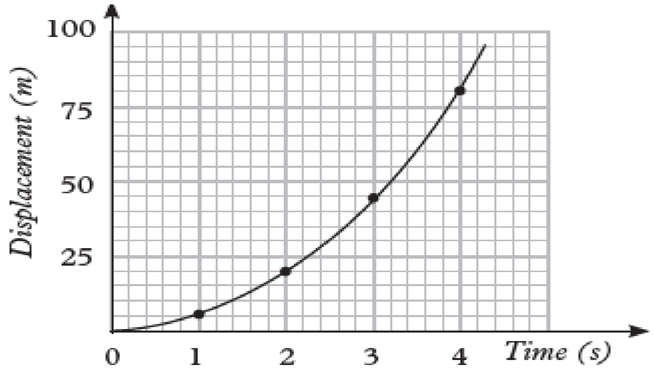


Fig2.19:. Displacement-time graph

(a) Determine the values of displacement(s) at t = 1, 2, 3 and 4

(b) Draw a graph of velocity (v) against time (t).

(c) Use your graph in (b) to find the value of gravitational acceleration.

3. The sketches in Fig. below represent the motions of bodies in a straight line. Match each graphs with appropriately description from the ones given.

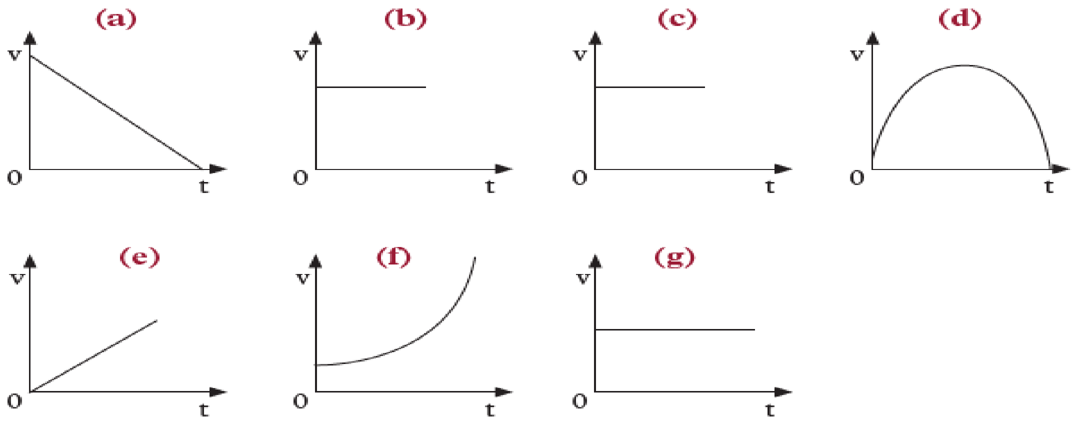


Fig.2.20: Motion graphs

(a) Uniform acceleration of a body starting from rest.

(b) The body moves with constant velocity.

(c) Body decelerates uniformly, starting with finite positive velocity.

(d) Body accelerates from a velocity.

(e) A ball thrown to hit the ground and bounces back.

(f) Body at rest.

(c) The figure below shows the velocity-time graph for a motorcar during a short drive.

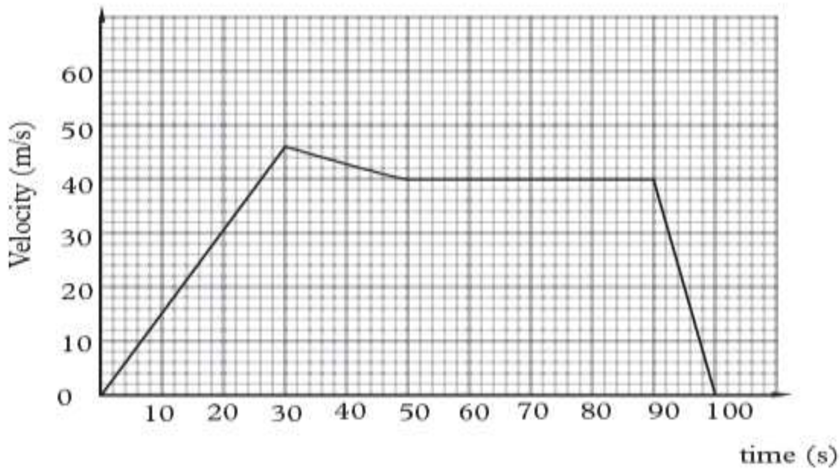


Fig.2.21 : Velocity-time graph

(a) Describe the motion of the car.
(c) Find the retardation in the interval 90 s-100 s.

Learning Outcome 2.2: Determine relationship between motion and forces

Newton's second law of motion provides an explanation for the behavior of objects when forces are applied to the objects. The law states that external forces cause objects to accelerate, and the amount of acceleration is directly proportional to the net force and inversely proportional to the mass of the object.

F = m× a

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

F: Force
m: mass
a: Acceleration

- Topic 1: Identification of the Newton's Laws of motion

2.2.1: Definition of force

In our daily lives, it is common to see things being pushed or pulled.
Example

1. Push a table in your classroom slightly to displace it.
2. Tie a stone or brick using a rope and pull it to other positions.

1. Push a table in your classroom slightly to displace it.

Fig.2.22 : Pushing a table

2. Tell your partner where a push or a pull is occurring.
3. Discuss with your partner other examples where a push or a pull occurs in our daily lives. List them down in your exercise book.
4. Compare and discuss your findings with different groups in your class.

This activity and many more involve either pushing or pulling. In physics, a pull or a push is called a **force**.

The SI unit of force is the **newton (N)**, named after the famous physicist **Sir Isaac Newton** (1642 –1727). Force is a **vector quantity**. It has both magnitude and direction. The magnitude is represented by a straight line while the direction is shown using an arrow as shown in Fig below

Fig.2.23: Force exerted to the right

2.2.2: Types of forces

1) **Contact forces**

Contact forces are those forces that act at the point of contact between two objects, in contrast to body forces. Examples of contact forces are ***frictional force, tension, normal action reaction force, air resistance and upthrust*.**

i. **Friction force**

Activity

To demonstrate friction in solids

Materials

- Wooden block
- A light spring

Steps

1. Place the wooden block with the spring attached on the bench.
2. Pull a wooden block using a light spring slowly and then faster across the bench. (Fig. 3.4). Observe what happens.
3. Discuss with your group members the observations made in step 2.

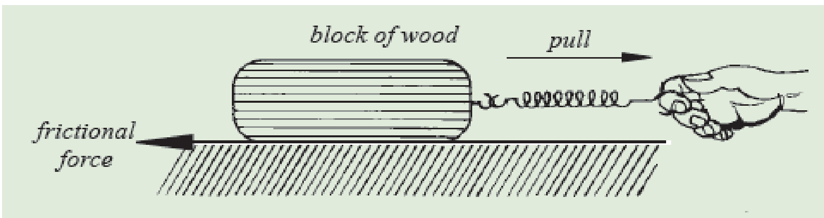


Fig.2.24: Direction of frictional force

4. Place a pencil on the horizontal bench and give it a slight push. Observe and explain what happens.

We defined **friction** as the force that opposes the relative motion of two surfaces that are in contact.

The two factors that affect the friction between two surfaces are the **nature of the surfaces** and the **normal reaction (R).**

Coefficient of friction

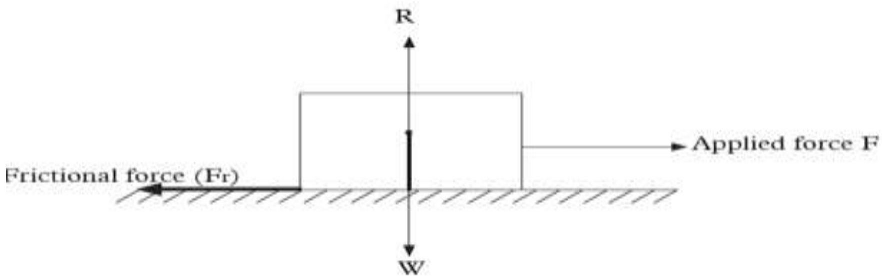


Fig.2.25 : Forces acting on a solid block on a horizontal surface

When the block is just about to move, solid friction between the block and the surface is called ***static friction***. Static friction is the force opposing motion between surfaces when the surfaces are just about to move. When the block is moving, friction force is reduced and is called ***dynamic friction***. Dynamic friction is the opposing force motion when there is relative motion between surfaces.

ii. Tension force

Activity

To demonstrate the existence of tension force in strings

Materials:

- A string
- A pail with water

Steps

1. Hold one end of a string and your friend the other end.
2. Let both of you pull the ends away from each other as shown in Figure 3.5. What happens to the string?

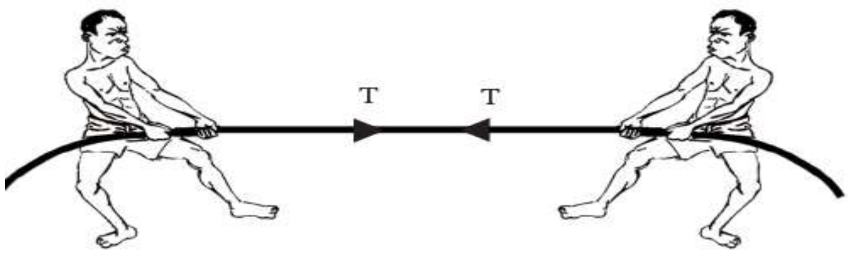


Fig.2.26: Showing tension force

3. Discuss your observations in step 2 with your class partner.
4. Tie a string to the pail and hang it as shown in Figure 3.6.
5. Discuss with your class partner any forces acting on the string and the pail in fig 3.5.
6. Compare your findings in step 5 and 6 with those of other pairs in the class.

The tension force can be shown on a force diagram by an arrow pointing inwards along the string marked with the letter, T. (Fig. above).

In figure above, you should have felt that the string pulls inwards with a force. This force that develops in the string, cable or rope when it is being pulled tightly by forces acting from opposite end is called tension force.

iii. Action and reaction forces

Activity

To demonstrate action and reaction forces

Materials:

- A rigid support
- Two identical spring balances

Steps

1. Hook one end of a spring balance A to a rigid support e.g a wall. Pull the other end until the spring shows a reading (see Fig below (a)).
2. Discuss with your partner what happens to the rigid support.
3. Repeat the activity by using a similar spring B instead of a rigid support.
4. Pull the two springs until the reading on spring A is the same as before (see fig below (b)). What reading is shown by spring B?

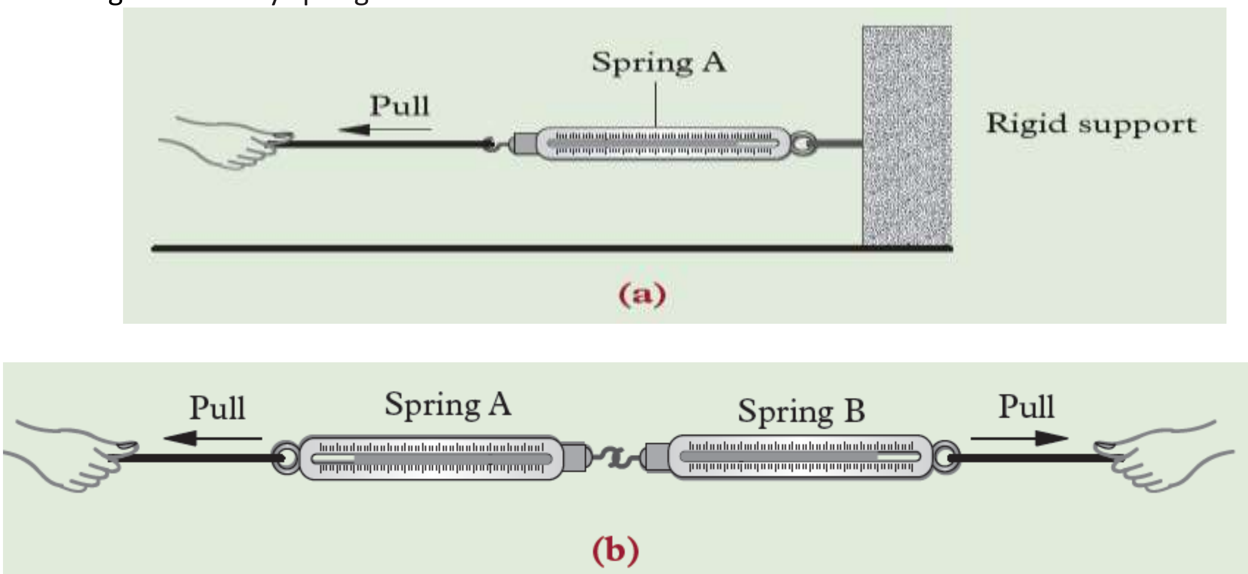


Fig.2.27: To demonstrate action and reaction forces

From the above activity, you should have noted that the reading of spring A is the same as of spring B. This implies that there are two equal forces which are acting in opposite directions in the two springs.
Similarly, when spring A pulled the rigid support, the support also pulled it with an equal and opposite force. These two equal forces that act in opposite directions are called **action** and **reaction force**.

iv. Air resistance (Friction due to air)

Activity

To demonstrate the existence of air resistance

Materials

- An umbrella
- A stopwatch

Steps

1. Run with an open umbrella as shown in Fig. (a) below. What do you observe?
2. Record the time you take to move a given distance.
3. Repeat the activity, but this time with the umbrella closed as shown in Fig. (b) below. Note the time taken to move the same distance.
4. Compare the time obtained in steps 2 and 3. What do you notice? Explain to your colleague in class.

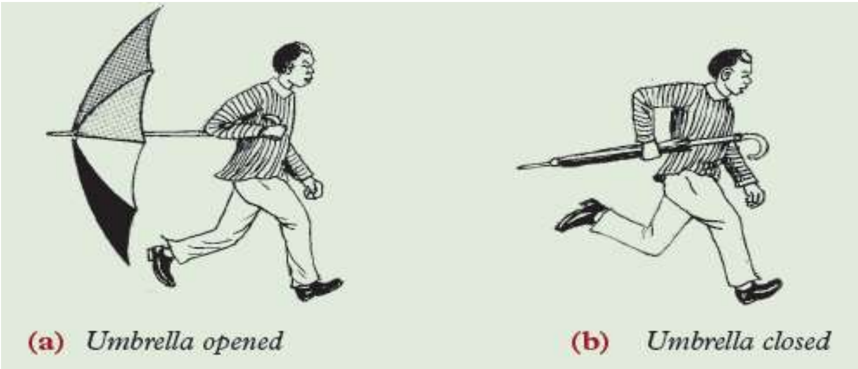


Fig.2.28 : Friction due to air

From the above figure, you should have noted that the time taken is more with open umbrella than the closed one. This shows that air offers hindrance to the movement. This hindrance is due to air resistance, also referred to friction due to air). Frictional force in fluid (liquids and gases) is called **viscous drag**.

iv. Upthrust

Activity

To demonstrate upthrust force

Materials

- resort stand
- a spring balance
- meter rule
- beaker with water
- a solid mass.

Steps

1. Suspend a solid in air using a spring balance (Fig (a) below. Note its weight.
2. Push the solid upwards gradually with your hand (Fig (b) below.What happens to the reading of the balance? Explain.
3. Release the solid and submerge it in a fluid such as water as shown in Fig (c) below. What is the weight of the solid? Note it down.

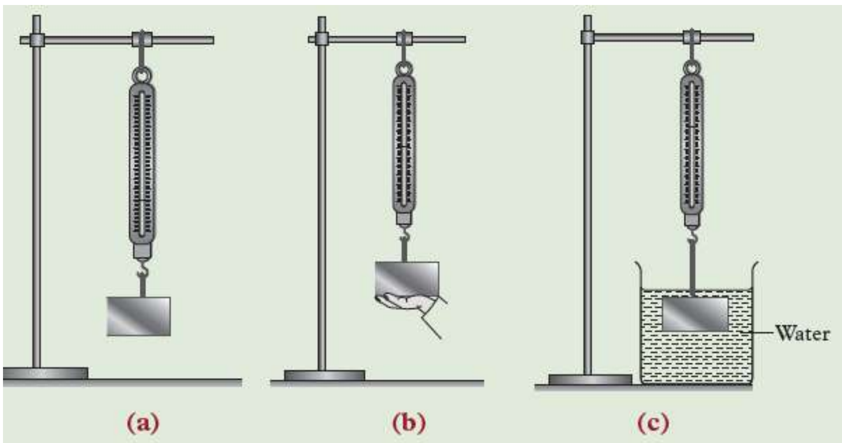


Fig. 2.9: To demonstrate upthrust force

4. Compare the weight of the solid? Note it down. Suggest the reason for your observation.

In the above activity, you must have noted that the pointer of the spring balance moves upwards in both cases. However, the pointer moves upwards in step 3 due to upward force in water which acts from below the solid submerged in it. This upward force due to a fluid is called **upthrust.**

Exercises

In pairs, do a research on the importance of upthrust force to:

1. Divers and some animals e.g crocodiles.
2. Ship industry.

2) **Non-contact forces**

A non-contact forces is a force applied to an object by another body that is not in direct contact with it. Examples of non-contact forces are ***gravitational, electrostatic and magnetic force***s.

(i) Gravitational force

Sir Isaac Newton observed that an apple falling from a tree and wondered why this was so (see Fig below).

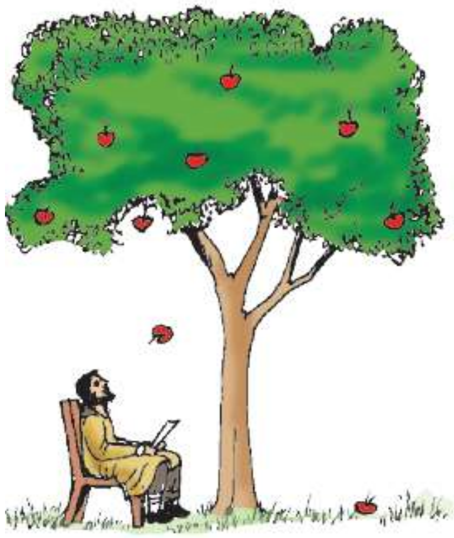


Fig. 2.30: A falling apple

After many experiments, Newton concluded that the apple he saw falling from a tree was attracted downwards by a force in the earth. He called this force of attraction **gravitational force** or **force of gravity**. The force of gravity pulls bodies towards the center of the earth, as observed in activity 3.18 above.

Fig 3.19 shows how bodies are attracted by gravitational force towards center of the earth.

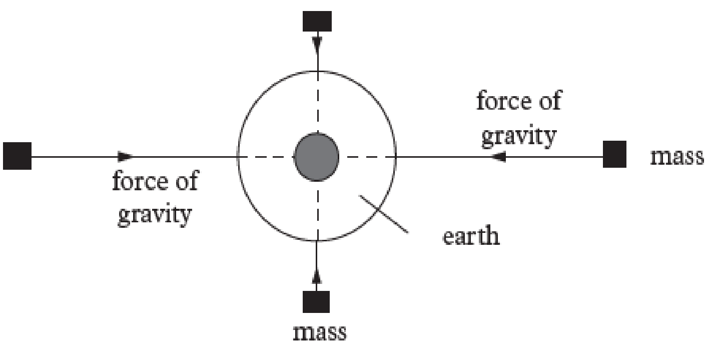


Fig.2.31: Force of gravity pulls bodies towards the center of the earth

(ii) **Electrostatic force**

To demonstrate electrostatic force

Activity

Materials

- Plastic ruler/pen
- Dry piece of cloth
- Piece of paper

Steps

1. Rub a plastic ruler against a dry piece of cloth. Suggest a reason why we do so.
2. Bring the plastic ruler close to small pieces of paper (Fig below). What happens to the pieces of paper? Explain.
3. Discuss with your colleagues in class your observation in step 2.

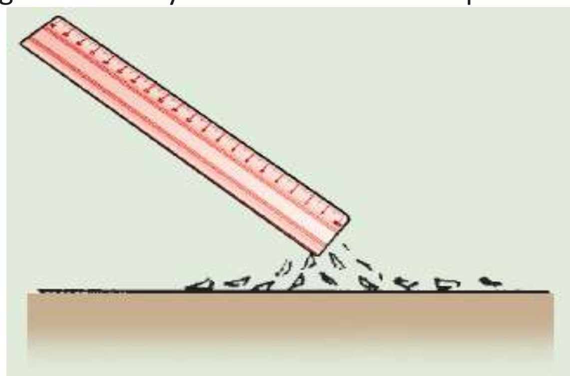


Fig.2.32 : Ruler pulling up a paper

You must have noticed that the pieces of paper were attracted towards the ruler in step 2 in Activity . The force of attraction or repulsion between static charges is called ***electrostatic force***.

Electrostatic force is created when the plastic ruler was rubbed against a dry piece of cloth.

(iii) **Magnetic force**

To investigate repulsion and attraction effects of a magnetic force

Activity

Materials

- 2 bar magnet
- A thread
- Iron rod

Steps

1. Suspend a bar magnet from a support using a light thread. Allow the bar magnet to swing freely until it comes to rest.
2. Bring a second bar magnet near it (Fig below). What do you observe? Explain your observations.

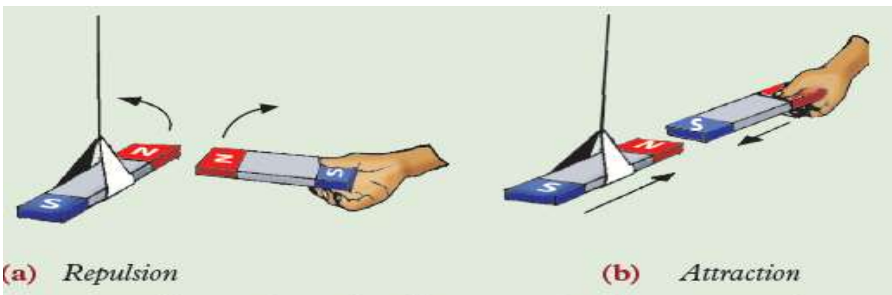


Fig.2.33 : Behaviour of two poles of bar magnets brought near one another

In this Activity , you must have observed that when like poles of the suspended magnet and the other magnet are near each other, the suspended magnet is repelled (Fig (a). However, when or unlike pole or iron rod are brought close the suspended magnet, they are attracted (Fig (b)). The repulsion and attraction between magnets is called **magnetic force**. Magnetic force also exists between magnets and other materials such as iron rod. Such materials with magnetic force are called **magnetic materials**.

2.2.3: Effects of forces

- Topic 2: Description of the different effects of forces

The effect of a force depends on the size, nature, how and where the force is applied. The following activities illustrate the effect of forces on bodies.

To demonstrate the effect of a force on an object at rest or in motion

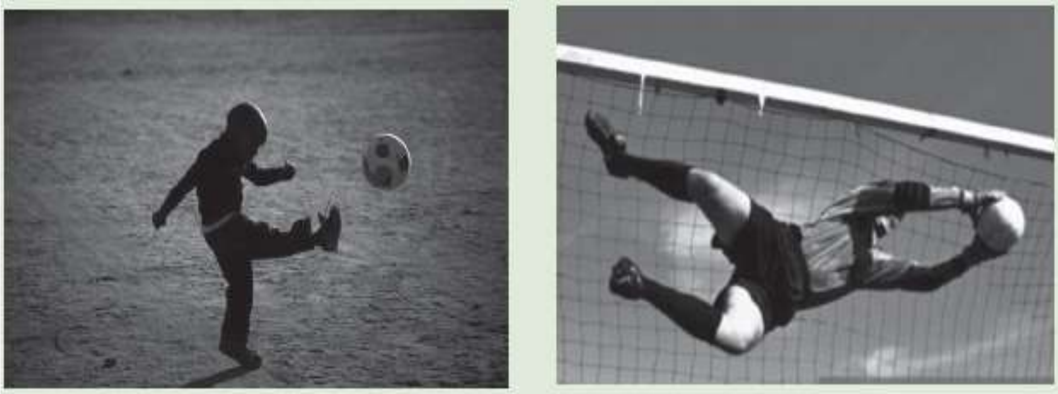
Activity

Materials

A ball

Steps

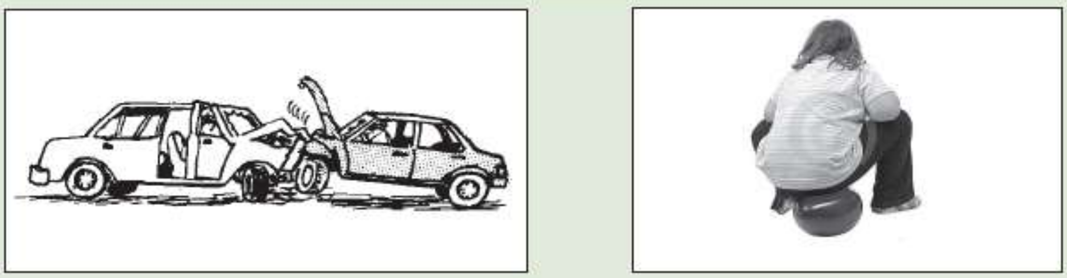
1. Kick the ball from its resting position. What do you observe? Explain your observation.
2. Identify the effects of forces shown in Fig. (a) and (b).



(a) Kicking a ball (b) Catching a moving ball

Fig.2.34: Forces changing state

A force can make a body at rest to start moving or a moving body to come to rest . It can also change the direction of motion of a body. Therefore, force can **change the state of motion of a body**.



(a) *Cars colliding.* (b) *A girl sitting on a balloon.*

Fig.2.35: Forces changing shape

A force can **distort or change the shape** of an object. For example, stretching a rubber band or a spring when compressed by a force and squeezing a balloon. Clay and plasticine are also other examples of substances whose shapes change easily when a force acts on them.

A force due to an earthquake can also cause massive destruction such as death of people and animals. It can also cause land deformation which leads to soil erosion and consequently contribute to pollution.

Force produces a turning effect on an object

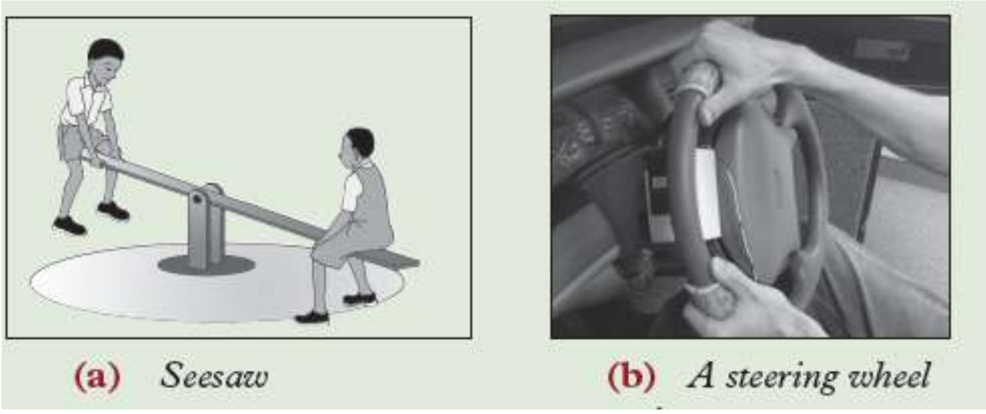


Fig.2.36: Forces causing turning and rotation

We notice that, forces when suitably applied can make a body to **turn about a point or cause a rotation**

Force can cause tear and wear as caused by a force

Fig.2.37: Conditions of tyres

From the above Fig. , tyre (a) has its treads still in good condition.
The tyre in (b) has its treads worn out. The tyres wear and sometimes tear because of friction between the road and the tyre when in use. This shows that, forces can cause wear and tear.

Briefly, the following are the effects of forces:

1. Force can cause change in the state of motion of a body, i.e. force can start, stop, increase or reduce motion and change the direction of a body in motion.
2. Force can change the shape of a body i.e. force can distort, stretch or compress a body.
3. Force can cause turning effect. Examples are a seesaw and a beam balance.
4. Force can cause rotation in the bodies e.g a steering wheel.
5. Force can cause heating effect, i.e. frictional force cause heating, e.g. lighting a matchstick.
6. Frictional force causes noise when rough surfaces are rubbed together.

2.2.4: Representation of forces using vector diagrams

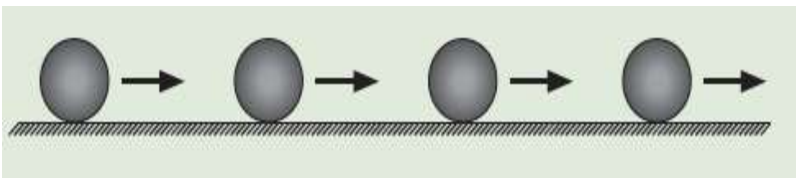


Fig.2.38: Movement of marbles

From the above figure, you should have observed that the force on the marble made others to start moving in a particular direction.

Force is a **vector quantity**, that is, it *has both magnitude (size) and direction*. A vector is normally represented by a line with an arrow head.

The length of the line represents the magnitude and the arrow head shows the direction. We therefore need a way of representing both magnitude and direction on a diagram in order to represent forces.
A diagram showing all the forces acting on a body in a certain situation is called **a free body diagram** or simply a **vector diagram.** A free body diagram shows only the force acting on the object under consideration, not those acting on other objects.

The following figure, shows a body moving toward right on a rough surface.

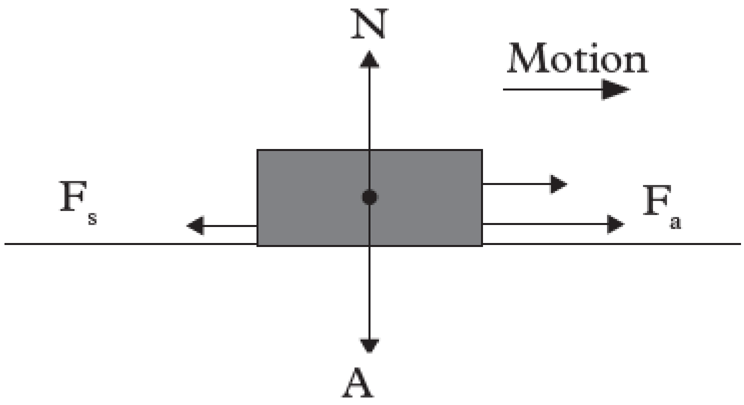


Fig.2.39: Normal, applied force and friction force

N is the normal reaction.

F_a is the applied force.

Fs is the friction force.

A is the action force or (weight).

Weight and mass

Weight is the measure of gravitational pull on an object. It always act from the center of a body downwards in the direction of gravitational acceleration. The SI unit of weight is **newton (N).**
Weight is measured using a spring balance (See the Fig.).

Fig.2.40 : A spring balance

Relationship between mass and weight

Weight = mass x gravitational field strength

w = mg

Hence,

Weight (w) / Mass (m) = gravitational field strength (g) abbreviated as w / m = g

w = mg or m = w /g

Experimentally it has been shown that the earth pulls a mass of 1 kg with a force of 9.8 N/kg. However a convenient rounded up value of 10 N/kg is commonly used.

Gravitational field strength (g) = Force (N) / Mass (kg) = 10 N / 1 kg

g = 10 N/kg

Differences between mass and weight

Table2.6: The main differences between mass and weight.

Mass	Weight
Quantity of matter in a body.	Pull of gravity on a body.
SI unit is kilogram (kg).	SI unit is newton (N).
Constant everywhere.	Changes from place to place.
Scalar quantity.	Vector quantity.
Measured using a beam balance.	Measured using a spring balance.

Example

A van of mass 2500 kg is authorized to carry 14 passengers. If the average mass per passenger is 50 kg, calculate the:

(a) weight of the van.

(b) weight of all passengers.

(c) total weight of the van and the passengers.

Solution

(a) w = mg

w = 2 500 kg × 10 N/kg = 7 000 N

= 25 000 N

(b) w = mg = (50 × 14) Kg × 10 N/Kg

(c) w = (25 000 + 7 000) N

= 32 000 N

Exercises

1. Distinguish between mass and weight.

2. Calculate the weight of the following. (Take g = 10 N/kg).

a. 300 g mass of water.
b. 700 kg mass of sand.
c. 0.05 mg mass of wool.

3. A metal bob of mass 20 g is suspended using a light thread. Calculate the tension developed in the thread.

Take g = 10 N/kg

2.2.4: Balanced and unbalanced forces

To demonstrate balanced and unbalanced force in a tug of war
Activity

Material

- A rope
- 5 very strong boys
- 5 very small boys

Step

1. Let the 5 very strong boys pull a rope on one end and 5 small boys pull on the other end.

2. Observe and explain what happens.

3. Suppose the boys on both sides are of equal strength. What would you observe?

4. Discuss with your group members other different situations where balanced and unbalanced forces are experienced.

From this Activity, you should have noticed that the rope moves to the side with the stronger boys ones who applied a greater force than the weak ones. The pulling forces are said to be **unbalanced**.

In case the two teams had equal strength or force, the rope will stay in the same place. The pulling force applied is said to be **balanced** or **at equilibrium**.

Similarly, consider the following:

1. A book is placed on a table top as shown in Fig. below. The gravity pulls the book vertically downward while the table supports the book with a force acting vertically upwards.

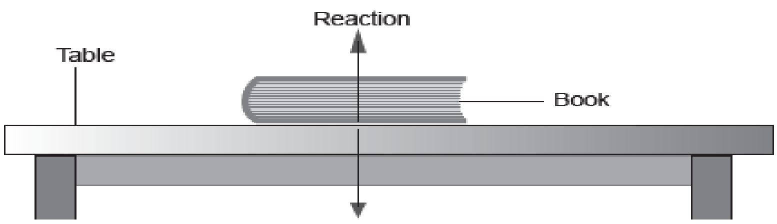


Fig. 2.41: Gravity pull downward on the book

Since the two forces are of equal magnitude and in opposite directions, they balance each other. The book is said to be in **equilibrium**. There is no unbalanced force acting on the book and therefore the book maintains the state of rest. Also, there is no change in motion.

2. If you compete in arm wrestling competition with someone who is just as strong as you are, and both of you are pushing as hard as you can, your arms stay in the same place. This is an example of **balanced forces**. The force exerted by both of you are equal, but are acting in opposite directions. The resulting force is zero hence there is no change in motion. See Fig. below

Fig.2.42 : Arm wrestling

If one of the forces is greater than the other, motion occurs towards the weaker forces. The forces are said to be **unbalanced**.

- Topic 3: Operation of parallel and non- parallel forces

2.2.6: Addition of parallel and non-parallel forces Parallel forces

1. Parallel forces

A. Addition of parallel

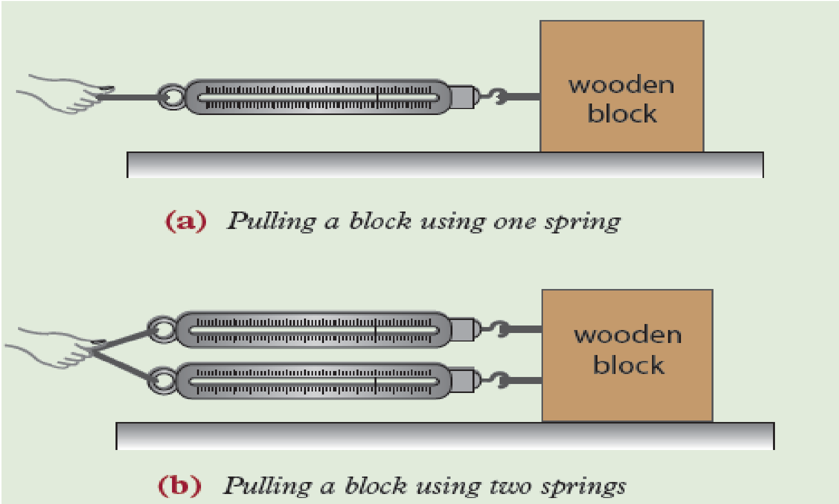


Fig.2.43: Measuring force using spring balance

From the above figure, the two spring pulling together record the same value. This value is half of that recorded by the single spring.

Let the force applied by the single spring A values = y

Force applied by each one of the two spring = x

Therefore, $x + x = y$

$2x = y$

$x = \frac{y}{2}$

When several parallel forces act together on the same body in the same direction the combined or resultant force can be added by the ordinary rules of arithmetic.

If the above figure is with two equal forces pulling the wooden block at the same time but in opposite direction, one force cancels or counters the other one. If the force in one direction is taken as positive, then the force in the other direction is taken as negative.

When a number of parallel forces act on a single body, the resultant force acting on the body can be found by adding all the forces taking considerations of the directions (+ or –).**Example**

Two oxen are pulling a heavy block along a floor in the same direction. One exerts a horizontal force of 800 N and the other a force of 1000 N. If the frictional force between the crate and the floor is 430 N.

(a) Draw the force diagram.

(b) Find the total horizontal force in (a) above.

(c) Find the direction of the force in (a) above.

Solution
(a)

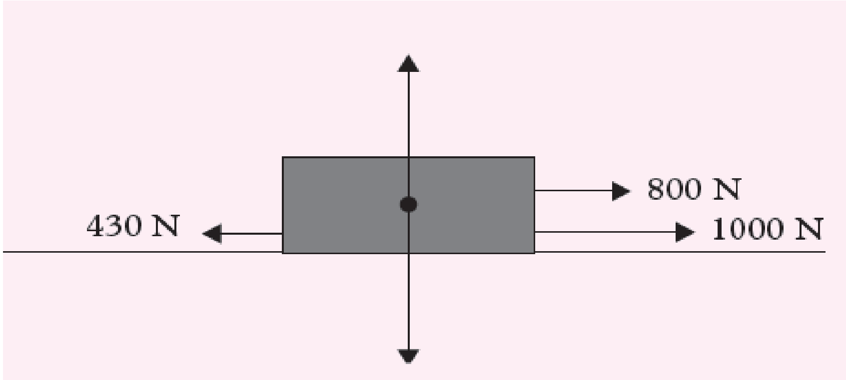


Fig. 2.44: Addition of parallel forces

(b) We shall choose the forward direction as positive since the frictional force opposes motion i.e acts backwards in the negative direction.

Force exerted by the oxen = 800 N + 1000 N

Force exerted by friction = -430 N

The total force on the crate = 800 + 1000 – 430 N

= 1370 N

The resultant force on the crate = 1370 N

(c) Since the force is positive its direction is forward.

Exercises

1. Name all the forces acting on the following:

a. A book resting on a table.
b. A book which is being pushed across a flat rough table by a student's finger.
c. A stone resting on a rough sloping board.
d. A box supported on a tall thin pillar.

2. Draw force diagrams for the cases in question 1.

3. Find the resultant of the following sets of forces:

a. A force of 35 N backwards and a force of 35 N forward.
b. A force of 120 N upwards and a weight of 150 N.
c. A force of 29 N upward, a force of 34 N upward, and a force of 50 N downwards.

B. Non-parallel forces

To demonstrate non-parallel forces
Activity

Materials

- A ring
- 3 ropes/strings

Steps

1. Tie three ropes at different points on the ring as shown in Fig below

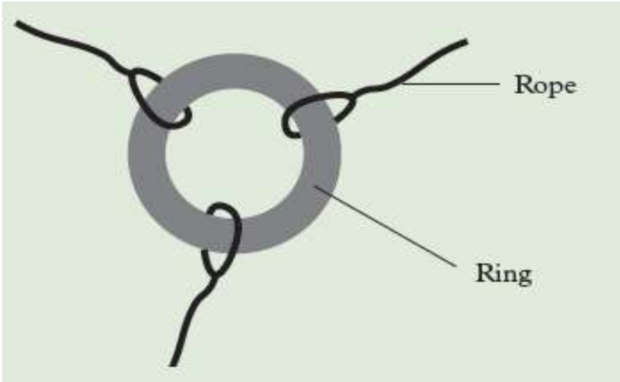


Fig2.45: Strings tied to a ring

2. Let three of you pull each rope in different directions. What do you observe? Explain.

When one rope is pulled by a greater force than the rest, the other two, move towards its direction. However, when the ropes are pulled with the same force, neither of you moved to any particular direction since the forces are balanced.
These three forces in this activity acting on the ring in different directions. Such forces are called non-parallel forces.

2. Addition of non-parallel forces
To illustrate addition of non-parallel forces
Activity

Materials

- 3 - identical spring balances
- A ring
- Plane paper
- 3 - heavy wooden blocks

Part A

1. Cover the top of a table with a plane paper.
2. Hook the springs balances to wooden blocks.
3. Hook the springs to the ring by means of loose loops of the string as shown in Fig below

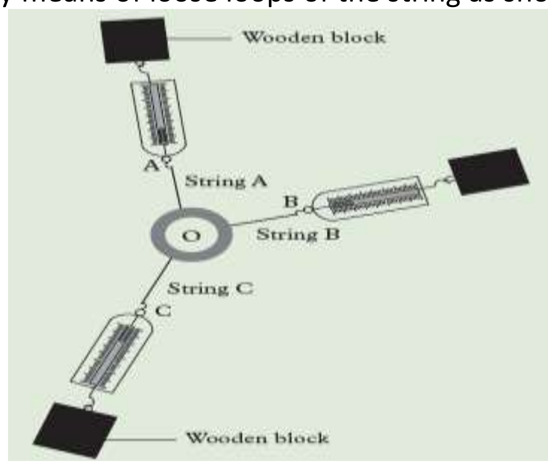


Fig.2.46: Addition of non-parallel forces

4. Move the wooden blocks outwards until each spring balance is showing appreciable reading. Record the readings of the spring balances.

5. Tap the ring and the strings so as to be in their true position. Is the ring balanced? Give a reason. Mark the center of the ring as point O.

6. Draw a straight line along each string. Mark points A, B and C along the lines representing the respective strings as shown in Fig. above.

From this Activity part A, the ring is observed to be in equilibrium i.e. state of balance. Therefore, the total force acting upon it must be zero. This can be shown by adding together the forces exerted by spring balances A, B and C as shown in part B below.

Part B

Steps

1. Remove the set ups.

2. Produce the lines through A, B and C inwards to meet at O.

3. Using a suitable scale, mark off distances OA, OB and OC accurately and proportional to the readings you recorded for the respective springs.

4. Construct a parallelogram OBRA and draw the diagonal OR (see Fig below).

5. Find the length OR and compare it with the length OC. What can you say about forces OC and OR. What is the relationship between Forces OA, OC and OR.

The magnitude force OR and OC are equal in magnitude but opposite in direction (Fig. below).

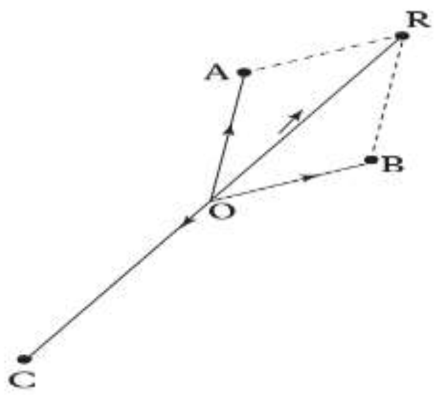


Fig.2.47 : Construction of parallelogram

This force OR represent the resultant force exerted by OA and OB. This method of obtaining the resultant of two forces is called **the parallelogram law method** which says that;

If two forces are represented in magnitude and direction by two sides OA and OB of the parallelogram OARB, then the resultant is represented in magnitude and direction by the diagonal OR.

Example

A wooden crate is pulled horizontally by two forces of 250 N and 150 N at an angle of 70º to each other. (Fig. below). Determine the resultant force on the box.

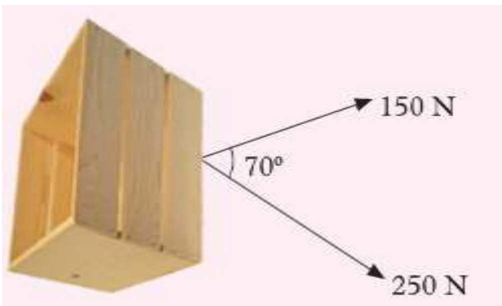


Fig.2.48: Wooden crate being pulled by two forces

Solution

Using a scale of 1.0 cm represent 50 N

Draw a line OA to represent 250 N

Draw a line OB to represent 150 N

Let O be the common point and the angle between the two lines be equal to 70º

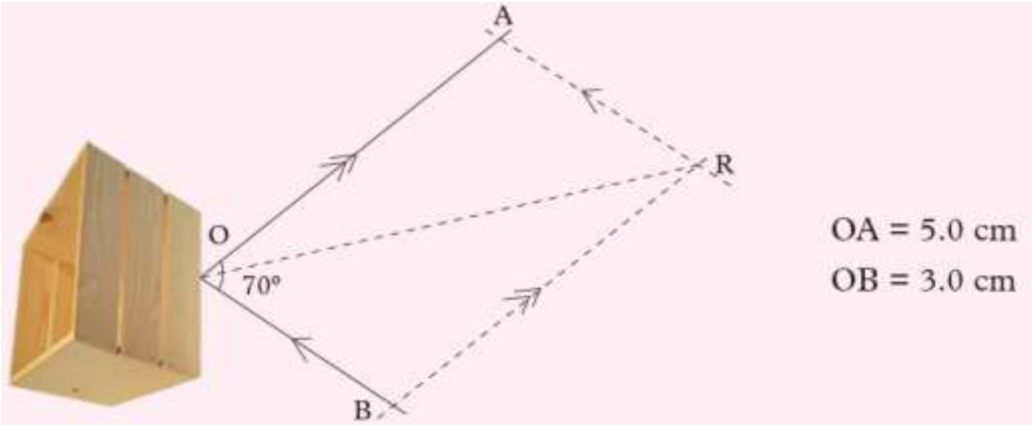


Fig2.49: Parallelogram of forces acting on a crate

Construct the parallelogram OARB using these lines OA and OB as adjacent sides and measure the diagonal OR = 6.9 cm.

Using the scale of 1.0 cm = 50 N, we find the resultant force is 345 N.

NB: When the angle between two forces is very close to 0º or close to 180º, the parallelogram of forces folds down into a flattened form lying almost along a single straight line. The parallelogram rule of addition of slanting forces then gives the same result as the simple addition rule for parallel forces.

Exercises

1. State the parallelogram law.

2. Explain the term equilibrium.

3. A box is moving constantly across a rough horizontal floor, pulled by two horizontal ropes. One of the ropes has a tension of 150 N and makes an angle 20º with the direction of motion of the box. The other rope with a tension force of 90 N makes an angle 40º with the direction of motion of the box.

- **(a)** Sketch the arrangement.
- **(b)** By scale drawing find the resultant forward force acting on the box.
- **(c)** Give the backward force on the box due to friction.

4. Calculate the weight of the following. (Take g = 10N/kg.)

- **(d)** 300 g mass of water
- **(e)** 700 kg mass of sand
- **(f)** 0.5 mg mass of wool

5. A metal bob of mass 20 g is suspended using a light thread. Calculate the tension developed in the thread. (Take g = 10N/kg.)

6. Find the resultant of the following forces:

a. 150 N due East and 200 N due West.

b. 450 N due North and 250 N due South.

7. State four differences between mass and weight.

2.2.7: Newton's Laws of Motion

- Topic 4: Identification of the three newton's laws of motion

1) **Newton's first law of motion: Principle of inertia**

Statement of Newton's first law of motion

This law states that:

A body continues in its state of rest or uniform motion in a straight line unless compelled by some external force to act otherwise. From this law we can define a force as that quantity which produces motion of a body at rest or that which alters its existing state of motion.

To demonstrate effect of inertia

Activity 1

1. A passenger lurches backwards when a bus initially at rest suddenly starts moving forward.

2. When a bus is moving very fast and suddenly negotiates a corner in one direction, the passengers lurches to the opposite side.

3. If the brakes of a fast moving bus are applied suddenly, the passengers lurch forward.

From the observation in the above Activity, we see that the body of the passenger is always tending to resist any action taken by the bus e.g when the bus wants to move, the body wants to remain behind; when the bus wants to stop the body wants to continue moving.

The reluctance of a body to resist change to its state of motion i.e either to remain at rest or to continue moving is known as inertia (latin word meaning laziness).

Activity 2

To demonstrate inertia using a coin

Materials

- A coin
- A beaker
- A smooth cardboard

Steps

1. In groups, place a coin on a smooth cardboard and place it over a beaker. Pull the card away slowly (Fig. (a)). Observe what happens to the coin.
2. Repeat the activity but this time pull the card away suddenly (Fig. (b)). Observe what happens to the coin.
3. Discuss with your members the observations in steps 1 and 2 and suggest a reason why the coin behave differently in these steps.

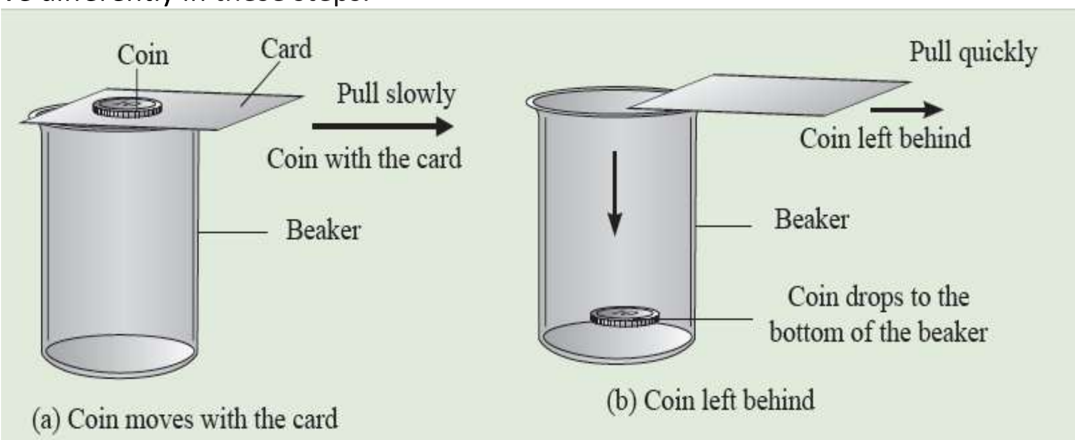


Fig.2.50 : Card with coin pulled (a) slowly (b) suddenly

In this Activity, you should have observed that when the card is pulled slowly, the coin moves together with the card Fig. (a). This is because the frictional force between the card and the coin makes the two to move together. However, when the card is pulled suddenly, the coin is left behind and drops vertically down into the beaker (Fig. (b)). This is because the coin resists motion and does not move with the card and hence drops vertically downwards into the beaker.

The coin resists changing its state of rest but due to lack of support from below, falls into the beaker.

When bodies tend to resist change to their states of motion i.e they exhibit inertia. These observations were summarised by Sir Isaac Newton in his first law of motion, called the **law of inertia**.

2) Newton's second law of motion: Fundamental principle of dynamics

This law states that:

The acceleration (a) of an object is directly proportional to net (resultant) force(F) acting on it and inversely proportional to its mass; and the acceleration takes place in the direction of the resultant force. F α m(Δs) / t .

This law is mathematically represented as follows; $a \propto \frac{F}{m}$.

This means, a = kF /m where **k** is a constant.

Experiments have shown that the value of k =1. Hence, $a = \frac{F}{m}$.

By cross multiplication we get F = ma

If mass is 1 kg and acceleration is 1 m/s^2, then the force is 1 N.

This is the definition of 1 newton i.e 1 newton is the force that will accelerate a mass of 1 kg at the rate of 1 m/s^2.

Thus, F = ma implies that:

(i) When the resultant force acting on a body is increased, the acceleration produced on the same body increases in the same proportion and vice versa (when the mass is constant).

(ii) The same resultant force produces a smaller acceleration on a body of a greater mass than when it acts on a body of a smaller mass.

Example 1

A truck of mass 2.5 tones accelerate at 7.5 m/s^2. Calculate the force generated by the truck's engine to attain this acceleration.

Solution

$F = ma = 2.5 \times 1\,000 \text{ kg} \times 7.5 \text{ m/s}^2$

= 18 750 N

Example 2

An object of mass 4 kg accelerates to 5 m/s2. Calculate the resultant force.

Solution

F = ma

$= 4 \text{ kg} \times 5 \text{ m/s}^2$

= 20 N

Example 3

Calculate the acceleration produced by a force of 20 N on an object of mass 300 kg.

Solution

a = $\frac{F}{m}$ = $\frac{20N}{300kg}$

= 0.066 7 m/s^2

Example 4.

The Table below shows the values of force, F, and the acceleration, a, for the motion of a trolley on a friction compensated runway.

Force F (N)	0.2	0.4	0.6	0.8	1.2
Acceleration, a (m/s)	0.90	1.8	2.7	3.5	5.3

(a) Plot a graph of acceleration, a, against force, F.

(b) Use your graph to determine the force when the acceleration is 4.0 m/s2

(c) Calculate the mass of the trolley, in grams, from your answer in (b).

Solution

(a) The graph is shown in Fig. below

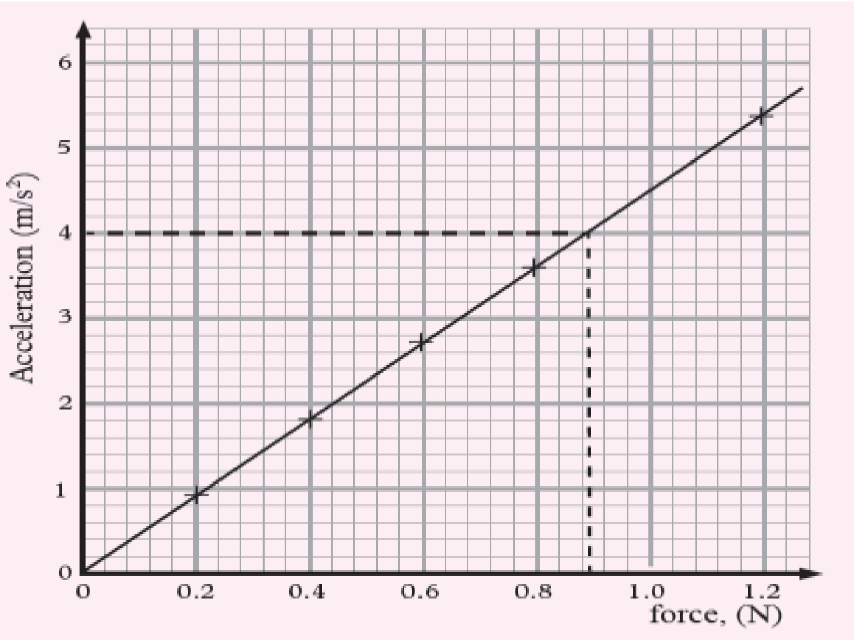


Fig.2.51: A graph of acceleration against force

(b) As shown in the graph, force F = 0.9 N when acceleration, a = 4.0 m/s2.

(c) Since F = ma, m = $\frac{F}{a}$

= 0.9 N 4.0 m/s^2

= 0.225 kg

The mass of the trolley = 225 g

1. (a) State Newton's second law of motion.

(b) Use Newton's second law of motion to derive to the equation F = ma.

(c) Define the unit of force; 'the newton' using F = ma

2. Find the force that is needed to make a mass of:

(a) 6 kg to accelerate at 10 m/s^2,

(b) 30 g to decelerate at 12 cm/s^2,

(c) 8 kg to accelerate at 6 m/s^2.

3. Find the force that should be applied to an object of mass 8.0 kg to make it accelerate by 20 m/s2.

4. A football of mass 500 g attains acceleration of 25 m/s2. Find the average force exerted on the ball.

5. A force of 15 N makes a body of mass 3.0 kg to move. Calculate the average acceleration of the body.

6. A car of mass 800 kg moving with an acceleration of 20 m/s2 crashes into a wall. Find the average force exerted by the car.

3) Newton's third law of motion: **Principle of Action and Reaction**

When you push a rigid wall/ body, you move in the opposite direction i.e the wall pushes you back. The force applied on the wall is called action force and the one applied back by the wall is called reaction force. Action and reaction force act in the opposite direction.

Other example of action and reaction

A book placed on a table provides the action, while the table supports the book by providing a reaction force

It states that *whenever a body exerts a force on another body, the other body exerts* ***an equal but opposite force on the first body.***

This is sometimes stated as, *to every action there is an equal and opposite reaction.*

Exercises

1. For each of the following forces, describe the reaction, giving its direction and stating where it acts.

a. The push of a boot on a football.
b. The push (backwards) of a swimmer on water.
c. The pull of gravity on a mango resting on a table.

2. State Newton's third law of motion. Explain how this law is applied in the propulsion of rockets.

3. Give an explanation to the following:

a. A gun recoils when it is fired.
b. A fireman moves backwards when a water hose he is aiming at a fire is suddenly turned on.

Learning Outcome 2.3: Calculate the work, energy and power

Introduction

Everyday, we do many types of work. We work in the offices, in the farms, in the factories etc. To make our work easier, we use machines ranging from simple tools to sophisticated machinery. Different machines or people do work at different rates (known as power). The ability and the rate of doing certain amount of work depends on how much energy is used. In this unit, we will seek to understand these three terms i.e work, energy and power from the science point of view.

- Topic 1: Description of Work and Power

2.3.1: Description of Work

Look at the activities being performed by the people in Figure below:

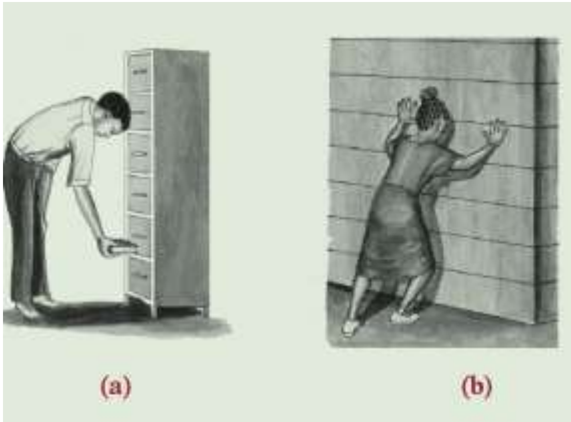


Fig.2.52 : People performing different tasks

In science, work is only said to have been done when an applied force moves the object through some distance in the direction of force.

However, no work was done when you sat on you chair without moving .

i. Definition of work

Work is defined as the product of force and distance moved in the direction of the force. i.e

Work = force × distance moved in the direction of the force

$W = F \times d$

ii. The unit of work

The SI unit of work is **joule (J)**.

Where 1 joule =1 newton × 1 meter

A joule is the work done when a force of 1 newton moves a body through a distance of 1 meter.

Bigger units used are kilojoules (1 kJ) = 1 000 J

Megajoule (1 MJ) = 1 000 000 J

Note: Whenever work is done, energy is transferred.

Work done in pulling an object along a horizontal surface

Activity

To determine the work done in pulling an object along a horizontal surface

Materials: a block of wood, a spring balance, and a tape measure/meter ruler.

1. Place the block of wood on a smooth horizontal surface.
2. Attach the spring balance on the block and pull it slowly. What do you observe?
3. Record the force needed to pull the block of wood.
4. Measure the distance through which the block of wood has moved from the beginning to the end (d) in meters using a tape measure/meter ruler.
5. Calculate the work done in pulling the block. What assumption did you make? Explain.

While doing the activity, you should have observed that when the block of wood was being pulled, the spring balance registered the force applied. Since the block was on a smooth surface, we assume that friction force is negligible hence the force applied is constant along the distance of motion, *d*.

Work done in moving the block is given by:

Work = force × distance = F × d

Example 1

A horizontal pulling force of 60 N is applied through a spring to a block on a frictionless table, causing the block to move by a distance of 3 m in the direction of the force. Find the work done by the force.

Solution

The work done = F × d = 60 N × 3 m

= 180 Nm

= 180 J

Example 2

A horizontal force of 75 N is applied on a body on a frictionless surface. The body moves a horizontal distance of 9.6 m. Calculate the work done on the body.

Work = force × distance

= 75 N × 9.6 m

= 75 × 9.6 Nm

= 720 J

Exercises

1. Explain why in trying to push a rigid wall, a person is said to be doing no work.
2. Define the term work and state its SI unit.
3. How much work is required to lift a 2 kilogram mass to a height of 10 meters (Take $g=10\ m/s^2$).
4. A garden tractor drags a plow with a force 500 N a distance of 2 meters in 20 seconds. How much work is done?
5. Find the work done in lifting a mass of 2 kg vertically upwards through 10 m. ($g = 10\ m/s^2$)

2.3.2: Description of Power

Definition of power

Power is the rate of doing work. i.e. is the workdone per unit time

$$\text{Power} = \frac{\text{work done}}{\text{time taken}} = \frac{\text{force} \times \text{distance}}{\text{time}}$$

The unit of power

The SI units of power are **Watts (W).**

$$1\text{watt} = 1\ \frac{\text{joule}}{\text{second}}$$

Large units used are kilowatt and megawatt.

1kilowatt = 1 000 W

1megawatt = 1 000 000 W

Example

What power is expended by a boy who lifts a 300 N block through 10 m in 10 s ?

Given data;

Force = 300 N, Distance = 10 m, Time = 10 s

Work done by the boy = F ×d = 300 ×10

= 3000 J

$$\text{Power} = \frac{\text{work}}{\text{time}} = \frac{3000\ \text{J}}{10\ \text{s}}$$
$$= 300\ \text{W}$$

Activity

To estimate the power of an individual climbing a flight of stairs

Materials: stopwatch, weighing machine, tape measure

Steps

1. Find a set of stairs that you can safely walk and run up.
2. Count their number, measure the vertical height of each stair and then find the total height of the stairs in meters.
3. Let one member weigh himself/herself on a weighing machine and record the weight down.
4. Let him/her walk then run up the stairs. Using a stopwatch, record the time taken in seconds to walk and run up the stairs (Fig below).

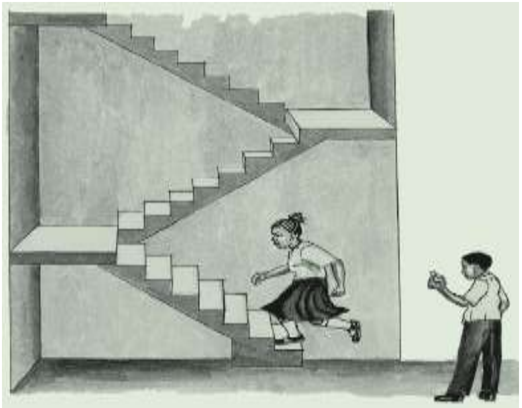


Fig.2.53 : Measuring one's own power output

5. Calculate the work done in walking and running up the stairs. Let each group member do the activity. Is the work done by different members in walking and running up the stairs same? Discuss.
6. Calculate the power developed by each individual in walking and running up the stairs. Which one required more power, walking or running up the flight of stairs? Why?

Note

(i) The disabled should be the ones to time others. Care must be taken on the stairs.

(ii) Incase of lack of stairs, learners can perform other activities like lifting measured weights.

From your discussion, you should have established that:

Height moved up (h) = Number of steps (n) × height of one step (x)

$h = n \times x$

$= n x$

Time taken to move height (*h)* = *t*

$$P = \frac{\text{Work done against gravity}}{\text{time}} = \frac{mgh}{t} = \frac{w \times h}{t}$$

$$= \frac{w \times n \times x}{t}$$

$$P = \frac{wnx}{t}$$

If *x* is in meters, *w* in newton's and *t* in seconds then power is in **watts**.

Example

A girl whose mass is 60 kg can run up a flight of 35 steps each of 10 cm high in 4 seconds. Find the power of the girl. (Take g = 10 m/s^2).

Force overcome (weight) = mg

= 60 × 10

= 600 N

Total distance = 10 × 35 = 350 cm = 3.5 m

Work done by the girl = F × d = 600 × 3.5

= 2100 J

$$\text{Power} = \frac{\text{work}}{\text{time}} = \frac{2100 \text{ J}}{4 \text{ s}}$$

The power of the girl is 525 W

Exercises

1. A machine is able to do 30 joules of work in 6.0 seconds. What is the power developed by the machine?
2. Mitaako is 42 kg. She takes 10 seconds to run up two flights of stairs to a landing, a total of 5.0 meters vertically above her starting point. What power does the girl develop during her run?
3. Student A lifts a 50 newton box from the floor to a height of 0.40 meters in 2.0 seconds. Student B lifts a 40 newton box from the floor to a height of 0.50 meters in 1.0 second. Which student has more power than the other?

4. Four machines do the amounts of work listed in Table 6.1 shown. The time they take to do the work is also listed.

2.3.3: Description of Energy

- Topic 2: Description of the different forms of energy

Energy is one of the most fundamental requirements of our universe. It moves motorcycles, cars along roads, airplanes through air, and boats over water. It warms and lights our homes, makes our bodies grow and allows our minds to think. A person is able to push a wheelbarrow, a stretched catapult when released is able to make a stone in it move, wind mills are turned by a strong wind and cooking using electricity in a cooker. All these are possible because of energy.

Therefore, for any work to be done, energy must be provided. But what is energy?

1. **Definition of energy**

Energy is the ability or capacity to do work.

Work done = energy transferred

2. The unit of energy

The S.I unit of energy is **joules (J).**

3. Forms of energy

Energy is not visible, it occupies no space and has neither mass nor any other physical property that can describe it. However, it exists in many forms, some of these forms include:

a. Solar energy

This energy from the sun is in form of *radiant heat* and *light*. In some countries where the sun shines throughout, large concave mirrors have been set to collect energy from the sun by focusing its rays on special boilers which provide power for running electric generators.

b. Sound energy

Activity

To investigate the production of sound energy

Materials: Two pens, a stone

Steps

1. Get two pens and knock them against each other. What do you hear? Explain to your class partner.
2. Lift a stone a meter above the ground and release it. What do you hear? Explain.
3. In what form is the energy released by the pen and the stone. Discuss with your class partner.

From your discussion, you should have heard sound in steps 1 and 2. In each case, kinetic energy has been converted to sound and heat energy. Sound energy is the energy associated with the vibration or disturbance of bodies or matter.

c. Heat energy

Heat energy is a form of energy that is transferred from one body to another due to the difference in temperature.

d. Electrical energy

Electrical energy is the energy produced by the flow of electric charges (electrons). Work is done when electrons move from one point to another in an electric circuit with electrical appliances such as bulbs.

e. Nuclear energy

Nuclear energy is the energy that results from nuclear reactions in the nucleus of an atom. It is released when the nuclei are combined or split.

f. Chemical energy

Chemical energy is a type of energy stored in the bonds of the atoms and molecules that make up a substance. Once chemical energy is released by a substance, it is transferred into a new substance. Food and fuels like coal, oil, and gas are stores of chemical energy. Fuels release their chemical energy when they are burnt in the engine (e.g in a car engine).

g. Mechanical energy

Mechanical energy is the energy possessed by a body due to its motion or due to its position. It can either be kinetic energy or potential energy of both. When an object is falling down through the air, it posses both potential energy (PE) due to its position above the ground, and kinetic energy (KE) due to its speed as it falls. The sum of its PE and KE is its mechanical energy.

Mechanical energy = kinetic energy + potential energy.

1. **Potential energy**

The energy possessed by a body (e.g. a stone) due to its position above the ground is called gravitational potential energy.

Similarly, when the spring was released, it relaxed to a bigger size. This also implies that the spring had stored energy due to compression.

The energy possessed by a body due to compression (e.g. a spring) or stretch (e.g catapult) is called elastic potential energy.

Therefore, potential energy is in two forms; gravitational potential energy and elastic potential energy.

(i) Gravitational potential energy

Bodies which are at a given height above the ground possess gravitational potential energy. This energy depends on the position of objects above the ground.

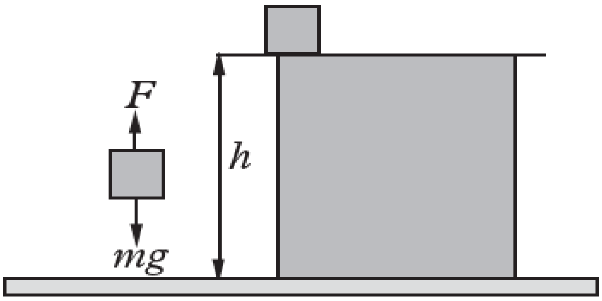


Fig.2.54 : Potential energy depends on height, h.

The work done to overcome gravity is equal to the gravitational potential energy gained by the stone.

But work done = $F \times h$; $F = mg$

∴ Work done = $m \times g \times h$

But, potential energy = work done.

Therefore: **P.E =** $\boldsymbol{m \times g \times h}$

Example

A crane is used to lift a body of mass 30 kg through a vertical distance of 6.0 m.

(a) How much work is done on the body?

(b) What is the P.E stored in the body?

(c) Comment on the two answers.

Solution

(a) Work done = F × d = *mg* × d = 30 × 10 × 6 = 300 × 6 = 1 800 J

(b) P.E = *mgh* = 300 × 6 = 1 800 J

(c) The work done against gravity is stored as P.E in the body.

(ii) Elastic potential energy

In figure below, we saw that a stretched catapult or compressed (Fig. below) has energy stored inform of elastic potential energy. When the stretched spring catapult is released it releases the energy that can be used to do work e.g. to throw a stone.

Fig.2.55 : A compressed and a stretched spring

2. **Kinetic energy**

The energy which is possessed by a moving object due to its speed is called kinetic energy (KE).

Examples of objects that possess KE include moving air, rotating windmills, falling water, rotating turbines and a moving stone. In general, any moving body possesses energy called kinetic energy.

The kinetic energy of a moving body is given by:

$$\textbf{Kinetic energy} = \frac{1}{2}\,\mathbf{mv^2}$$

Where *m* and *v* are the mass and velocity of the body respectively.

Exercises

1. Define the term energy.

2. State and explain briefly six forms of energy.

3. Differentiate between:

(a) Potential energy and kinetic energy.

(b) Gravitational potential energy and elastic potential energy.

4. A brick of mass 0.5 kg is lifted through a distance of 100 m to the top of a building. Calculate the potentials energy attained by the brick.

5. A fork-lift truck raises a 400 kg box through a height of 2.3 m. The case is then moved horizontally by the truck at 3.0 m/s onto the loading platform of a lorry.

(a) What minimum upward force should the truck exert on the box?

(b) How much P.E. is gained by the box?

(c) Calculate the K.E of the box while being moved horizontally.

(d) What happens to the K.E once the truck stops?

Learning Unit 3: Apply the knowledge of Calorimetry

Introduction

Heat energy is the result of the movement of tiny particles called atoms, molecules or ions in solids, liquids and gases. **Heat** energy can be transferred from one object to another. The transfer or flow due to the difference in temperature between the two objects is called **heat**.

The effect of this transfers of energy usually, but not always, is an increase in the temperature of the colder body and a decrease in the temperature of the hotter body.

Heat is the form of energy that is transferred between two substances at different temperatures.

The direction of energy flow is from the substance of higher temperature to the substance of lower temperature.

Heat is measured in units of energy, usually calories or joules.

Heat is the form of energy that is transferred between two substances at different temperatures. The direction of energy flow is from the substance of higher temperature to the substance of lower temperature. Heat is measured in units of energy, usually calories or joules. Heat and temperature are often used interchangeably, but this is incorrect. **Temperature** is the measure of hotness or coldness of matter. Stated another way, temperature is the average kinetic energy per molecule of a substance. Temperature is measured in degrees on the Celsius (C) or Fahrenheit (F) scale, or in kelvins (K). In simplest terms, temperature is how hot or cold an object is, while heat is the energy that flows from a hotter object to a cooler one. For example, the temperature of a cup of coffee may feel hot if you put your hand around it. It is hot because heat from the coffee is transferred to the cup.

Learning Outcome 3.1: Differentiate heat and temperature

Introduction

Heat and temperature pervade our lives. Just think about it. We give attention to hotness and coldness in deciding what to eat or drinking and what to wear during the day or at night.

Our bodies are highly sensitive to hot and cold environments. We learn very early in life through the school of pain that we shouldn't touch a hot pot on the stove or a hot lamp. In the same school, we learnt that we should be careful about mouthing or tasting hot foods. We also learnt how to use our hands to feel the heat that emanates from such foods and how to blow gently on them to help cool the food down.

In this unit, we are going to learn more about temperature and how to measure it using different instruments.

- Topic 1: Identification of heat and temperature

3.1.1: Definition of Heat and temperature

- **Heat** is a form of energy due to temperature. More specifically, it is thermal energy which can be transferred from an object to another.
- Heat is a form of energy which passes from a body at high temperature to a body at low temperature.
- The SI unit of heat is the joule (J).
- It is associated with the overall energy generated due to the motion of molecules in a substance.
- **Temperature** is a physical property of a substance that signifies the determination of the amount of heat content in a substance is known as temperature.
- It tells about the hotness or coldness of the substance thus corresponds to the average kinetic energy of the particles.
- Temperature is the *degree of hotness or coldness of a body or a place*. In Activity 9.1, the fact that the bowl feels warmer, means that temperature has increased. This suggests that ice and bowl have gained heat energy.
- Temperature is measured using a device called thermometer while heat is measured using thermal imaging (infra-red) instrument.

Activity

To investigate the difference between heat and temperature

Materials: Cooking oil, two identical test tubes, two identical thermometers, a beaker, a stirrer

Steps

1. Take equivalent masses of water and cooking oil in two identical test tubes fitted with two identical thermometers.
2. Place these test tubes in a large beaker containing water (See Fig. below).

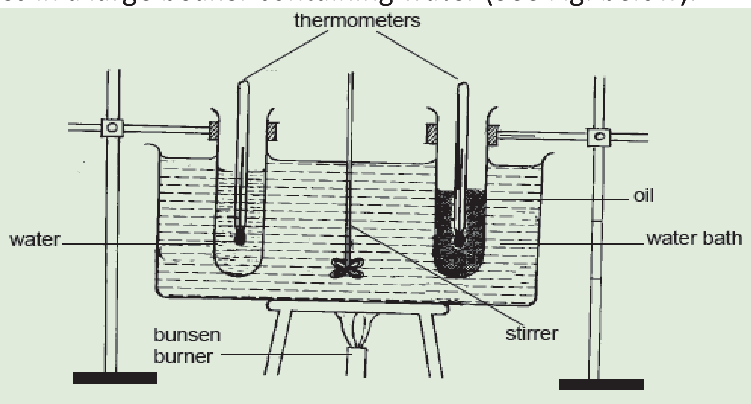


Fig.3.1 : A set up to investigate the difference between heat and temperature

3. Note the initial temperature of both water and oil in the tubes. Heat the water in the beaker and make sure that the heat is distributed uniformly by stirring the water.
4. After sometime, note the temperature of water and oil in the tubes. Are the two temperatures the same? Explain.

From the Activity, you should have observed that the temperature of water is lower than that of oil.

When the tubes are heated for the same time, i.e. the same heat energy passes from the burner to the tubes, both oil and water gain equal amount of heat energy but are at different temperatures.

Therefore, two substances can have equal heat energy supplied but be at different temperatures.

3.1.2: Difference between heat and temperature

Table 3.1: Difference between heat and temperature

Basis Comparison	Heat	Temperature
Basic	A form of energy	Measurement of thermal energy in a substance.
Symbolically represented as	Q	T
Defined as	Ability to do work.	Measures the amount of heat.
SI unit	Joule	Kelvin
Other measuring units	Calories	Fahrenheit, Celsius
Depends on	Mass, type of particle, speed of particle.	Only on average molecular motion.
Measured by	Calorimeter (using principle of calorimetry)	Thermometer
Signifies	Total potential and kinetic energy of the substance	Average kinetic energy of the molecules of the substance.
Measurement	Product of no. of molecules and energy possessed by each molecule.	The speed of molecular motion in a substance signifies the level of temperature.

3.1.3 Temperature scales

A temperature scale is a range of values for measuring the degree of hotness or coldness referred to as temperature. Temperature is commonly expressed in ***degrees celsius*** (also called ***degrees centigrade***) using the celsius scale. However, the SI unit for temperature is the ***kelvin (K)*** which is measured using the *kelvin scale*. This is the unit that is used in scientific work. Other temperature scales include, *Fahrenheit* and *Reaumur*. Let us discuss each of these scales in details.

(a) The celsius scale

This scale uses the *degree celsius* (**°C**) as the unit of measuring temperature. Two values in this scale are fixed such that the temperature at which pure ice melts is 0°C and boiling point of pure water is 100°C (under standard atmospheric pressure of 101 325 Pa).

These two fixed points are called the *lower* and *upper fixed points* of the celsius scale respectively. The region between these two points on the scale (called fundamental interval) is graduated into 100 equally spaced temperature marks (Fig. below). Temperature below 0°C have negative (–) value.

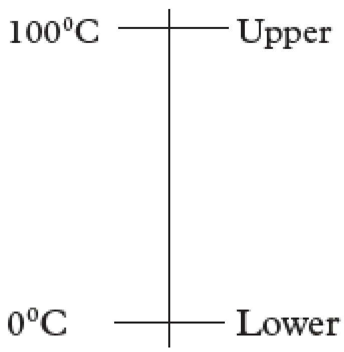


Fig.3.2 : Celsius scale

(b) The kelvin scale

This scale uses *kelvin (K)* as the unit of measuring temperature. The scale uses the absolute zero (-273°C) as its reference point. Thus, 0 K on kelvin scale is equivalent to –273ºC on the celsius scale. It is worth noting that a temperature change of 1 K is equal in size to a change of 1ºC.

(c) Fahrenheit

This scale uses *degree Fahrenheit (°F)* as the unit of measuring temperature. Two values in this scale are fixed such that the temperature at which water freezes into ice is defined as 32°F and the boiling point of water is defined to be 212°F.
The two have a 180°F separation (under standard atmospheric process) Fig. 9.3 shows a Fahrenheit scale.

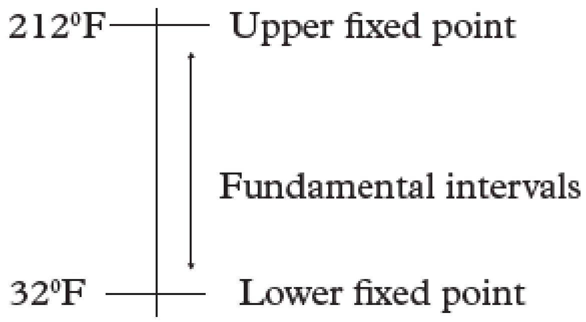


Fig.3.3 : Fahrenheit scale

(d) Reaumur Scale

This scale uses the degree Rankine (0°Re). In this scale, lower fixed point is the freezing of water (0°Re) and upper fixed point in the boiling of water 80°Re.

- Topic 2: Converting temperature scales from one scale to another

3.1.4: Conversion of temperature from one scale to another

Temperature is converted from:

(i) Celsius to Kelvin scale.
(ii) Celsius to Fahrenheit scale.
(iii) Fahrenheit to Kelvin.
(iv) Reaumur to Fahrenheit.
(v) Fahrenheit to Reaumur.

(i) Relationship between Celsius and Kelvin scale

To convert temperature from degree Celsius (°c) to Kelvin temperature (K), we add 273 to degrees temperature i.e.

$$\text{Temperature in K} = \text{temperature in °C} + 273$$
$$T_{(K)} = (\theta + 273)\text{K}$$

To convert kelvin (K) temperature to degrees celsius (°C) temperature, we subtract 273 from kelvin temperature i.e.

$$\text{Temperature in °C} = \text{temperature in K} - 273$$
$$T_{(°C)} = (T_{(K)} - 273)°\text{C}$$

The figure below shows a summary of the relationship between Kelvin scale and Celsius scales.

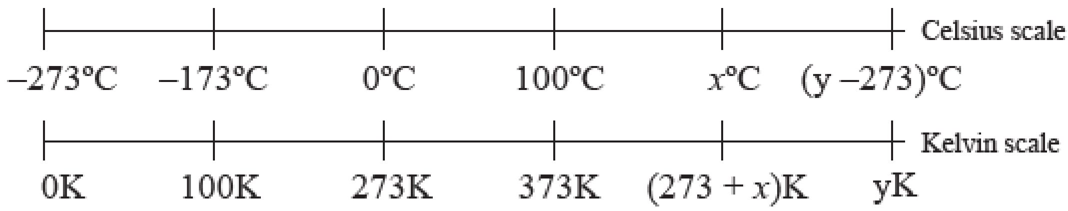


Fig.3.4 : Relationship between Kelvin and Celcius scale

In this case; *x* is any value of temperature in degrees celcius and *y* is any value of temperature in Kelvin.
N.B: The lower fixed point (ice point) is the temperature of pure melting ice at normal atmosphere measure. The upper fixed point (steam point) is the temperature of pure boiling water at normal atmosphere pressure.

Example1

What is the lower fixed point (L.F.P) in Kelvin?

Solution

Lower fixed point is 0ºC. To convert ºC to kelvin, add 273.
Therefore, L.F.P = (0ºC + 273)K = 273 K.

Example2

Express the room temperature of 27ºC in Kelvin.

Solution

To convert ºC to kelvin, add 273.
Therefore, room temperature is (27 + 273)K = 300 K.

Example 3

Convert 327 K to degrees celsius.

Solution

To convert kelvin to degrees celsius, subtract 273.
Therefore, 327 K = (327 – 273) ºC = 54ºC.

(b) Relationship between Celsius and Fahrenheit

To convert Fahrenheit into Celsius, we subtract 32 and then multiply by 5 / 9 i.e

$$T_{(°C)} = [T_{(°F)} - 32] \times \frac{5}{9}$$

Example 4

Convert 42 Fahrenheit to Celsius scale.

Solution

$$T_{(°C)} = [T_{(°F)} - 32] \times \frac{5}{9} = (42-32) \times \frac{5}{9}$$
$$= \frac{50}{9}$$
$$= 5.56°C$$

To convert Celsius to Fahrenheit, we multiply by 9 /5 then add 32 i.e.

$$T_{(°F)} = T_{(°C)} \times \frac{9}{5} + 32$$

Example5

Convert 37 degree Celsius to degree Fahrenheit.

Solution

$$T_{(°F)} = T_{(°C)} \times \frac{9}{5} + 32 = [37 \times \frac{9}{5}] + 32$$
$$= 98.6\ °F$$

(c) Relationship between Fahrenheit and Kelvin

To convert Fahrenheit to Kelvin, we add 459.67 then multiply by 5 / 9 i.e.

$$T_{(K)} = (T_{(°F)} + 459.67) \times \frac{5}{9}$$

Example 6

Convert 22 degree Fahrenheit to Kelvin.

Solution

$$T_{(K)} = (T_{(°F)} + 459.67) \times \frac{5}{9}$$
$$= (22 + 459.67) \times \frac{5}{9}$$
$$= 481.67 \times \frac{5}{9}$$
$$= 267.59\ K$$

(d) Kelvin to Fahrenheit

To convert Kelvin to Farhrenheit, we multiply by 9/5 then subtract 459.67. i.e

$$T_{(°F)} = (T_{(K)} \times \frac{9}{5} - 459.67)$$

Example 7

Convert 302 Kelvin to Fahrenheit scale.

Solution

$$T_{(°F)} = T_{(K)} \times \frac{9}{5} - 459.67$$
$$= 302 \times \frac{9}{5} - 459.67$$
$$= 543.6 - 459.67$$
$$= 83.93\ °F$$

(e) Relationship between Fahrenheit and Reaumur

To convert Fahrenheit to Reaumur, we add 459.67 i.e

$$T_{(°R)} = T_{(°F)} + 459.67$$

Example 7

Convert 35 degree Fahrenheit to degree Rankine.

Solution

$$\text{Rankine}(°R) = °F + 459.67$$
$$= 35 + 459.67$$
$$= 494.67\ °R$$

(f) Reaumur to Fahrenheit

To convert Reaumur to Fahrenheit, we subtract 459.67.i.e

$$(T_{(°F)}) = (T_{(°R)}) - 459.67$$

Example 8

Convert 503 degree Rankine to degree Celsius.

Solution

We first convert degree Rankine to degree Fahrenheit, then to degree Celsius i.e.

$$T_{(°F)} = T_{(°R)} - 459.67$$
$$= 503 - 459.67$$
$$= 43.33\ °F$$

$$\text{But,} T_{(°C)} = (°F - 32) \times \frac{5}{9}$$

$$\text{Substituting,} = (43.33 - 32) \times \frac{5}{9}$$
$$= 6.29\ °C$$

Note:

$$°F = 1°R = \frac{5}{9}°C = \frac{5}{9}K$$

Exercises

1. Differentiate between heat and temperature. State their SI units.
2. Describe an experiment to differentiate between heat and temperature.
3. Name two fundamental intervals in a temperature scale.
4. Convert each of the following into kelvin scale.
   (a) 34 °C **(b)** -371 °C **(c)** 17 °C
5. Convert each of the following into degrees celsius.
   (a) 314 K **(b)** -6 K **(c)** 273 K **(d)** 45 K
6. Convert each quantity in question 4 and 5 into:

(a) Degree Fahrenheit.

(b) Degree Reaumur.

3.1.5 Thermal equilibrium

- Topic 3: Description of the different types of thermometers

Activity

To investigate thermal equilibrium

Materials: source of heat, cold water, two beakers, thermometer

Steps

1. Pour cold water into a beaker and place it on a source of heat for 30 min then measure the temperature T_1.
2. Put some cold water in another beaker and measure its temperature T_2.
3. Mix the warm water and cold water into one of the beaker and stir well.
4. After stirring, measure the temperature T_3 of the mixture. In what state is the mixture after stirring?
5. What is the final value of temperature?

Thermal equilibrium is the state achieved when two regions or substances that are in thermal contact no longer transfer heat between them.

Therefore, two substances in thermal equilibrium are at the same temperature. For example, when measuring the human body temperature, heat energy is transferred from the human body to the liquid inside the thermometer until the two (i.e. human body and thermometer) have the same temperature e.g. 37^0C in thermal equilibrium.

3.1.6 Measurement of temperature

We learnt that temperature is the degree of hotness or coldness of an object. It is measured using an instrument called thermometer.

In the construction of a thermometer, a thermometric substance is chosen first. Then, a temperature scale is defined by means of two fixed points; lower and upper.

A) Thermometric substances

There are different thermometric substances used in different thermometers , like alcohol, mercury, kerosene, etc. Their properties changes uniformly with temperature.

Thermometric properties

Some important characteristics of thermometric substances are:

1. The property should remain constant, if temperature is constant.
2. The property should change uniformly with change in temperature.
3. The property should change uniformly for every 1ºC change in temperature.
4. The property should acquire thermal equilibrium as quickly as possible, when temperature measurements are needed.
5. The property should cover a wide range of temperatures (should not freeze or boil at normal temperatures).
6. The property should be able to register the rapid changing temperature.
7. The property should have a large change even if the change in temperature is small.
8. The property should be such that the temperature can be taken easily without waiting for a long time.

Some of the common thermometric substances used in thermometers include mercury and alcohol..

i) Mercury as a thermometric liquid

Advantages of using mercury as a thermometric substance

1. Mercury is a shiny and opaque liquid. The position of the mercury meniscus is seen easily and readings taken without strain.
2. Mercury does not wet glass. Hence it does not stick to the sides of the capillary tube.
3. Mercury has a large increase in volume for 1ºC rise in temperature.
4. Mercury expands uniformly. Its volume changes by equal amounts for equal change in temperature.
5. Mercury has a high boiling point of 357ºC.
6. Mercury has the ability to transfer heat energy easily. The whole mass of mercury in the bulb attains the temperature of the substance in which the bulb is placed easily.

Disadvantages of mercury as a thermometric substance

1. Usually, it is only the bulb which is in contact with the body when taking the temperature. A large portion of the stem is not in contact with the body.
2. There is a change in internal pressure due to the different positions of the thermometer. The reading of the mercury level is low when the tube is vertical as compared to the reading in the horizontal position.
3. Mercury takes sometime to contract to the original volume. The same thermometer cannot be used to measure a low temperature soon after a high temperature.
4. There may be non-uniformity in the capillary bore of the tube.
5. This thermometer is not suitable to measure temperatures below –39ºC.

ii. Alcohol as a thermometric liquid

Advantages of using alcohol as a thermometric substance

1. Alcohol has a very low freezing point of –114ºC hence its suitable in thermometers to record very low temperatures.
2. Alcohol can be coloured brightly (by adding a dye, generally red dye). This makes it clearly visible through glass.
3. Alcohol has a uniform expansion and contraction than mercury.
4. Alcohol is a good thermal conductor; it is also cheap and easily available.

Disadvantages of using alcohol as a thermometric substance

1. Alcohol sticks to the walls of the glass thus wetting it. This makes it difficult to read the temperature accurately.
2. Alcohol has a low boiling point of 78ºC, therefore it cannot be used to measure high temperature.

3.1.7 Types of thermometers

There are various types of thermometers in use. The liquid-in-glass thermometer is the most common one. Others include electrical, digital and gas thermometers. The main difference between them is in the property of the thermometric substance. In this level we shall discuss liquid-in-glass thermometers only.

Liquid-in-glass thermometers

A liquid-in-glass thermometer uses either mercury or coloured alcohol as the thermometric substance. They include laboratory (i.e mercury-in-glass and alcohol-in-glass) thermometers, clinic thermometer and six's maximum and minimum thermometer.

a) Mercury-in-glass thermometer

This thermometer consists of *a thin walled bulb*, containing mercury and a thin *capillary tube (bore)* of uniform cross-sectional area. There is a space above mercury thread which is usually evacuated to avoid excess of pressure being developed when mercury expands (Fig. below).

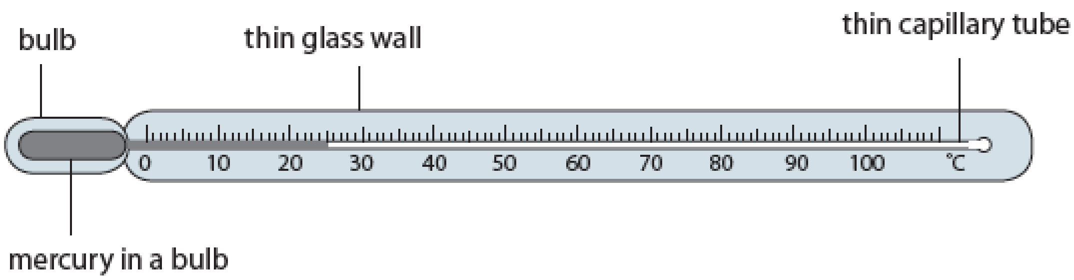


Fig.3.5: Mercury-in-glass thermometer

Some important precautions are taken in the construction of this type of thermometer include:

(a) The walls of the bulb should be thin. This is to ensure that the mercury can be heated easily.

(b) The quantity of mercury in the bulb should be small so that the mercury takes little time to warm up.

(c) The thin capillary tube should be of uniform cross-section so that the mercury level changes uniformly along its length.

b) Alcohol-in-glass thermometer

The alcohol-in-glass thermometer uses coloured alcohol instead of mercury.

Volume of alcohol changes uniformly and easily when heated. The change in volume of alcohol is about six times more than that of mercury for the same change in temperature.

The range of temperatures that can be measured with this thermometer is limited, as alcohol boils at 78ºC. However this thermometer is ideal for measuring low temperatures since alcohol freezes at –114ºC .

Using a laboratory thermometer

Before using a laboratory thermometer, you should note its initial reading (i.e room temperature reading) and while measuring temperature, ensure that its bulb is always in contact with the substance whose temperature is to be measured. Avoid direct heating of the bulb.

A. Clinical thermometer

A clinical thermometer is designed for measuring the human body temperature. It consists of a thin walled bulb containing mercury. The capillary bore is very narrow and of uniform diameter.

This thermometer has a narrow *constriction* in the tube just above the bulb. The thermometer has a limited range from about 35ºC to about 43ºC (Fig. below).

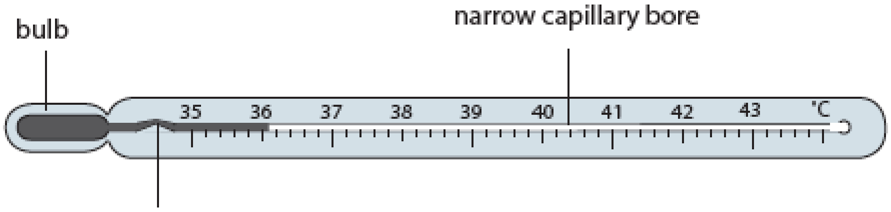


Fig.3.6 : Clinical thermometer

Working of a clinical thermometer

When the thermometer is in contact with a human body, mercury in the bulb expands. It forces its way through the constriction to the narrow bore. When the thermometer is removed from the body, the mercury in the bulb cools down and contracts. The mercury thread is broken at the constriction (Fig. below). Hence the mercury in the tube stays back. The reading of the thermometer on the stem can be taken without any hurry. After use, the mercury in the tube can be forced through the constriction back to the bulb by flicking the thermometer vigorously.
The normal human body temperature is 36.9ºC.

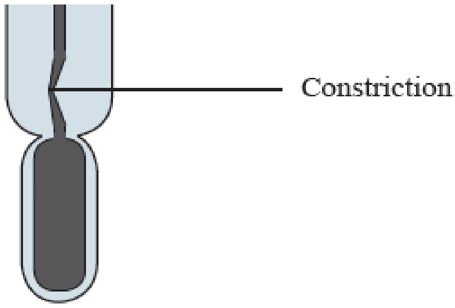


Fig.3.7 : Constriction of a clinical thermometer

B. The Six's minimum and maximum thermometer

Activity

To demonstrate the working of the six's thermometer

Materials: reference books, internet

Steps

1. Conduct a research on six's minimum and maximum thermometer.
2. In your research found out:
   - **(a)** How it is calibrated.
   - **(b)** The range of scales.
   - **(c)** The minimum and maximum values on each scale.
   - **(d)** The liquids used in the six's thermometer.
   - **(e)** How it works.
3. Compare and discuss you findings with other groups in class.

Six's maximum and minimum thermometer is used to measure the maximum and minimum temperature of a place during a day. It was invented by a physicist called ***John Six***. The thermometer consists of a U-shaped tube connected to two bulbs. The U-tube contains mercury. The two bulbs contain alcohol, which occupies the full volume of one of the bulbs. The other bulb has a space above alcohol. There are two indices fitted with light fine springs (Fig. below).

When temperature rises, alcohol occupying the full volume of bulb A, expands and forces mercury in the U-tube to rise on the right hand side. Mercury, in turn, pushes the index I_2 upwards. The maximum temperature can be noted from the lower end of index I_2.

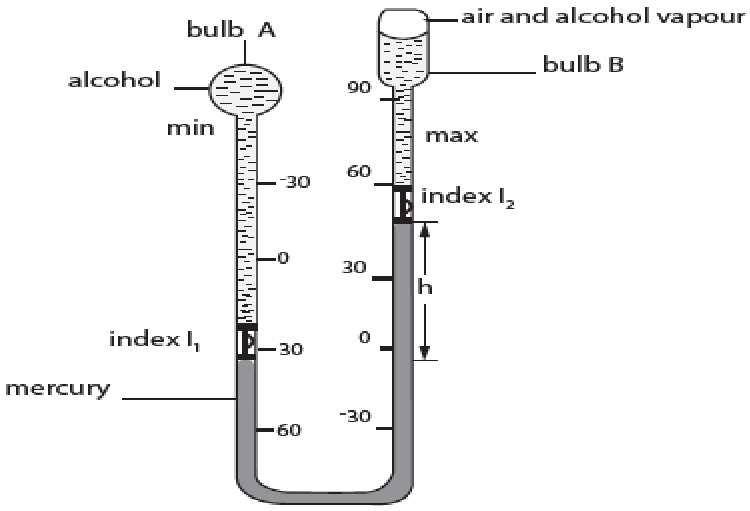


Fig.3.8 : Six's maximum and minimum thermometer

When the temperature falls, alcohol in bulb A contracts. Due to the pressure difference in the two arms of the U-tube, mercury level will rise on the left hand side of the U-tube pushing the index I_1 upwards. The index I_2 on the right hand side is left behind (held by the fine spring) to register the maximum temperature. The lower end of index I_1, touching the mercury meniscus gives the minimum temperature.
The two steel indices can be reset with the help of a magnet.

3.1.8 Calibration of thermometers

Calibration of mercury thermometer
Activity
To demonstrate how to calibrate a mercury thermometer
(a) Lower fixed point

Materials: Thermometer, ice, stand and clamp, bunsen burner, beaker

Steps

1. Immerse the bulb completely inside a beaker containing pure melting ice as shown in Fig. (a). What do you observe? Explain.
2. Wait for sufficient time for the mercury to attain the temperature of the melting ice (Fig. (b).
3. When there is no more change in the level of mercury, mark its position on the stem. Suggest the name given to the marked position.

The point marked is the lower fixed point. Mark it as 0ºC. Note that the melting point of ice is exactly 0ºC (mm Hg) at standard atmospheric pressure (760 millimeters of mercury).

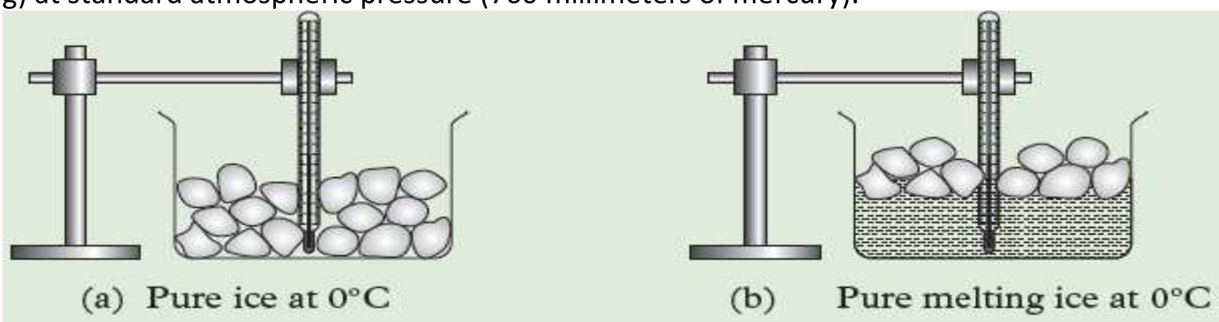


Fig.3.9 : Calibrating the lower fixed point

(b) Upper fixed point

Steps

1. Expose the bulb to steam just above the boiling water as shown in Fig. below

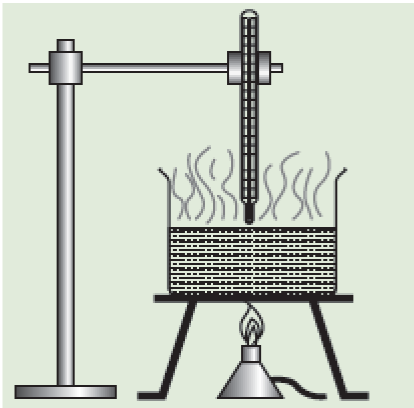


Fig. 3.10: Calibrating the upper fixed point

2. Give it time for the mercury to attain the temperature of the steam.
3. When there is no more change in the level of mercury, mark its position on the stem.

The point marked is the upper fixed point. Mark it as 100ºC. The temperature of steam is exactly 100ºC at standard atmospheric pressure (760 mmHg).

Thermometers are calibrated by identifying the fixed points. The fixed points will help in determining the highest and the lowest values a thermometer can measure.

Fixed point is a single temperature at which a particular physical event always takes place.

There are two types of fixed points namely: ***upper fixed point*** and ***lower fixed point***.

The upper fixed point (steam point) is the temperature of steam above pure boiling water at normal atmospheric pressure. It takes place at 100°C at sea level.

The lower fixed point (ice point) is the temperature of a pure melting ice at normal atmospheric pressure. It takes place at 0°C. The different between the lower fixed point and upper fixed point is called ***the fundamental interval***.

The distance between the two fixed points is divided into 100 equal parts. The scale obtained is called the ***centigrade scale***, and the thermometer is known as the ***centigrade thermometer***. Each division on the scale is one degree centigrade (1ºC).

Thermometers may be used to measure unknown temperature as shown below.

The stem of thermometer is y cm long between the upper and lower fixed points. The mercury thread is x cm above the lower fixed point at the unknown temperature θ.

Therefore, $\theta = \frac{x}{y} \times 100°C$

Where θ is the temperature in °C.

Example 1

Fig. 9.11, not drawn to scale, shows a mercury-in-glass thermometer where the mercury level stands at 1 cm mark in the tube at 0˚C.

(a) Calculate the temperature when the mercury level stands at 7.5 cm mark.

(b) Find the mercury level in the thermometer when the temperature is 61ºC

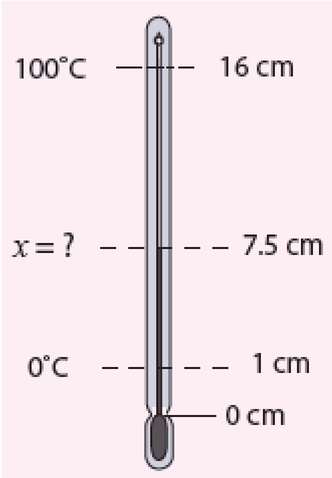


Fig. 3.11: Thermometer

Solution

(a) The distance between the two fixed points i s 16.0 – 1.0 = 15.0 cm.
This distance represents a temperature change of (100 – 0) = 100˚C.
Let (7.5 – 1.0) cm represent a temperature x ºC
15 cm represents 100ºC

1 cm represents $\frac{100}{15}$°C

$\therefore$ 6.5 cm represents $x = \frac{100}{15} \times 6.5$

$= 43.3$ °C

$\therefore$ The temperature reading is 43.3 °C

Or

$$\theta = \frac{x}{y} \times 100°C$$

$$= \frac{6.5}{15} \times 100°C$$

$$= 43.3°C$$

(b) 100ºC is represented by 15 cm

1°C represents $\frac{15}{100}$ cm

61°C is represented by $\frac{15 \times 61}{100}$ cm = 9.15

Level of mercury = 9.15 cm + 1.0 cm

= 10.15 cm

Exercises

1. Describe how a clinical thermometer works.
2. Briefly explain the meaning of:
   (a) Lower fixed point.
   (b) Upper fixed point.
3. State two properties of thermometric liquids.
4. A thread of mercury in the bore of a thermometer has a length of 9 cm when the temperature is 15°C. When the temperature rises to 101°C, the length increases to 20 cm. Find:
   (a) The length when the temperature is 75°C.

(b) The temperature when the length is 12 cm.

3.1.9: Measurement of heat quantity

Topic 5 Determination of Heat quantity

Activity 1

To show that the heat energy required to produce a certain change in temperature depends on the mass of the substance.

Materials

- Water bath
- An egg
- Heat source

Steps

1. Place an egg in a water bath. Heat the water bath till the water boils.
2. Transfer the egg to a beaker of cold water and observe. Explain what happens to the egg?

The larger the mass, the longer the time needed to change its temperature. This means the larger the mass, the more heat is supplied to change the temperature by one degree. Hence the quantity of heat energy, Q, gained by a substance through a certain temperature change is directly proportional to its mass, m. Therefore,

Heat energy is proportional to mass that is; $Q \alpha m$, when temperature change is constant.

Activity 2

To show that the heat energy required by a substance of a given mass depends on the change in temperature

Steps

1. Repeat the above activity step 2 with 200 g of water, but this time, heat to produce twice the change in temperature. Note the time taken for this to happen.
2. Which case takes more time, heating up to a given temperature or up to double that temperature?
3. What relationship does this observation show between quantity of heat and change in temperature?

The longer the time of heating, the more heat energy supplied and the greater the temperature change.

Heat energy, Q is proportional to change of temperature, $\Delta\theta$, when mass of a substance is constant. $Q \alpha \Delta\theta$.

The S.I unit of heat quantity is Joule (J). Other unit of heat quantity is calorie (cal) or Kilocalorie (Kcal).

Where 1 Cal ~ 4.2J in some books.

Example 1

200 J of heat energy is needed to change the temperature of a given mass of water from 20 ºC to 34 ºC.

How much heat energy is needed to change the temperature of this mass of water from 20 ºC to 48 ºC?

Solution

Case 1: temperature change = (34 – 20) = 14 ºC, heat required Q1 = 200 J

Case 2: temperature change = (48 – 20)ºC = 28 ºC

200 J ———————— 14 ºC

Q2 ———————— 28 ºC

Heat energy needed, Q2 = $\frac{200 \times 28}{14}$

= 400 J

Heat capacity of a substance can be therefore defined as the heat energy required to raise the temperature of a substance by 1 K.

Mathematically,

$$\text{Heat capacity (c)} = \frac{\text{Amount of Heat supplied (Q)}}{\text{Temperature change } (\Delta\theta)} \text{ J/K}$$

The SI unit of heat capacity is joule per kelvin (J/K)

Example 2

Calculate the quantity of heat required to raise the temperature of a metal block of capacity of 520 J/K from 9 ºC to 39 ºC.

Solution

Quantity of heat Q = Heat capacity × temperature change

Q = c × Δθ or Q = m×C× Δθ, C is the specific heat capacity

= 520 × (39 – 9)

= 15 600 J

Example 3

The quantity of heat required to raise the temperature of water from 10 ºC to 65 ºC is 6 200 J. Calculate the heat capacity of water.

Solution

$$Q = c\Delta\theta \Rightarrow C = \frac{Q}{\Delta\theta}$$

$$= \frac{6\ 200 \text{ J}}{(65 - 10)\text{K}} = 112.73 \text{ J/K}$$

The heat capacity of water is 112.73 J/K

Exercises

1. The heat capacity of water depends on the mass of the water being heated. TRUE or FALSE? Justify your answer.
2. Calculate the heat capacity of tea when 400 J of heat are supplied to change its temperature from 25 K to 40 K.
3. Calculate the amount of heat energy given out to lower the temperature of a metal block of heat capacity 520 J/K from 60 ºC to 20 ºC.

Specific heat capacity

From the above activities 1 and 2 we learnt that.

Quantity of heat, Q α mass, m

Q α change in temperature, Δθ

Q α mΔθ or

$Q = mC\Delta\theta$ *where C is a constant*

When the mass of the substance is 1 kg (i.e. m = 1 kg) and the change in temperature is 1K (i.e. Δθ = 1 K), then Q = C and C is referred to as the ***specific heat capacity*** of the substance.

The specific heat capacity, C of a substance is defined as the heat energy required to change the temperature of a substance of mass 1 kg by 1 Kelvin.

$$C = \frac{Q}{m\Delta\theta}$$

Therefore,

Quantity of heat = mass × specific heat capacity × temperature change

$Q = mC\Delta\theta$

where, Δθ = final temperature – initial temperature

The SI unit of specific heat capacity is joule per kilogram per Kelvin (J/kg K).

Example 4

Calculate the heat energy required to raise the temperature of 2.5 kg of aluminium from 20 °C to 40 °C, if the specific heat capacity of aluminium is 900 J/kg K.

Solution

Heat energy required = mass × specific heat capacity × temperature change

$Q = mc\Delta\theta$

$= 2.5 \times 900 \times (40 - 20)$

= 45 000 J

Example 5.

18 000 J of heat energy is supplied to raise the temperature of a solid of mass 5 kg from 10 ºC to 50 ºC. Calculate the specific heat capacity of the solid.

Solution

$$c = \frac{Q}{m\Delta\theta}$$

$$= \frac{180\ 000\ \text{J}}{(50 - 10)\text{K} \times 5\ \text{kg}}$$

$$= 900\ \text{J/kg K}$$

Example 6

Find the final temperature of water if 12 000 J of heat is supplied by a heater to heat 100 g of water at 10 ºC.

(Take specific heat capacity of water and 4 200 J/kg K)

Solution

$$Q = mc\Delta\theta \Rightarrow \Delta\theta = \frac{Q}{m \times c}$$

$$= \frac{12\ 000\ \text{J}}{(0.1 \times 4\ 200)\ \text{J/K}}$$

$$= \frac{12\ 000\ \text{J}}{420}$$

$$= 28.57^\circ\text{C}$$

$\Delta\theta = \theta_f - \theta_i$, where θf – final temperature, θi – initial temperature

$\Rightarrow \theta_f = \Delta\theta + \theta_i$ = 28.57 ºC + 10 ºC

θf = 38.57 ºC

The final temperature is 38.57 ºC.

Exercises

1. 45 000 J of heat are supplied to 5 Kg of aluminium initially at 25ºC. What is its final temperature? (Take the specific heat capacity of aluminium as 900 J/kgk).
2. What is the difference between heat capacity and specific heat capacity?
3. 24 000 J of heat energy is supplied to raise the temperature of a substance of mass 6 kg from 12 ºC to 48 ºC. Calculate the specific heat capacity of the substance.

Table below shows that different substances have different specific heat capacities. This is true for solids and liquids but not in gases

Table 3.3: Values of specific heat capacities of metals

Substance	Specific heat capacity (c) J/kg K
Aluminium	900
Brass	370
Copper	390
Cork	2000
Glass	670
Ice	2100
Iron	460
Lead	130
Silver and tin	230

Activity 3
To determine the specific heat capacity of a solid by the electrical method

Materials

- Electric circuit
- Heating element
- Metal cylinder
- Thermometer
- Variable resistor
- Cotton wool
- Aluminum foil
- Wooden container
- Solid metal blocks in the form of a cylinder, with 2 holes.

Steps

1. Measure and record the mass, m, of the metal cylinder.
2. Insert an electrical heater in position in the metal block through the larger hole and a thermometer through the other hole.
3. Note the initial temperature of the metal block θ1.
4. Cover the solid with cotton wool or felt material and wrap a aluminium foil around cotton wool.
5. Place the set up a wooden container. Complete the electrical circuit as shown in figure below

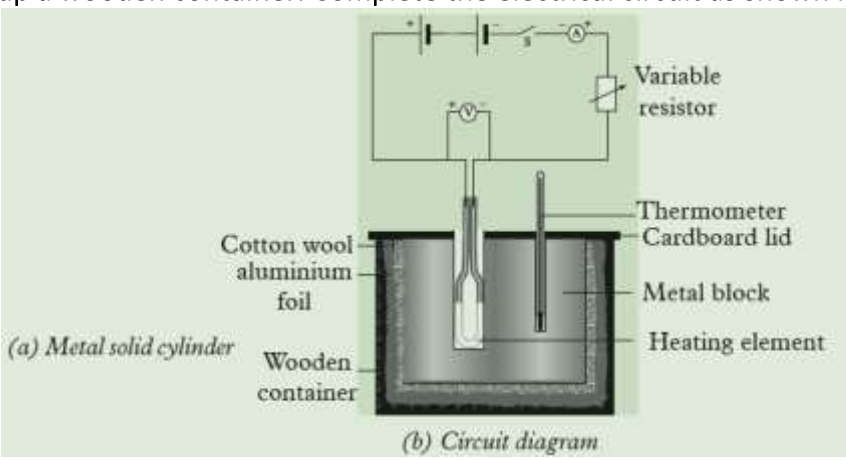


Fig.3.12 : Specific heat capacity of a solid by electrical method.

6. Close the switch S and start a stop watch at the same time.
7. Use the variable resistor to maintain a steady current passing through the heater.
8. Note the current I through the heater with the ammeter and the potential difference, *V* across the heater with the voltmeter.
9. Pass this steady current for some time so that the rise in temperature in the solid is about 8 ºC.
10. Note the time *t*, when the final temperature of the solid is θ2.
11. Calculate the change in temperature Δθ = θ2 – θ1.
12. Show the relationship between electrical energy used and the heat energy gained by the metal and hence calculate the specific heat capacity of the metal cylinder.
13. How much electrical energy has been spent in this time? What has happened to this energy? What is the purpose of cotton wool or felt material, aluminium foil and the wooden container?

Electrical energy *E,* spent by the heater in a time, *t* , is given by E = VIt. This energy is converted into heat energy and has been absorbed by the metal solid cylinder. Heat energy gained by the metal

$Q = mc\Delta\theta$

Assuming no energy from the heater is lost to the surrounding, electrical energy used = heat energy gained by the metal cylinder.

∴ $VIt = mc\Delta\theta$, from which the specific heat capacity, *c*, of the solid can be calculated.

$$c = \frac{VIt}{m\Delta\theta}$$

Example

The following data was obtained from an experiment similar to that of Activity 5.25. Mass of copper metal block = 200 g, initial temperature of the block = 22°C, ammeter reading = 0.5 A, voltmeter reading = 3.0 V, final temperature of the block = 30 °C, time of heating = 7 minutes. Use the data to calculate the specific heat capacity of copper. What does this value mean?

Solution

Electrical energy spent is given by, $E = VIt$.

Assuming no energy from the heater is lost to the surrounding,

Heat energy gained by the metal block = $mc\Delta\theta$.

$mc\Delta\theta = VIt$

$$\therefore c = \frac{VIt}{m\Delta\theta} = \frac{3.0 \times 0.5 \times (7 \times 60)}{0.200 \times (30 - 22)}$$

$$= \frac{3.0 \times 0.5 \times 420}{0.200 \times 8}$$

$$= 393.75 \text{ J/kg K}$$

$$\therefore \text{ specific heat capacity of copper} = 394 \text{ J/kg K}$$

This means that to raise the temperature of 1 kg of copper by 1 K(or by 1°C), 394 Joules of heat energy are required.

Example 2

Calculate the heat energy required to raise the temperature of 2.5 kg of aluminium from 20 °C to 40 °C, if the specific heat capacity of aluminium is 900 J/kg K.

Solution

Heat energy required $Q = mc\Delta\theta$

$= 2.5 \times 900 \times (40 - 20)$ J

$= 45\ 000$ J

3.1.11: Principle of heat exchange

- Topic6: Determination of the specific heat capacity of substances by using the principle of heat exchanges

Activity 1

To determine the specific heat capacity of water by the method of mixtures

Materials

- A solid of known specific heat capacity (cs)
- Weighing machine
- Water bath
- Thermometer
- Beaker
- Stirrer
- Heating source
- Tripod stand

Steps

1. Take a solid of known specific heat capacity (*c*s) and measure its mass (*m*s).
2. Heat it in a water bath till the water starts boiling, as shown in Fig. (a).
3. In the meantime, take an empty, clean and dry container of known specific heat capacity (*c*c) and measure its mass (*m*c).
4. Put water into the container, say to half of the container, and measure the total mass.
5. Calculate the mass of water (*m*w) whose specific heat capacity (*c*w) is to be determined.
6. Find the initial temperature (θ1) of water and the container (Fig. (b)).
7. When water in the water bath has started boiling, note the temperature of the solid (θs) in the water bath.
8. Quickly transfer the hot solid into cold water in the container and observe the temperature of the mixture.

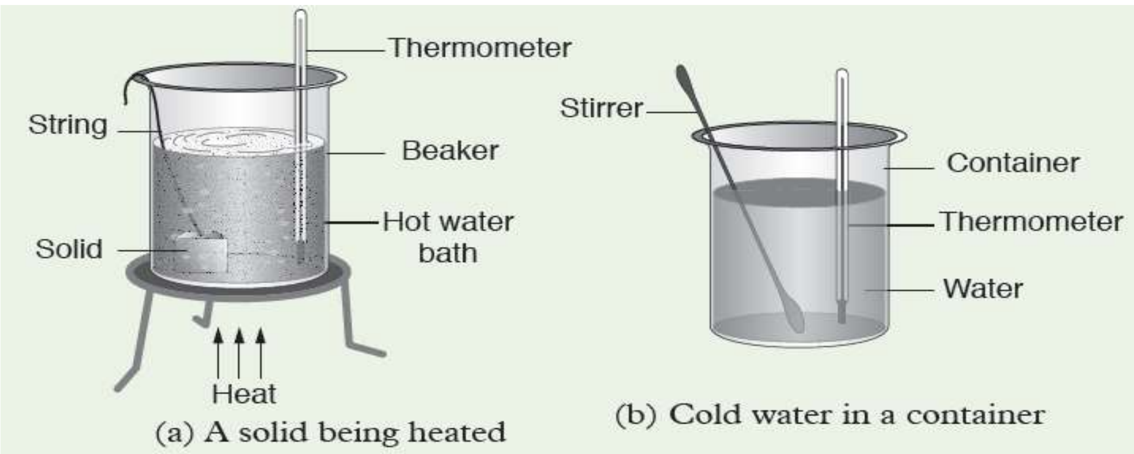


Fig.3.13 : Specific heat capacity of water by method of mixture.

9. Stir the contents gently to distribute the heat uniformly throughout the mixture and note the final maximum steady temperature of the mixture ($\theta 2$).
10. What happens to the cold water and the container when the hot solid is transferred into the container?
11. Using all the data you have collected, calculate the specific heat capacity of water using the equation:

    Heat lost by solid = heat gained by water (This is the principle of heat exchange)
12. What precautions have to be taken to ensure accuracy in the experimental procedure?
13. Highlight the assumptions for this activity.

The temperature of the solid has decreased from θs to $\theta 2$, showing that the solid has lost heat energy. The temperature of the cold water and the container has increased from $\theta 1$ to $\theta 2$ showing that they have gained heat energy.

Quantity of heat energy lost by the hot solid = $m_sC_s(\theta_s - \theta_2)$

Quantity of heat energy gained by the container and cold water

= $(m_cC_c + m_wC_w)(\theta_2 - \theta_1)$

Assuming no energy is lost to the outside;

Energy lost by the hot solid = heat energy gained by the container (calorimeter) and cold water.

∴ $m_sC_s(\theta_s - \theta_2) = (m_cC_c + m_wC_w)(\theta_2 - \theta_1)$ from which the specific heat capacity of water (C_w) can be calculated.

As a precaution, the container has to be covered with wool or felt and aluminium foil wrapped round the cotton wool. Note; the whole arrangement has to be placed inside a wooden container before the hot solid is transferred into the cold water in the container. These precautions ensure that minimum heat energy is lost from the mixture to the surroundings.

Experiments show that specific heat capacity of water is 4 200 J/kgK. This means that we need 4 200 Joules of heat energy to raise the temperature of 1 kg of water by 1K. Note that this value is about 10 times more than that of copper or iron. Once water is heated it retains the heat energy for a long time due to its high specific heat capacity.

Example

In an experiment, to calculate the specific heat capacity of water, the following data was obtained. Mass of the solid = 50 g, specific heat capacity of the solid = 400 J/kg K, initial temperature of the hot solid = 100 °C, mass of the container = 200 g, specific heat capacity of the material of the container = 400 J/kg K, mass of water = 100 g, initial temperature of the water and the container = 22 °C.

When the hot solid was transferred into the cold water in the container, the temperature of the mixture was 25 °C.

Use the data to calculate the specific heat capacity of water.

Solution

Let the specific heat capacity of water be cw

Heat lost by the hot solid = $mc\Delta\theta = 0.050 \times 400 \times (100 - 25)$

$= 1\,500$ J

Heat gained by the container and water = $mc\Delta\theta$ container + $mc\Delta\theta$ water

$= 0.200 \times 400 \times (25 - 22) + 0.100 \times cw\,(25 - 22)$ J

$= 80 \times 3 + 0.1\,cw \times 3$

$= 3\,(80 + 0.1\,cw)$ J

Assuming no energy losses to the surroundings

Heat lost = heat gained

1 500 J= 3 (80 + 0.1 cw)

500 = 80 + 0.1 cw (on dividing by 3 both sides)

420 = 0.1 cw

∴ cw = 4 200 J/kg K

Cw: Specific heat capacity of water

Activity 2

To determine the specific heat capacity of a liquid by electrical method

Materials

- Carolimeter
- Stirrer
- Themometer
- Heater
- A liquid
- Electrical circuit
- Variable resistor

Steps

1. Measure and record the mass, *m*c, of an empty, clean and dry copper container with the stirrer of the same specific heat capacity, *c*c.
2. Gently pour the liquid of known mass, *ml*, into the container. Let the specific heat capacity of the liquid be *cl*.
3. Note the initial temperature of the liquid and the container, θ1.
4. Complete the electrical circuit as shown in Fig. below with the heater fully immersed in the liquid without touching the base or the sides of the container.

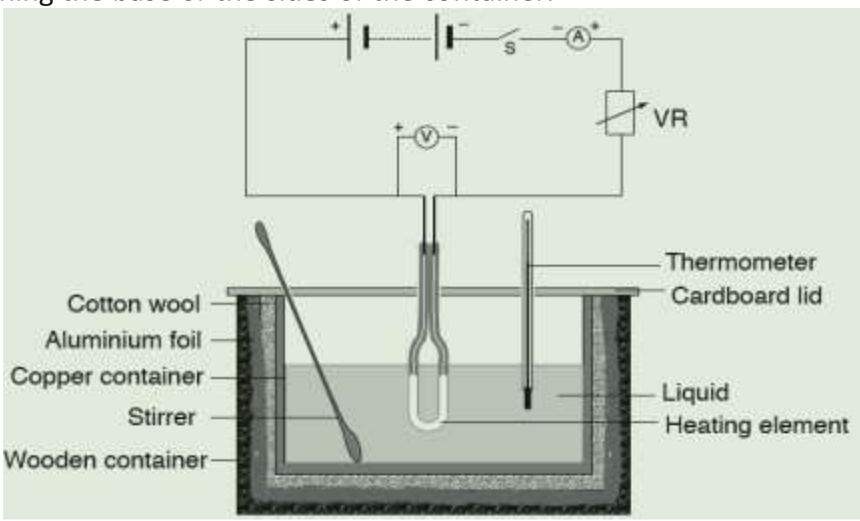


Fig.3.14 : Finding specific heat capacity of a liquid by electrical method.

5. Close the switch *S* and start a stop watch at the same time.
6. Use the variable resistor *VR* to maintain a steady current passing through the heater.
7. Note the current I through the heater with the ammeter and a p.d *V* across it with the voltmeter. Pass this steady current for some time so that the rise in temperature of the liquid and the container is about 5 ºC.
8. Keep stirring the liquid gently throughout the experiment. Note the time, t, taken when the final temperature of the liquid and the container is θ2. Calculate the change in temperature Δθ = (θ2 – θ1).

9. How much electrical energy has been spent in this time?
10. What has happened to this energy?
11. Using all the data you have collected, calculate the specific heat capacity of the liquid. (Hint: Electrical energy supplied = heat energy gained by liquid)
12. What precautions have to be taken during the experiment?

Electrical energy spent = heat energy gained by the liquid, the container and the stirrer.

∴ $VIt = m_c c_c(\theta_2 - \theta_1) + m_l c_l(\theta_2 - \theta_1)$

$VIt = (m_c c_c + m_l c_l)\Delta\theta$

From this equation, the specific heat capacity of the liquid c_l can be calculated.
Different liquids have different specific heat capacities.

Table3.4: Specific heat capacity of some liquid

Substance	Specific heat capacity (c) J/kg K	Substance	Specific heat capacity (c) J/kg K
Castor oil	2 130	Olive oil	2 000
Coconut oil	2 400	Paraffin oil	2 130
Glycerol	2 400	Sulphuric acid	1 380
Mercury	140	Water	4 200

Example

In an Activity similar to the above, the following data was obtained. Power of electric heater = 30 W, mass of the container and the stirrer = 200 g, specific heat capacity of the container and the stirrer = 400 J/kg K, mass of water in the container = 100 g, specific heat capacity of water = 4 200 J/kg K.

Use the data to calculate the time taken by the heater to rise the temperature of water, container and the stirrer from 20 °C to 23 °C. What assumption have you made in your calculations?

Solution

Assuming all the electrical energy is absorbed by the container, stirrer and water,

Electrical energy used = Heat energy gained

$VIt = (mc\Delta\theta)_{container + stirrer} + (mc\Delta\theta)_{water}$

As electrical power P = VI and the time taken is t,

$Pt = (mc\Delta\theta)_{container + stirrer} + (mc\Delta\theta)_{water}$

$\therefore 30\,t = 0.200 \times 400 \times 3 + 0.100 \times 4\,200 \times 3$

$30\,t = 3(0.200 \times 400 + 0.100 \times 4\,200)$

$30\,t = (80 + 420)3$

$\therefore t = 50$ seconds

Exercises

The assumption made is that there is no heat used to the surrounding.

Where necessary, take specific heat capacity of water = 4 200 J/kg K, acceleration due to gravity g = 10 m/s^2.

1. Define
   (a) Heat capacity
   (b) Specific heat capacity of a substance
2. Calculate the:
   (a) Heat energy required to raise the temperature of 200 g of gold of specific heat capacity 130 J/kg K by 1 000 ºC.

(b) Heat energy given out when a piece of hot iron of mass 2 kg cools down from 450 ºC to 25 ºC, if the specific heat capacity of iron is 460 J/kg K.

3. Describe an activity to determine the specific heat capacity of a solid by the method of mixtures. State the necessary precautions to be taken during the activity.
4. Define specific heat capacity of water. How would you determine the specific heat capacity of water by the method of mixtures?
5. An electric kettle rated 2 kW is filled with 2.0 kg of water and heated from 20 ºC to 98 ºC. Calculate the time taken to heat the water assuming that all the electrical energy is used to heat the water in the electric kettle and the kettle has negligible heat capacity.
6. A piece of metal of mass 200 g at a temperature of 150 ºC is placed in water of mass 100 g and temperature 20 ºC. The final steady temperature of the water and the piece of metal is 50 ºC. Neglecting any heat losses, calculate the specific heat capacity of the metal.
7. Describe an experiment to determine the specific heat capacity of a liquid by electrical method.
8. A piece of iron of mass 200 g at 300 ºC is placed in a copper container of mass 200 g containing 100 g of water at 20 ºC. Find the final steady temperature of the mixture, assuming no energy losses. The specific heat capacities of copper and iron are 390 J/kg K and 460 J/ kg K. respectively.
9. A class of Physics students decided to determine the specific heat capacity of water in a waterfall. They used a sensitive thermometer to find the difference in temperature of water at the top and the bottom of the waterfall and obtained the following results; height of the waterfall = 52 m, temperature of water at the top = 21.54 ºC. Temperature of water at the bottom = 21.67 ºC. Stating any assumptions made, calculate a value for the specific heat capacity of water.

Summary

• Heat is a form of energy which is transferred from a region of higher temperature to a region of lower temperature.

• The SI unit of heat energy is Joule (J).

• Two substances of equal masses can be at the same temperature but contain different amounts of heat energy and vice-versa.

- Heat energy can be transferred by three different modes: conduction, convection or radiation.
- Solids are heated by conduction and fluids by convection. Radiation can take place through vacuum.
- We get heat energy from the sun by radiation.
- The quantity of heat transferred depends on the following factors:
  i. The temperature difference.
  ii. The nature of the materials.
  iii. The cross-sectional area.
  iv. The length of the material.
  v. The time taken to transfer heat.
- Heat capacity of a substance is the quantity of heat energy required to change the temperature of the substance by 1 K. Specific heat capacity of a substance is the quantity of heat energy required to change the temperature of 1 kg of the substance by 1 K. Whenever there is a change in temperature of a substance, the quantity of heat energy involved is given by, $Q = mc\Delta\theta$.

Learning Outcome 3.2: Describe the heat transmission

- Topic1: Differentiate conductors from insulators

3.2.1: Difference between conductors and insulators

Definition of Conductor

A conductor is defined as the material which allows the electric current or heat to pass through it. The electrons in a conductor freely moved from atom to atom when the potential difference is applied across them. The conductivity of the conductor depends on the number of free electrons in the outermost shell of the orbit.

Silver is considered as the most conductive material. But the cost of the silver is very high and hence it is not used for making electrical wires and cables.

The resistance of the conductor is very low due to which the charges freely move from place to place when the voltage is applied across them. Copper, aluminium, silver, mercury, etc. are some of the examples of the conductor.

Definition of Insulator

The materials which do not allow the electric current or heat to pass through it such type of material is called an insulator. Thus, the electrons or charges do not move freely. The resistivity of the insulator is very high.

The insulator is mainly used for separating the conductor and for supporting the electrical equipment. It is also used in an electrical cable. Paper, wood, porcelain, etc., are some of the examples of an insulator.

Examples of Conductors

Examples of conductors include metals, aqueous solutions of salts (i.e., *ionic compounds* dissolved in water), graphite, aluminum, brass, bronze, silver, tin and lead and the human body.

Examples Insulators

Examples of insulators include plastics, Styrofoam, paper, rubber, glass, ceramic and dry air. The division of materials into the categories of conductors and insulators is a somewhat artificial division. It is more appropriate to think of materials as being placed somewhere along a continuum. Those materials that are super conductive (known as **superconductors**) would be placed at on end and the least conductive materials (best insulators) would be placed at the other end.

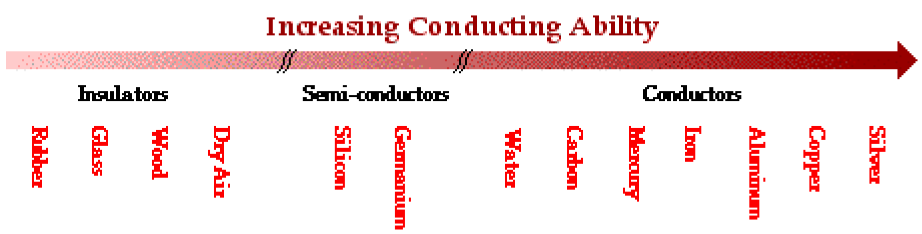


Fig.3.15: Increasing conducting ability

Table 3.7: Difference between Conductor and Insulator

Conductors	**Insulators**
A conductor is a substance that transmits heat or electricity	An insulator restricts the transfer of heat or electricity.
Conductors contain a large number of free electrons.	Insulators do not contain free electrons.
Metals are conductors.	Non-metals are insulators.
Conductivity is high	Conductivity is low
Conductors are used for making electrical wires	Conductors are used for insulating electrical wires or conductors for supporting electrical equipment, etc

3.2.2 Different modes of heat transfer

- Topic2: Identification of the three modes of heat transfer

Introduction

A) Modes of heat transfer

The heat from a substance to others can be transferred using three ways:

- Conduction
- Convection
- Radiation

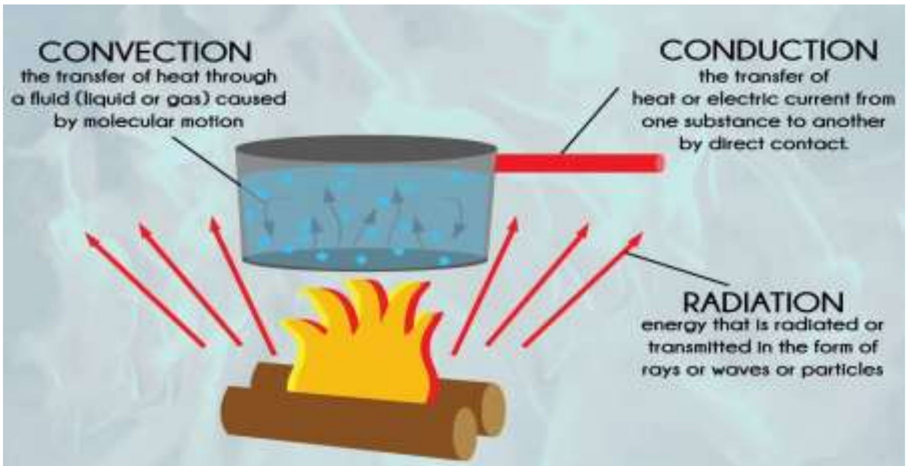


Fig.3.16: Modes of heat transfer

Activity

Heating some liquid in a saucepan

The figure below shows a person heating some liquid in saucepan over an electric coil.

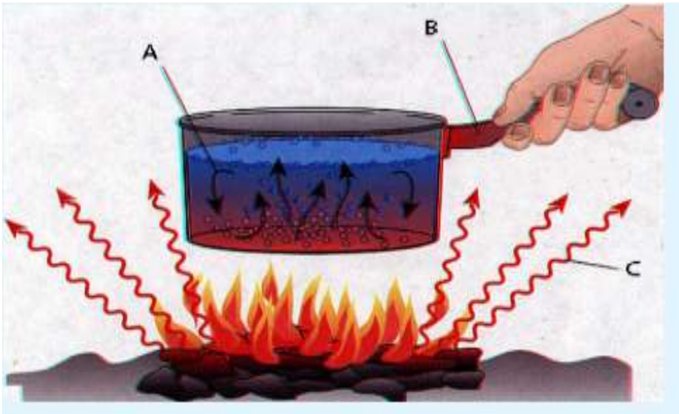


Fig.3.17 : Heating some liquid in a saucepan

Steps

1. Identify the modes of heat transfer marked A, B and C.
2. Discuss how each of the modes of heat transfer takes place, citing the states of matter through which the processes take place.
3. Describe one application of each type of the above modes of heat transfer in real life.
4. Present your findings to the rest of the class in a class discussion.

In our environment, most interactions between systems involve transfer of heat from one system to another. For example, when we bask in the sun, we feel warmer, when we touch a hot sauce pan, we feel the heat. In this learning outcome, we are will discuss the different modes through which heat is transferred from one region to another.

i) Heat transfer by conduction

Activity

Demonstration of conduction of heat

Materials:

- A metal spoon
- A beaker full of boiling water
- Bunsen burner
- Wax

Steps

1. Take a metal spoon at room temperature. Dip the spoon (with the other end waxed) into a beaker full of boiling water (Fig. below). After a few minutes, what do you observe? Touch the free end of the metal spoon outside water. What do you feel? Explain.

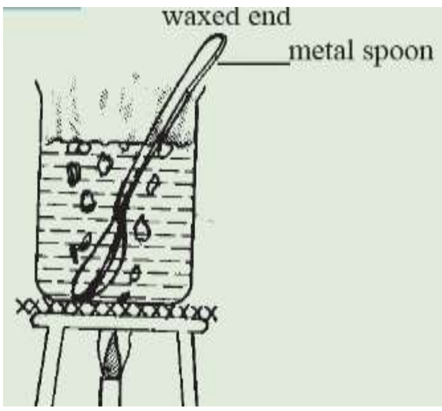


Fig.3.18 : A spoon inside boiling water

2. Discuss how heat is transferred by conduction.

Solids transfer heat from one point to another. For instance, the free end of the spoon outside the beaker in above Figure has become hot. Heat energy has been transferred from the inside to the outside through the metal spoon i.e. from a region of *higher temperature* to a region of *lower temperature*.

This process of transfer of heat energy in solids is called *conduction*. Conduction is the transfer of heat from one substance to another that is in direct contact with it. In conduction there is no visible movement of the heated particles.

Mechanism of conduction of heat

We have already learnt that when temperature increases, the molecules have larger vibrations. This knowledge can help us understand the mechanism of conduction of heat. When the molecules at one end of a solid receive heat energy from the heat supply, they begin to vibrate vigorously. These molecules collide against the neighbouring molecules and agitate them. The agitated molecules, in turn, agitate the molecules in the next layer and so on till the molecules at the other end of the solid are agitated. Thus, the heat is passed from one point to another till the other end becomes hot. Hence, in ***conduction,*** energy transfer takes place by vibration of the molecules. There is no actual movement of the heated particles. Heat energy flows due to ***temperature difference*.**

ii) Heat transfer by convection

Convection in liquids

Activity

To observe convection current in water

Materials

- A long straw
- A crystal of potassium permanganate
- A beaker containing water
- A bunsen burner

Steps

1. With the help of a long straw, drop a small crystal of potassium permanganate to the centre of the bottom of a flask or a beaker containing water. What do you observe?
2. Heat the flask gently at the center of the flask (Fig. below). Observe what happens.

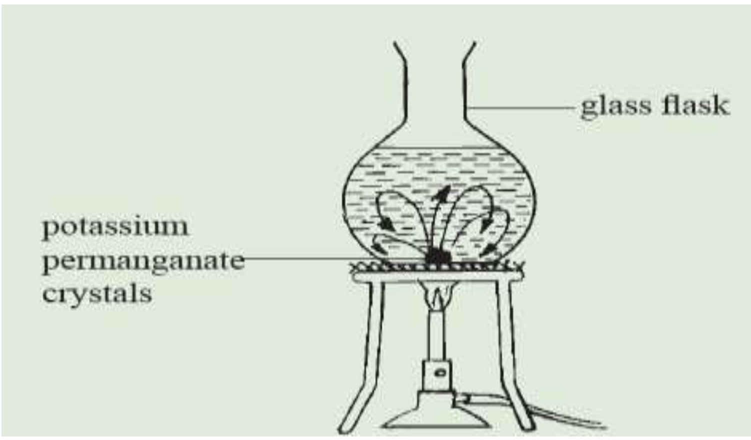


Fig.3.19 : Convection currents in water

Coloured streaks are observed to rise from the bottom to the top.

The crystal dissolves and the hot water of less density starts rising displacing the cold dense water down. The streams of physically moving warm liquid are called *convection currents*.

Heat energy is transferred by the convection currents in the liquid. The transfer of heat by this current is called ***convection***.

Convection in gases

Activity

To observe convection current in air

Materials:

- A box with a glass window, and two chimneys
- A candle
- Smouldering pieces of wick

Steps

1. Take a box with a glass window and two chimneys fixed at the top.
2. Place a lighted candle under one chimney and hold a smouldering piece of wick above the other chimney as shown in Fig. below. What do you observe?

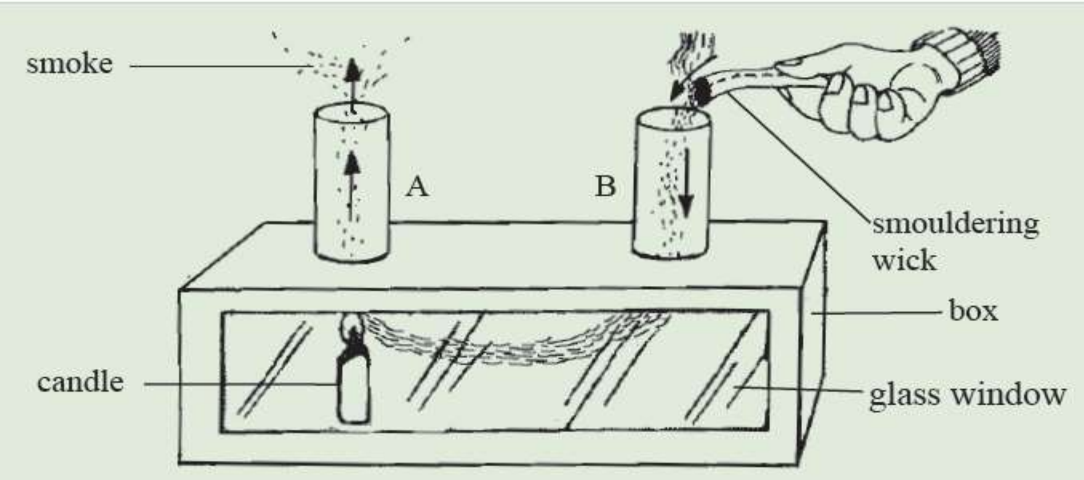


Fig.3.20 : Convection currents in air.

Smoke from the smoldering wick is seen to move down through chimney B then to the candle flame and finally comes out through chimney A.

Air above the candle flame becomes warm and its density decreases. Warm air rises up through chimney A and the cold dense air above chimney B is drawn down this chimney and passes through the box and up the chimney A. The smoke particles from the wick enable us to see path of convection current (Fig. above). Heat is transferred in air through convection currents.

iii) Heat transfer by radiation

The concept of radiation

If you stand in front of a fireplace, you feel your body becoming warm. Heat energy cannot reach you by conduction as air is a poor conductor of heat. How about convection? The hot air molecules in and around the fireplace can only rise and do not reach you by convection. How does the energy from the fireplace then reach you? Heat energy must be transferred by a different mode other than conduction and convection.

Activity
To demonstrate heat transfer by radiation

Materials:

- A thin tin lid painted black
- A thumb tack
- Wax
- A bunsen burner

Steps

- Take a thin tin lid painted black on one side. Stick a thumb tack with melted wax on the other side.
- Keep the bunsen burner flame close to the painted side (Fig. below). What happens? Explain.

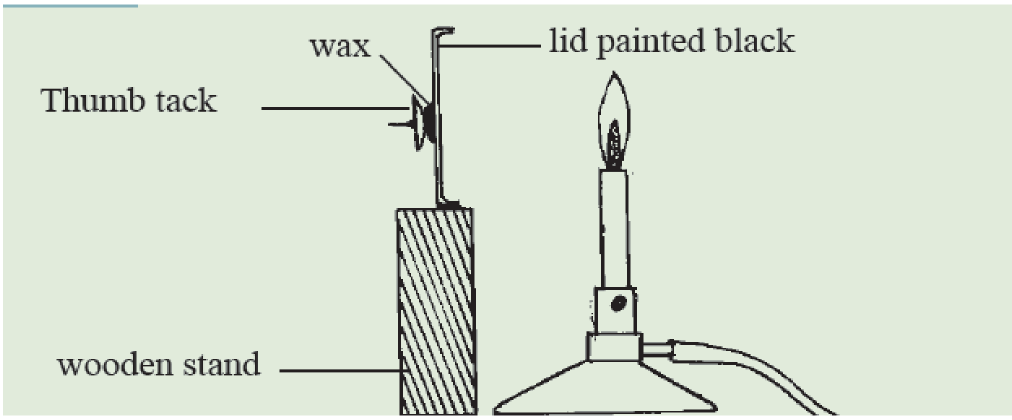


Fig.3.21 : Radiation

As discussed in the case of the fireplace, the energy from the flame reaches the tin lid and the wax by a different mode other than conduction and convection. This third mode of heat transfer is called *radiation.* Radiation is the emission or transmission of energy in the form of a wave or particles through a material or space. Heat transfer from the sun travels through empty space (vacuum) and reaches the Earth. This energy is transferred by radiation. The surfaces of all luminous bodies emit radiation. A human face also emits some mild radiations. While conduction and convection need a medium to be present for them to take place, radiation can take place without a medium.

The amount of heat energy radiated depends upon the temperature of the body. In the above Activity , if the bunsen burner is replaced by a candle flame, it will take a longer time for the wax to melt. The temperature of the candle flame is lower than that of a bunsen burner.

Heat transfer can take place without contact or in a vacuum. This method of heat transfer is called ***radiation*.**

Note:

- ✓ If a black and shiny surface receives the same amount of heat energy by radiation, the black surface *absorbs* more heat than the shiny surface.
- ✓ A dull black surface is a better *absorber* of heat radiation than a shiny surface.
- ✓ A shiny surface is a good emitter than a dull black surface

3.2.3 Applications of heat transfer

1. Vacuum flask

The vacuum flask popularly known as ***thermos flask***, was originally designed by *Sir James Dewar.* It is designed such that heat transfer by conduction, convection and radiation between the contents of the flask and its surroundings is reduced to a minimum.

A vacuum flask, Fig. below is a double-walled glass container with a vacuum in the space between the walls. The vacuum minimizes the transfer of heat by conduction and convection. The inside of the glass walls, is silvered so as to reduce heat losses by radiation. The felt pads on the sides and at the bottom support the vessel vertically.

The cork lid is a poor conductor of heat.

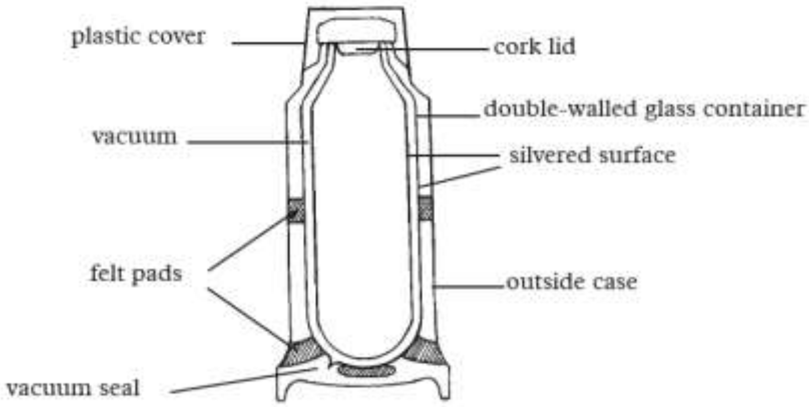


Fig.3.22: Vacuum flask

When the hot liquid is stored, the inside shiny surface does not radiate much heat. The little that is radiated across the vacuum is reflected back again to the hot liquid, by the silvering on the outer surface. There is however some heat lost by conduction through the walls and the cork.

2. Windows and ventilators in buildings

As shown in Fig. below, warm exhaled air of less density goes out through the ventilator and fresh air of high density enters through the windows at a lower level. This refreshes the air in a room.

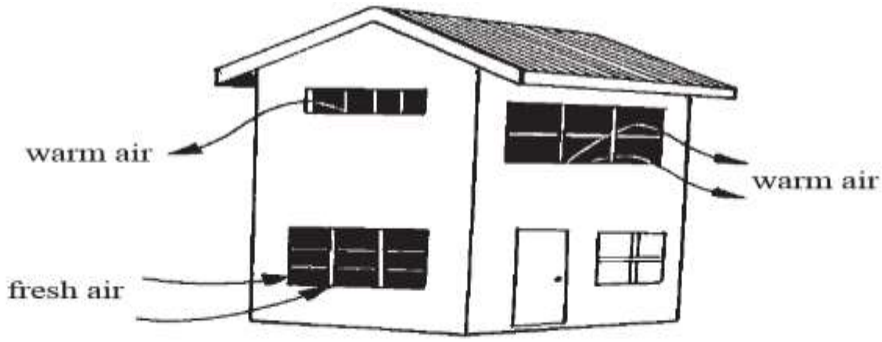


Fig.3.23: Ventilation in building

3. Natural convection currents over the earth's surface

(a) Sea breeze

During the day, the temperature of the land rises faster than the temperature of sea water and the air over the land becomes warmer than the air over the sea water. The warm air of less density rises from the land allowing the cold dense air over the sea to blow to the land. This creates a *sea breeze* in the daytime (Fig. below).

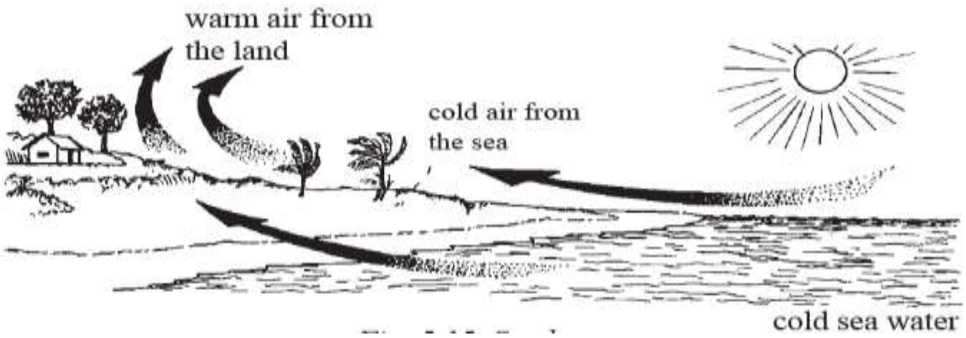


Fig.3.24: Sea breeze

(b) Land breeze

During the night, the land cools faster than the sea water. Warm air from the sea rises and the dense air from the land moves to the sea. This sets up a land breeze in the sea (Fig. below).

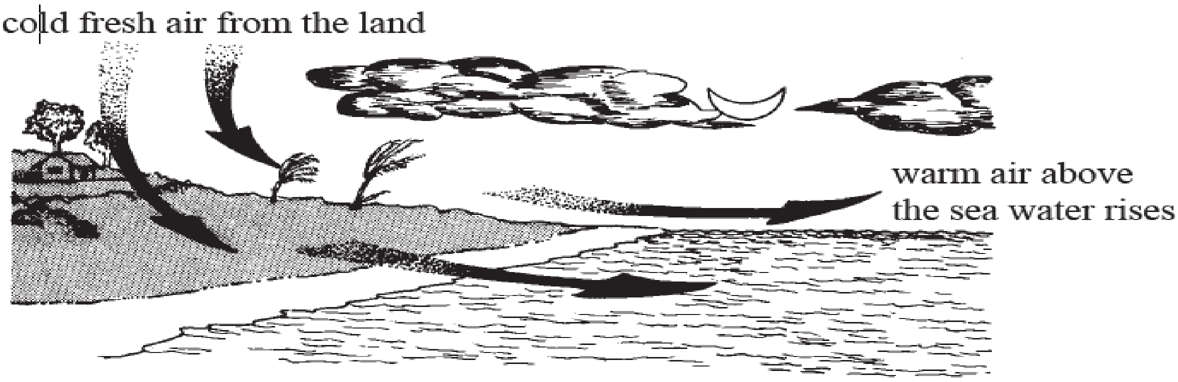


Fig.3.25 : Land breeze

Exercises

1. Distinguish between *heat* and *temperature*.
2. What are the different modes of heat transfer? Explain clearly their difference using suitable examples.
3. State three factors which affect heat transfer in metals. Explain how one of the factors you have chosen affects heat transfer.
4. Describe an experiment to show that water is a poor conductor of heat.
5. Use particle behavior of matter to explain conduction.
6. Describe a simple experiment to demonstrate that the heat radiated from a hot body depends upon the temperature of the body.
7. With a suitable diagram, explain the working of a vacuum flask.

3.2.5: Transformation of state of matter

- Topic 3: Identification of the three physical states of matter

Introduction

In our daily life we interact with solids, liquids and gases. We see them behaving in certain ways under particular conditions. But what are they exactly made of and what makes them behave in such ways? In this unit we will study the particulate nature of solids, liquids and gases and their behaviour when heated. This is usually referred to as the kinetic theory of matter.

In physics, a **state of matter** is one of the distinct forms in which **matter** can exist. Four **states of matter** are observable in everyday life: solid, liquid, gas, and plasma. ... **Matter** in the liquid **state** maintains a fixed volume, but has a variable shape that adapts to fit its container.

I. Types of state of mater

There are mainly three different kinds of the physical states of matter, namely:
- Solid
- Liquid
- Gas

Plasma a fourth class of matter has also been identified. These states of matter are also termed as phases.

1) Solid : Solids are characterized by their definite shape and also their considerable mechanical strength and rigidity. Solids tend to resist the deformation of their shape due to strong intra molecular forces and absence of the translatory motion of the structural units (atoms, ions etc). A solid is relatively non compressible, i.e. temperature and pressure have only a slight effect on its volume.

Solids are broadly classified as crystalline or amorphous.

Crystalline solids : Here the atoms are arranged in a definite pattern which is constantly repeated.

Amorphous solids : These have no definite geometrical form.

2) Liquid : A liquid has no definite shape and it takes the shape of the vessel containing it. Like solids, the volume of a liquid is slightly altered by variations in temperature and pressure. Liquids have three typical physical properties, namely:

i) Vapor pressure : A Liquid when kept in a closed container vaporizes into the free space above it. The process of vaporization will continue till the equilibrium is reached between liquid and vapor. The pressure at which the liquid and vapor can co-exist is called the vapor pressure of the liquid at a given temperature.

ii) Surface tension : The surface of a liquid is always in a state of tension because a molecule at the surface is attracted towards the bulk by a force much greater than that drawing it toward the vapor where the attracting molecules are more widely spread. Due to this, a certain force is required to penetrate along any line in the surface. This force is called surface tension.

iii) Viscosity : It determines the flow of the liquid. It is the internal friction between layers of the liquid. Higher the rate of friction, greater the viscosity of the liquid and its flow will be retarded. Conversely, a lower rate of friction lessens the viscosity and makes the liquid more fluid.

3) Gases : A gas has no bounding surface at all and will occupy completely any vessel in which it is filled. It has no definite volume or shape and can be easily expanded or compressed.

Laws governing behavior of gases will be dealt with in detail in the next chapter.

Water is the ideal example to show the different states of matter.

Water when cooled to 0^0C becomes solid. When the temperature of solid water is raised it becomes liquid. If the liquid is heated to 100^0C it gets converted to steam or vapor (The Gas phase).

Almost all chemical substances can exist in more than one physical state (phase) depending on external pressure and temperature.

Plasma: This is the fourth state of matter. It is a type of gas containing positively and negatively charged particles in approximately equal numbers and present in the sun and most stars.

Physical properties of matter

Matter can be in the form of solids, liquids and gasses and can be classified based on its chemical property and physical properties that have been tested and have been observed.

Some physical properties are only known through experimentation, while others are visible to the unaided eyes.

A physical property is a characteristic that can be observed or measured without changing the composition of the sample.

For example copper is a solid metal at room temperature, with a high melting point of about 1083ºC. It is shiny, bendable, and orange-brownish in colour. It can be stretched into a wire or flattened into a very thin sheet of metal. All these are physical properties because they do not change into anything else when these properties are observed. Similarly, passing electricity through copper will not change it into another substance.

A chemical property is a characteristic of a substance that is only altered through a chemical reaction and results into a substance of different composition and internal structure. In the same activity, you observed that when the piece of wood was burned, the chemical composition change hence it become ash. This is an example of a chemical property.

Other properties of matter are:

(i) **Intensive property**; it is a characteristic of matter that does not depend on the amount of matter being measured. They are the same even if it is for one gram or a 1000 kg of the substance. e.g. colour, odour, density, conductivity, hardness etc.

(ii) Extensive property; is any characteristic of matter that depends on the amount of matter being measured e.g. mass, weight, volume and length.

Examples of physical properties of matter include;

- **Mass**: is the amount of matter in an object. It is measured in g or kg.
- **Weight**: is a measurement of the gravitational force of attraction of the earth acting on an object. It is measured in newtons (N).
- **Solubility**: is the amount of substance that will dissolve in a given amount of solvent. Some substances are soluble while others are not. Examples of soluble substances are sugar, salt while insoluble substances are stones, metals, and sand.
- **Volume**: is the measurement of the amount of space a substance occupies.
- **Malleability**: is the ability of a substance to be beaten into thin sheets (by hammering or rolling of matter).
- **Ductility**: **is** the ability of a substance to be drawn into the wire (stretched into a wire).
- **Conductivity**: is the ability of a substance to allow the flow of electrical energy.
- **Hardness**: is how easily a substance can be scratched (how resistant a solid matter is to external force).
- **Melting point**: is the constant temperature at which a substance in solid state changes into the liquid state. The process is called melting.
- **Evaporation**: is the process of changing from liquid to gas. Evaporation from a liquid's surface can happen at a wide range of temperatures.

- **Boiling point**: is the constant temperature at which a liquid changes into a gas when the saturated vapor pressure of the liquid is equal to the external atmospheric pressure under one atmosphere.

  Note: if we know the melting and boiling point of a substance then we can say what state (solid, liquid or gas) it will be in at any temperature.

- **Freezing point**: **is** the constant temperature at which a liquid changes its state to become a solid. The process is called freezing.
- **Condensation**: is the process of changing from gas to liquid.
- **Sublimation**: is the process of going from a solid to a gas without passing through the liquid state. The reverse process is called deposition.
- **Density**: is the mass per unit volume of the substance.
- **Brittleness**: is the tendency of a material to break under stress.
- **Elasticity**: is the tendency of a material to return to its former shape when stretched or compressed.
- **Viscosity**; is a measure of how much a fluid resists movement of an object through it. Water has very low viscosity while honey has higher viscosity. An object will travel through water much faster than it does through honey.

1. Physical properties of solids

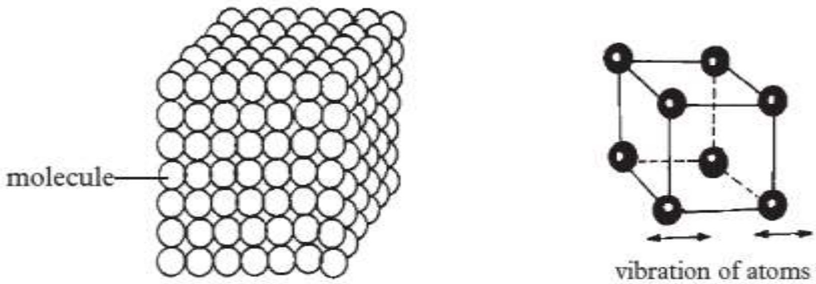


Fig.3.26: Arrangement of particles in solids

- The particles in a solid are so tightly packed making them difficult to move.
- Solids have strong intermolecular forces in between the particles making them particles to be closely packed in fixed positions (rigidity).
- Therefore, solids have a definite shape and volume. They are rigid and incompressible.
- They have the highest density compared to liquids and gases.
- A large force is needed to change the size and shape of a solid.
- Also, for a solid to melt into a liquid, it requires a lot of heat energy since the cohesive forces between the particles are strong.

2. Physical properties of liquids

- The liquid molecules move freely,
- The distance between the molecules is slightly greater than the distance between molecules of a solid.
- The molecules of a liquid are loosely packed unlike those of the solid (Fig. below).

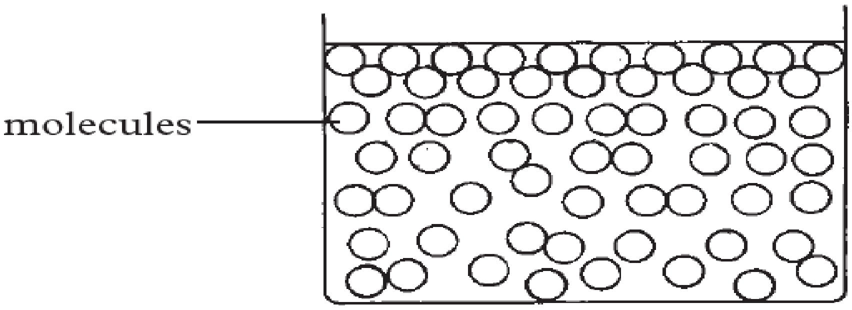


Fig.3.27 : Arrangement of particles in liquids

Though solids have a definite volume, they have no definite shape. The force of attraction between the molecules is lower than the force of attraction between the molecules of a solid.

Though liquids have definite size (volume), they have no particular shape. They take the shape of the container.

When the temperature increases, liquid molecules acquire more kinetic energy and hence move faster. This increase in kinetic energy of liquid molecules weakens the intermolecular forces between the particles. A further increase in kinetic energy makes the molecules to escape through the surface of the liquid. i.e., change into steam or gaseous state. The process of a liquid changing into the gaseous state is called **evaporation/boiling**.

The following are some other physical properties of liquids:

(a) Viscosity

Water has the lowest viscosity than other liquids since it offers minimum resistance to the movement. Honey has the highest viscosity than the other liquids.

(b) Solubility

The solubility of a substance is the amount of that substance that will dissolve in a given amount of solvent. Some substances are soluble while others are not. Examples of soluble substances are sugar, salt while insoluble substances are stones, metals, and sand.

(c) Evaporation

Evaporation is the process of changing from liquid to gas. Evaporation at a liquid’s surface can take place at a wide range of temperatures.

(d) Boiling point

Boiling point is the temperature at which a liquid changes into a gas when the saturated vapor pressure of the liquid is equal to the external atmospheric pressure under one atmosphere. At this point, the liquid changes to gases state at constant temperature.

Fixed: keeps the shape when placed in a container

Indefinite: takes the shape of a container

3. Physical properties of gases

In gases, the intermolecular forces are so weak to be considered.
Weak intermolecular forces only exist upon collision.
A gas has no definite shape and volume, so they fill the container of any size and shape completely.

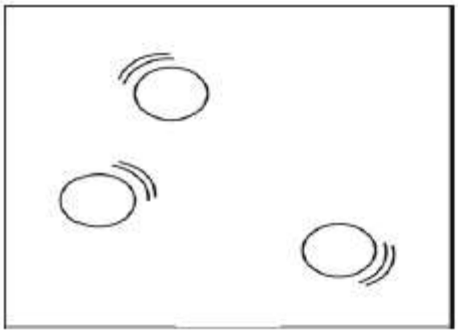


Fig.3.28: Arrangement of gas particles

The distance between the molecules is large (see above Fig) and the force of attraction between the molecules is very small (almost negligible).

These molecules move about freely in all directions colliding with each other and with the walls of the container.

The movement of molecules from a region of higher concentration to a region of lower concentration is called diffusion.

Gases can diffuse into each other rapidly, this is because gases are light (less dense) compared to solid and liquid and that gas particles are smaller.

Gases are compressible (they can be squeezed) into a small volume, like in a car tyres and bicycle tyres when pumped. This is because they have spaces in between them (above Fig).

Table 3.7: Different states of matter and their physical properties.

State	Shape	Volume	Compressibility	Density	Spacing of molecules
Solid	Fixed	Fixed	No	High	Very close
Liquid	Indef.	Fixed	No	Medium	Close
Gas	Indef.	Indef.	yes	Low	Far apart

Exercises

1. Explain why the density of a gas is much less than that of a solid or a liquid.
2. Draw a diagram to show how one air molecule moves in a closed container.
3. Explain why it is easier to compress a gas than a liquid or a solid?
4. State one similarity between particles of a liquid and those of a gas.
5. Describe the difference between solids, liquids, and gases in terms of the arrangement of the molecules throughout the bulk of the material.
6. Explain why tyres burst when left outside during hot weather?
7. According to the kinetic theory, what is temperature?
8. State and explain two applications of physical properties of solids, liquids and gases and show how they have improved our lives.

3.2. 8: Changes of physical states of matter

Water can change its state if temperature varies and under the action of Sun and wind.

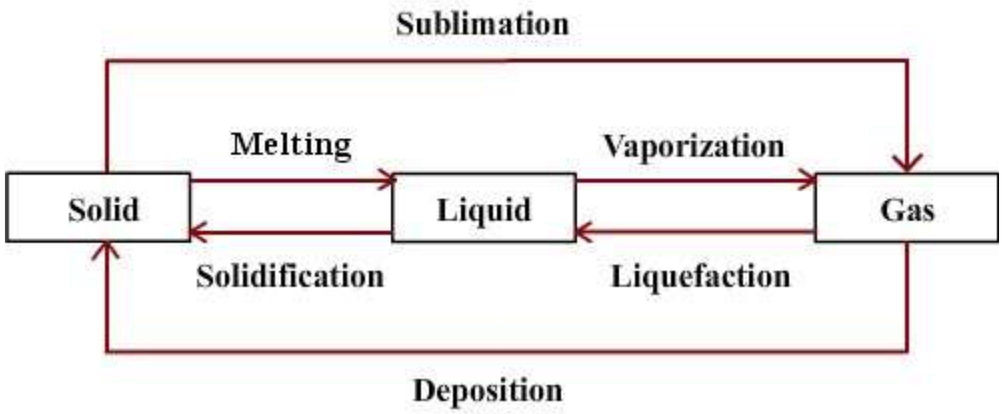


Fig.3.29: Different changes of state

Definitions:

- Melting (or fusion): transition from solid to liquid state.
- Vaporization: transition from liquid to gaseous state.
- Liquefaction (or **condensation**): transition from gaseous to liquid state.
- **Solidification** (or **freezing**): transition from liquid to solid state.
- Sublimation: transition from solid to gaseous state.
- **Deposition**: transition from gaseous to solid state.

Note:

The vaporization of a liquid may be gradual and natural (such as when exposed to sunlight). We then say that there is “evaporation ". It can also be obtained by a rapid temperature rise which causes the formation of gas bubbles: this is called “boiling ".

Learning Outcome 3.3: Describe thermal expansion

3.3.1: Different types of thermal expansion

- Topic: Identification of 3 types of thermal expansion

In general, nearly all substances increase in size when heated. The process in which heat energy is used to increase the size of matter is called ***thermal expansion***. The increase in size on heating of a substance is called *expansion*. On cooling, substances decrease in size. The decrease in size on cooling of a substance is called *contraction.*

Thermal expansion and contraction in solids

When a solid (e.g. a metal) is subjected to heat, it:

a. Increases in length (Linear Expansion).
b. Increases in volume (Volume Expansion).
c. Increases in area (Surface Expansion).

Why solids expand on heating?

In Senior I, we learnt that molecules of a solid are closely packed and are continuously vibrating about their fixed positions. When a solid is heated, the molecules vibrate with larger amplitude about the fixed position. This makes them to collide with each other with larger forces which push them far apart. The distance between the molecules increases and so the solid expands. The reverse happens during cooling.

3.3.2: Linear expansion

(a) Demonstrations of linear expansion

Activity 1

To demonstrate expansion and contraction using the bar and gauge apparatus

Materials

- A bar and gauge apparatus
- Bunsen burner

Steps

1. Move the metal bar in and out of the gauge at room temperature (Fig. below). Observe what happens.

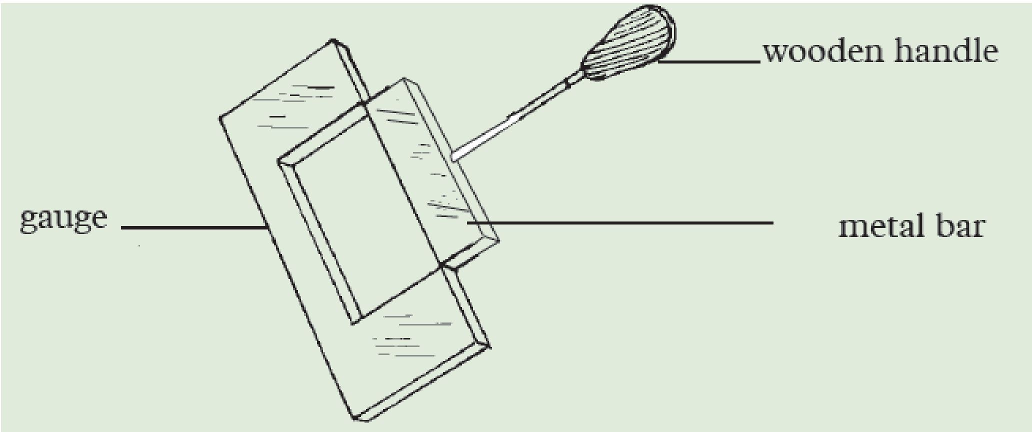


Fig.3.30: Bar and gauge apparatus

2. Keep the metal bar away from the gauge and heat the bar for sometime.
3. Try to fit the bar into the gauge and observe what happens. Explain your observation.
4. Allow the bar to cool and try to fit it into the gauge. What happens? Explain.

A bar and gauge apparatus consists of a metal bar with a suitable wooden handle and a gauge. When both the metal bar and the gauge are at room temperature, the bar just fits into the gauge.

On heating, the metal bar expands. There is an increase in length. It hence expands linearly and therefore, the bar cannot fit into the gauge.

On cooling the bar easily fits into the gauge due to contraction.

Solids expand i.e increase in length on heating and contract i.e reduced in length on cooling.

Activity2

To demonstrate the bending effect of expansion and contraction

Materials

- A bimetallic strip
- Bunsen burner

Steps

1. Observe a bimetallic strip at a room temperature (Fig. below).

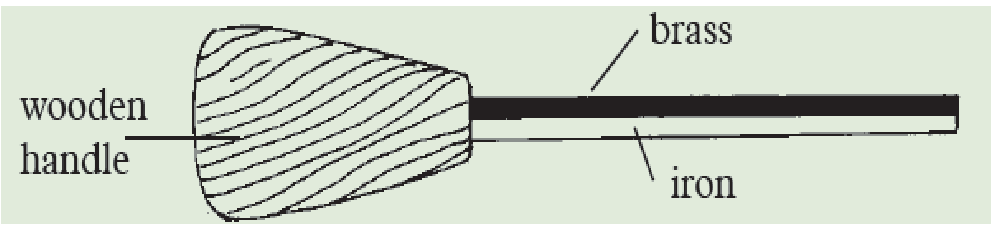


Fig.3.31 : A bimetallic strip

2. Take the bimetallic strip with the brass strip at the top and heat it with a bunsen burner flame for sometime. Observe what happens. Explain the observation.
3. Remove the flame and allow the bar to cool to a room temperature. Observe and explain what happens.
4. Discuss with your friend what will happen if the bar is cooled below room temperature. Sketch the strip at that temperature.

When the bimetallic strip is heated, it bends downwards with the brass strip on the outer surface of the curvature, as shown in Figure (a). Why does this happen?
When the flame is removed and the strip left to cool to room temperature, the strip returns back to its initial state (straight) as shown in Figure above.
If the strip is cooled below room temperature, it bends upwards with the iron strip underneath as shown in Figure (b). What has happened?

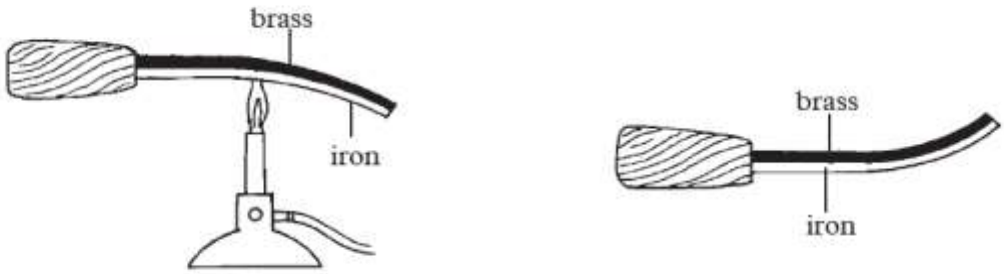


Fig.3.33: Bending effect of expansion and contraction

As the bimetallic strip is heated, brass expands more than iron. The large force developed between the molecules of brass forces the iron strip to bend downwards. On cooling below a room temperature, the brass contracts more than iron and the iron strip is forced to bend upwards.
The force developed during expansion or contraction causes a *bending* of the metals.
As we know from the kinetic theory of matter, the different states of matter expands when heated but at different rates.

(c) Coefficient of linear expansion
Consider a thin metal of length l_0. in Fig. below

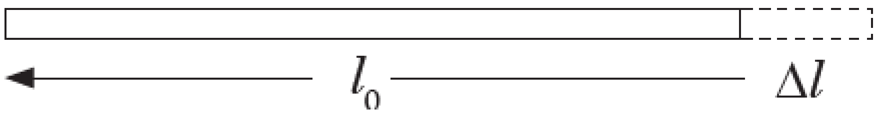


Fig.3.34 : A thin rod showing increase in length.
When the rod is heated, a temperature change of Δθ occurs and its length increases by *l.*

The ratio of increase or decrease in length to original length ($\frac{\Delta l}{l_0}$) is directly proportional to the change in temperature Δθ.

$$\frac{\Delta l}{l_0} \propto \Delta\theta \quad \Rightarrow \frac{\Delta l}{l_0} = \alpha\,\Delta\theta \quad \text{and} \quad \alpha = \frac{\Delta l}{l_\theta \Delta\theta}$$

$\propto$: *Proportionality sign*
α: *Alpha – constant symbol*

Where α is a constant called the **coefficient of linear expansion.** It is the value of the increase in length per unit rise in temperature for a given material. The SI units of α is $\mathbf{K}^{-1}$

Suppose: The temperature change = $\Delta\theta$,

l_0 represents the original length of the rod

l represent the new length for a temperature rise of θ

Then, $\Delta l = l - l_0$

The above expression may be expressed in terms of l_0, l, θ and α as follows.

$$\alpha = \frac{\Delta l}{l\Delta\theta} = \frac{l - l_0}{l\Delta\theta} \quad \text{Rearranging} \quad l - l = l_0\alpha\Delta\theta$$

$$l = l_0 + l_0\,\alpha\Delta\theta$$

$$l = l_0(1 + \alpha\Delta\theta)$$

Example 1

A copper rod of length 2 m, has its temperature changed from 15 °C to 25 °C. Find the change in length given that its coefficient of linear expansion

α = 1.7 × 10–5 K–1.

Solution

Δθ = (25 – 15) oC = 10 °C

$\Delta l = l_0\ \alpha\ \Delta\theta$ = 2 × 1.7 × 10–5 × 10

= 3.4 × 10–4 m

= 0.34 mm

3.3.3: Area/surface expansion

(a) Demonstrations of area

Activity 3

To demonstrate surface and volume expansion and contraction using the ball and ring apparatus

Materials:

- A ball and a ring
- Bunsen burner
- A bowl of cold water

Steps

1. Move the ball in and out of the metal ring at room temperature (see Fig. below). What do you observe?
2. Keep the metal ball away from the ring and heat it for sometime.
3. Try to pass the ball through the ring. What do you observe this time? Explain.
4. Cool the metal ball in a bowl of cold water and try to pass the ball through the ring again. What do you observe now? Explain the observation.

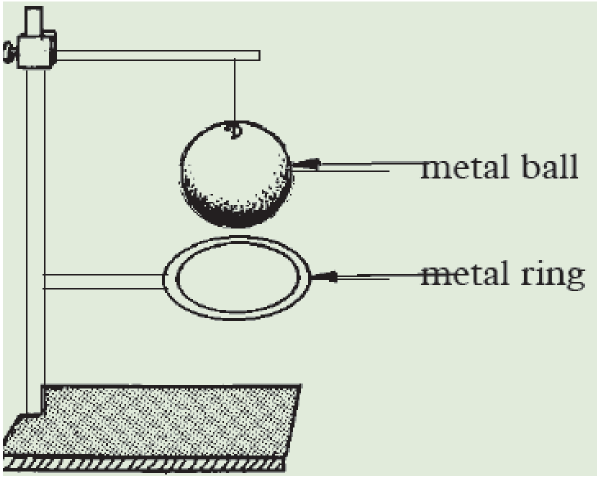


Fig.3.35 : Ball and ring apparatus

A ball and ring apparatus consists of a ball and ring both made of the same metal.

At a room temperature, the ball and the metal ring have approximately the same diameter, thus the ball just passes through the ring. On heating, the metal ball expands. There is an increase in volume and surface area of the ball. As a result, the ball cannot pass through the ring. On cooling, contraction occurs and the original volume is regained. The ball can now pass through the ring again. This activity shows volume and surface area expansion and contraction in solids.

Most solids expand on heating and contract on cooling.

Coefficients of area expansion of solids

Consider a solid whose surface area is A_0.

When the surface of the solid is heated or cooled to a temperature change of $\Delta\theta$, its surface area increases or decreases by ΔA to a new value A.

Experiments have proved that the ratio of the change in surface area to original area i.e $\frac{\Delta A}{Ao}$ is directly proportional to the change in temperature ($\Delta\theta$)

$$\frac{\Delta A}{A_0} \propto \Delta\theta \Rightarrow \frac{\Delta A}{A_0} = \beta\Delta\theta \quad (\beta \text{ is a constant called coefficient of area expansivity})$$

$$\text{Hence } \beta = \frac{\Delta A}{A_0\Delta\theta} \qquad \text{Or} \qquad \beta = \frac{A - A_0}{A\,\Delta\theta} \quad (\text{since } \Delta A = A - A_0)$$

$$\Rightarrow A - A_0 = A_\theta\beta\Delta\theta$$

$$A = A_0 - A_0\beta\Delta\theta$$

$$\therefore A = A_0(1 - \beta\Delta\theta)$$

Note:

Coefficient of area expansivity = 2 × coefficient of linear expansivity

β = 2α

Example.2

A round hole of diameter 4.000 cm at 0 °C is cut in a sheet of brass (coefficient of linear expansion is 0.0000017(Co)-1. Find the new diameter of the hole at 40 °C.

Solution

$\Delta A = \beta A_0 (\theta_2 - \theta_2)$

Given: $\alpha = 0.00017/K$, $(\theta_2 - \theta_1) = 40°C$, D = 4.000 cm so r = 2.000 cm, $\beta = 2\alpha$

then

$$\text{Area } (A_0) = \pi r^2 = \left(\frac{22}{7} \times 2.000 \times 2.000\right) cm^2$$

$$= \mathbf{12.571\ cm^2}$$

$$\text{New area } A = A_0 + \Delta A = (12.571 + 0.017)\ cm^2$$

$$= 12.588\ cm^2$$

$$\text{Since } A = \pi r^2, \quad \text{the new radius } r = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{12.587}{3.141}}$$

$$= 2.002\ cm$$

3.3.4: Volume/cubic expansion

Coefficients of volume expansion in solids

When a solid is heated or cooled to a temperature change of $\Delta\theta$, its volume increases or decreases by ΔV to a new value V.

The ratio of the change in volume to original volume i.e $\frac{\Delta v}{V_0}$ is directly proportional to the change in temperature ($\Delta\theta$)

$\frac{\Delta V}{V_0} \alpha\ \Delta\theta \Rightarrow \frac{\Delta V}{V_0} = \Upsilon\Delta\theta$ (Υ is a constant called coefficient of volume expansivity)

$$\text{Hence } \Upsilon = \frac{\Delta V}{V_0\Delta\theta} \qquad \text{Or} \qquad \Upsilon = \frac{V - V_0}{V\Delta\theta} \quad (\text{since } \Delta V = V - V_0)$$

$$\Rightarrow \quad V - V_0 = V_\theta \Upsilon\Delta\theta$$

$$V = V_0 - V_0\Upsilon\Delta\theta$$

$$\therefore \quad V = V_0(1 - \Upsilon\Delta\theta)$$

Note:

Coefficient of volume expansivity = 3 × coefficient of linear expansivity

ϒ = 3α

Example 3

A metal vessel has a volume of 800.00 cm3 at 0 °C. If its coefficient of linear expansion is 0.000014/K, what is its volume at 60 °C?

Solution

Given: V0 = 800.00 cm3, (θ2 – θ1) = 60 °C and α = 0.000014/K = 0.000014/ °C

Change in volume, $(\Delta V) = 3\,\alpha V_0 \Delta\theta$

$$= 3(0.000014/°C) \times 800.00\ cm^3 \times 60°C$$

$$= 2.016\ cm^3$$

New volume (at 60°C) $= V_0 + \Delta V$

$$= (800.00 + 2.016)\ cm^3$$

$$= 802.016\ cm^3$$

Exercises

1. What do you understand by the phrase *'coefficient of linear expansion*'?
   A vertical steel antenna tower is 400 m high. Calculate the change in height of the tower hence its new height that takes place when the temperature changes from –15 °C on winter day to 35 °C on a summer day. (Take α = 0.00000645/K
2. A 8 m long rod is heated to 50 °C. If the rod expands to 10 m after some time, calculate its coefficient of linear expansion given that the room temperature is 32 °C.
3. A rectangular solid of Brass has a coefficient of volume expansion of 56 × 10-6 /°C. The dimensions of the rectangle are 5 cm × 6 cm × 8 cm at 10 °C. What is the change in volume and the new volume if the temperature increases to 90 °C?
4. A solid plate of lead of linear expansion 29 × 10-6 /°C is 8 cm × 12 cm at 15 °C. What is the change in area and the new area of the lead if the temperature increases to 95 °C?
5. A cup made of pyrex glass has a volume of 200 cm3 at 0 °C. If the coefficient of linear expansion is 0.000003/K, what will be its volume if it holds hot water at 92 °C.

References

A. Books

1. Aflak, 2014. *Electronics Weighing Scale .Retrieved 11 November 2014.*
2. *Andrew.ucsd.edu. September 29, 1997. "Applying air buoyancy corrections" .Archived from the original (PDF) on September 7, 2006. Retrieved 2014-03-05.*
3. Dr Masatoshi Kajita, 2018 *The Quantum Physics Atomic Frequency Standards* p (Bristol: Adam Hilger) 610, Copyright © IOP Publishing Ltd 2018
4. *Fahey, Margaret C.; Klesges, Robert C.; Kocak, Mehmet; Wayne Talcott, G.; Krukowski, Rebecca A. (2018). "Changes in the Perceptions of Self-weighing Across Time in a Behavioral Weight Loss Intervention".*
5. Hazewinkel, Michiel, ed. (2001). "*Theory of Errors*." *Encyclopedia of Mathematics*. Springer Science+Business Media B.V. / Kluwer Academic Publishers. ISBN 978-1-55608-010-4.
6. Igor S Grigoriev; Evgeniĭ Zalmanovich Meĭlikhov, 1997, *Handbook of physical quantities*, Boca Raton : CRC Press, ©1997
7. John H. Lienhard IV 2000, *A Heat Transfer Textbook*, 5th ed University of Houston, Massachusetts Institute of Technology
8. Josef Kuneš, 2012, *Dimensionless Physical Quantities in Science and Engineering,* Department of Physics, University of West Bohemia, Plzeň, Czech Republic

B. Internet

1. https://circuitglobe.com/accuracy-and-precision.html
2. https://circuitglobe.com/difference-between-heat-and-temperature.html
3. https://www.edinformatics.com/math_science/how-is-heat-transferred.html
4. https://www.google.com/search?q=description+of+physical+states+of+matter&safe=strict&rlz
5. https://www.reb.rw/fileadmin/SCIENCE_E_BOOKS/E_BOOKS/Physics/Physics%20S3/Physics%20Book%203.pdf