SS1 PHYSICS SECOND TERM SCHEME OF WORK/NOTE FOR 2024/2025 SESSION.

1 REVISION/. HEAT ENERGY /TEMPERATURE AND THERMOMETER
*Revision of first term examination, *Concept/definition of heat and temperature * Difference between heat and temperature * Effect of heat on matter *Use of kinetic molecular theory to explain effect of heat on matter, *Definition of thermometer *Construction and graduation of a simple thermometer * Temperature Scales * Types of thermometer * kinetic molecular theory explanation of Temperature.

2. THERMAL EXPANSIVITY AND ITS APPLICATION
*Concept of Thermal Expansion, *Linear expansivity, *Area expansivity, *Volume expansivity, *Kinetic molecular theory explanation that gas expands more than solid and liquid when heated *Consequence and Applications of Expansion * Experiment to determine the linear expansivity of a metal rod, *Advantages and disadvantages of thermal expansion of solids* Thermal Expansion of liquids * Real and apparent expansivity *Anomalous expansion of water, *simply problems involving Linear, Area and Volume expansivity

3. HEAT TRANSFER
* Transferred heat by conduction and their applications, * Transferred heat by convection and their applications
* Transferred heat by radiation and their applications, *Explaining conduction, convection and radiation in terms of the molecular theory

4. DESCRIPTION AND PROPERTY OF FIELD
*Concept and definitions of fields, *Types of fields-gravitational and magnetic field and electric field *Concept and definition of Gravitational field, *Gravitational Field for Two Masses, *Field from a Single Point Mass, *Concept of Electric field, *Electric lines of force-around isolated +ve charge, isolated –ve charge, two like charges placed near each other, two unlike charges placed near each other, * Properties of lines of force,
*Coulomb's law,*Electric field intensity,*Electric potential, *Magnetic field, *Field pattern -use of iron fillings to show fields and field lines

5. GRAVITATIOANAL FIELD AND LAW
*Concept of Gravitational field. *Newton's Law of Gravitation, *Acceleration due to gravity,
*Shape and dimension of the earth *Gravitational potential, *Potential energy in gravitational field, *Properties of a force field- force of gravity, *Escape velocity,

6. ELCTRIC CHARGES/ELECTROSTATICS/ GOLD LEAF ELECTROSCOPE
* Electric charges, *Types of charges-charged bodies either similarly or oppositely,
*Electrostatics or Static electricity, *Production of Electrostatic charges (charged bodies) by friction, induction and contact, *Distribution and storage of charges, * Gold leaf electroscope and its uses, *lighting and lighting conductor

7. CAPACITORS
*Definition of Capacitor, Capacitance of a Capacitor, Factors that affect the capacitance of a capacitor, Arrangement of capacitors, Energy stored in a capacitor, Uses of capacitor.
8. PRACTICALS
9. & 10 REVISIONS

WEEK ONE LESSON NOTE

HEAT ENERGY /TEMPERATURE AND THERMOMETER

Concept Heat and Temperature

Knowing the difference between heat and temperature is important to lead to a clearer understanding of energy. We must understand that Heat is not temperature. Often the concepts of heat and temperature are thought to be the same, but they are not. Perhaps the reason the two are usually and incorrectly thought to be the same is because as human beings on Earth our everyday experience leads us to notice that when you add heat to something, say like putting a pot of water on the stove, the temperature of that something goes up. We say that heat moves from heating stove to the cold water. Thus heat flows from hot to cold object when they are in contact with each other. More heat, more temperature.

Definition of Heat

Heat energy is the energy that is transferred from a hot object to a cooler object as a result of their difference in temperature. It is defined as a measure of the total internal energy of a body.

Definition of Temperature

Temperature can be defined as:

- The degree of hotness or coldness of a body or environment.
- A measure of the warmth or coldness of an object or substance with reference to some standard value.
- A measure of the average kinetic energy of the particles in a sample of matter.
- A measure of the ability of a substance, or more generally of any physical system, to transfer heat energy to another physical system.

Unit of Temperature and Heat: Kelvin and degree Celsius are units of temperature while Joules is the unit of Heat energy

Difference between Heat and temperature

Heat	Temperature
It is a form of energy	It is a measure of the degree of the hotness or coldness of a body
It is the total internal energy possessed by a body	It is a measure of the average kinetic energy of the molecules of the body.
It measures the direction of transfer of temperature	It directly relates to the kinetic energy of the molecules
It causes a change in the temperature of a body	It does not change the heat energy of a body
It's unit is Joules (J)	It's unit is Kelvin or Celsius (K) (^oC)

Effects of heat on matter

Effects of heat on (substance) matter include:

1. It causes a rise in temperature
2. It causes a change in state
3. It causes expansion of a body or change in size
4. It causes the change in the physical property of a body or change in colour
5. It causes the emission of electron from the surface of a metal or thermionic emission
6. It causes chemical changes in a body

7. It causes change in the pressure of a gas at constant volume

Use of kinetic molecular theory to explain effect of heat on matter

1. **Rise in Temperature**

The substance can experience a rise in temperature when heat is added. When heat is added to a substance, the molecules absorb the heat energy which is converted to the kinetic energy of the molecules hence increases the speed of the molecules. That is, when the average kinetic energy of the molecules goes up due to added heat, the average speed of the molecules increases. This increase in average kinetic energy is registered as a number called temperature that changes proportionally with change in average speed molecules. Note that this increase in the average kinetic energy of the molecules means that the molecules will now, on average, be travelling faster than before the heat arrived

2. Change of State

The substance can change state if heat is added. For example, if the substance is ice, it can melt into water. Perhaps surprisingly, this change does not cause a rise in temperature. At the exact moment before melting, the average kinetic energy of the **ice** molecules is the same as the average kinetic energy of the **water** molecules at the exact moment after melting. That is, the melting ice and the just melted water are at the same temperature. Although heat (energy) is absorbed by this change of state, the absorbed energy is not used to change the average kinetic energy of the molecules, and thus proportionally change the temperature. The energy is used to change the bonding between the molecules. Changing the manner in which the molecules bond to one another can require absorption of energy (heat) as in the case of melting, or require a release of energy (heat) as in the case of freezing.

So, when heat comes into a substance, energy comes into a substance. That energy can be used to increase the kinetic energy of the molecules, which means an increase in their temperature which means an increase in their speed. Or at certain temperatures the added heat could be used to break the bonds between the molecules causing a change in state that is not accompanied by a change in temperature. Other effects of heat on substance include:

3. Expansion of a body

Addition of heat will usually cause the expansion. During expansion, the dimension or size of the body increases.

4. Change in the physical properties of a body

Addition of heat to a body may cause change in the electrical resistance, magnetic properties, conductivity, elasticity, density and colour of a body.

5. Thermionic Emission

Addition of heat to a metal may result in emission of electrons from the surface of the metal. The process is known as thermionic emission

6. Chemical change:

When heat is added on a body, it may bring about changes in the chemical properties of the body

7. **Change in pressure**

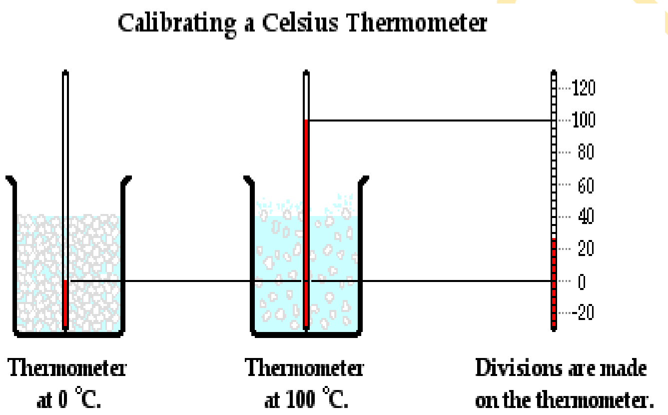
Added heat to a gas may bring about increase in the pressure and volume of the gas.

What is thermometer?

A **Thermometer** is a device that measures temperature or temperature gradient using a variety of different principles. A thermometer has two important elements:

- The bulb on a mercury thermometer (that is, the temperature sensor) in which some physical change occurs with temperature,
- The scale on a mercury thermometer (that is, means of converting this physical change into a numerical value).

Construction and graduation of a simple thermometer



A thermometer is calibrated by using two objects of known temperatures. The typical process involves using the freezing point and the boiling point of water. Water is known to freeze at 0°C and to boil at 100°C at an atmospheric pressure of 1 atm. By placing a thermometer in mixture of ice water and allowing the thermometer liquid to reach a stable height, the 0-degree mark can be placed upon the thermometer. This is known as the **Lower Fixed Point**.

Definition of Lower Fixed Point; The Lower Fixed point is defined as the temperature of **pure** melting ice at standard atmospheric pressure 760mm of mercury.

Similarly, by placing the thermometer in boiling water (at 1 atm of pressure) and allowing the liquid level to reach a stable height, the 100-degree mark can be placed upon the thermometer. This is known as the **Upper Fixed Point**.

Definition of Upper Fixed Point: The Upper Fixed point is defined as the temperature of a steam from **pure** water boiling at standard atmospheric pressure 760mm of mercury.

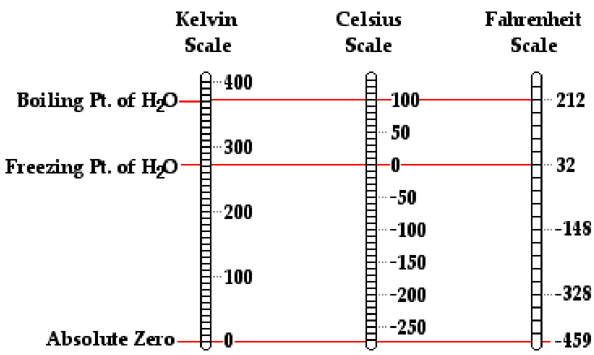
With these two markings placed upon the thermometer, 100 equally spaced divisions can be placed between them to represent the 1-degree

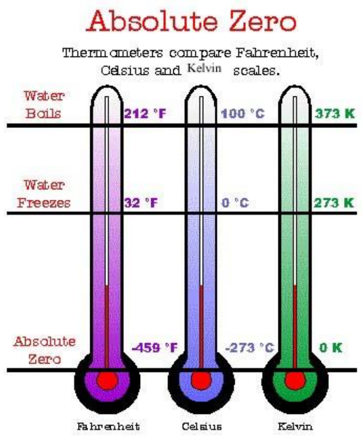
Marks. Since there is a linear relationship between the temperature and the height of the liquid, the divisions between 0 degree and 100 degree can be equally spaced. The difference in temperature between the two temperature points is called Fundamental interval (or temperature interval) of the thermometer. With a calibrated thermometer, accurate measurements can be made of the temperature of any object within the temperature range for which it has been calibrated.

Temperature Scales:

The calibration of this interval depends on the temperature scale chosen. There are three types of scales in current use:

1. The Celsius scale,
2. The Fahrenheit scale and
3. The Absolute (or thermodynamic or kelvin) scale





Celsius scale:

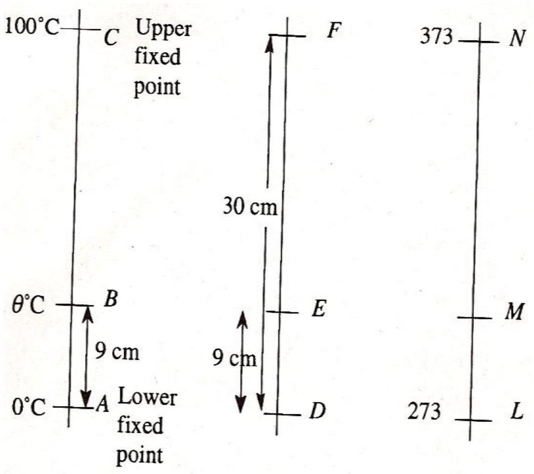
The thermometer calibration process described above results in what is known as a centigrade thermometer. A centigrade thermometer Lower and Upper fixed points are 0°C and 100°C. It has 100 divisions or intervals between the normal freezing point and the normal boiling point of water. Today, the centigrade scale is known as the Celsius scale, named after the Swedish astronomer Anders Celsius.

Fahrenheit Scale:

A thermometer can be calibrated using the Fahrenheit scale in a similar manner as was described above. The difference is that the normal freezing point of water is designated as 32 degrees and the normal boiling point the length of mercury thread in the thermometer is 9 cm above the ice point (0^oC). What is the temperature recorded by the thermometer in (a) Celsius scale (b) Kelvin scale?

Solution: We assume the temperature increases in linear scale.

$$\frac{AB}{AC} = \frac{DE}{DF} = \frac{LM}{LN}$$



$$\frac{\theta - 273}{373 - 273} = \frac{9cm}{30cm}$$

$$\frac{\theta - 273}{100} = \frac{9}{30} = 30(\theta - 273) = 900$$

$$30\theta - 8190 = 900$$

TYPES OF THERMOMETERS

Thermometers use any physical property of a substance which varies in a known way with temperature, and is easily measurable as a means of gauging temperature. The substance of whose physical property is so used is known as a **thermometric substance.** Direct temperature measurements are based on any of the easily measureable properties of matter that change uniformly with temperature. Today, there are different types of thermometers and thermometric substances. These include:

Types of Thermometers	Thermometric substance	Properties of Thermometric substance
Liquid-in-glass thermometer	Mercury, Spirit and Alcohol.	Change in volume of a fixed mass of liquid with temperature
Constant – volume gas thermometer	Gas	change in pressure of a fixed volume of gas with temperature
Resistance thermometer	Resistance wire	change in the electrical resistance of a fine piece of wire with temperature
Thermoelectric/Bimetallic thermometer	Two dissimilar metals (e.g. copper and constantan)	Change of electric current (or electrical potential difference) between two metal junction at different temperature.

Choice of a thermometric Liquid:

For Liquid – in – glass thermometer, some of the desirable properties of the liquid are that it should;

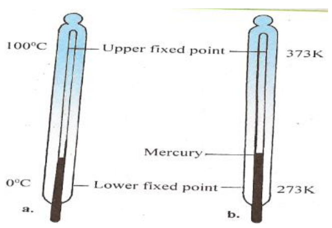
I. Expand or contract uniformly with temperature
II. High coefficient of expansion
III. Be good conductor of heat
IV. Have high boiling point and low melting point
V. Be easily seen in glass (be opaque)
VI. Have low specific heat capacity

Note:

Water is not suitable for use as a thermometric liquid because	Mercury is suitable for use as a thermometric liquid because
(i) it wets glass	(i) it does not wets glass
(ii) it expands abnormally	(ii) It expands regularly
(iii) it needs to be coloured (it is colourless)	(iii) has silvery colour that makes it easily seen
(iv) it has fairly high boiling point	(iv) it has very high boiling point
(v) it vaporizes easily	(v) It is not easily vaporize
(iv) it is a poor conductor/low conductivity	(iv) it has high conductivity

However mercury has a relatively high freezing point (-39ºC), hence cannot be used for low temperature. Alcohol's expansion is not quite as regular as mercury's but its freezing point is low (-119ºC) hence it can be used to measure low temperature but cannot be used to measure high temperature because its boiling point is (78ºC)

Liquid-in-glass thermometer



A liquid-in-glass thermometer is widely used due to its accuracy for the temperature range -200 to 600°C. Compared to other thermometers, it is simple and no other equipment beyond the human eye is required. The LIG thermometer is one of the earliest thermometers. It has been used in medicine, metrology and industry. Thermometers with mercury were found to give a more linear scale than spirits. In response to our understanding of the danger which mercury exposure poses to human health, alcohol was used in place of mercury. These liquid thermometers are based on the **principal of thermal expansion**. When a substance gets hotter, it expands to a greater volume. It is the basis of the design and operation of thermometers

Characteristics of a thermometer:

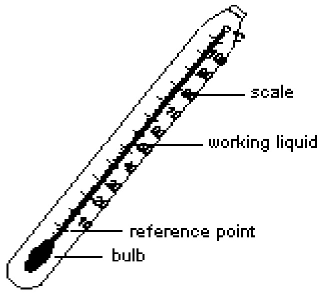
All thermometers have limitations. In general, there are three characteristics concerning a thermometer. These include; Sensitivity, Linearity and Range.

Sensitivity

Sensitivity refers to the ability to give a large response to a small change in temperature. A sensitive thermometer is able to detect small changes in temperature. It can also give a rapid response to temperature change.

To make a liquid-in-glass thermometer sensitive,

- a **bulb** is used , a reservoir in which the working liquid can expand or contract in volume. Large bulb will cause a big change in volume of the mercury, which will appear as a change in the length of mercury up the capillary tube.
- a **stem** a glass tube containing a tiny capillary connected to the bulb and enlarged at the bottom into a bulb that is partially filled with a working liquid. Making the capillary tube small also increase the sensitivity of the thermometer because volume change results in a big change in the length of liquid up the tube.



- an **inert gas** is used for mercury intended to high temperature.
- a **working liquid** usually mercury or alcohol. Lastly, a liquid-in-glass thermometer may increase its sensitivity by choosing a liquid that expand more. Alcohol expands more than mercury, and would make a thermometer more sensitive than a mercury-in-glass thermometer.
- a **reference point**, a calibration point, the most common being the ice point

Linearity

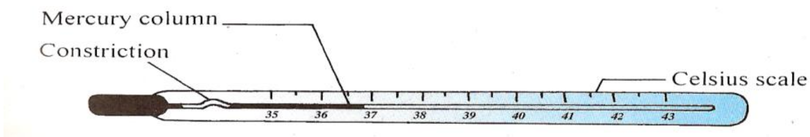
A temperature scale is calibrated using two fixed points. Between these two fixed points, 100 equal divisions are marked to represent temperature change of 100 °C. It is fixed or engraved on the stem supporting the capillary tube to indicate the range and the value of the temperature. It is the case for the precision thermometers whereas for the low accurate thermometers such as industrial thermometer, the scale is printed on a separate card and then protected from the environment. Different materials change their thermometric properties differently at different temperatures. Hence, a good thermometer should have thermometric property that changes linearly in between the two fixed points such that the thermometric property at a particular temperature corresponding to the reading on the interpolated scale.

Range

Range refers to the operating temperature which the thermometer can be used. A laboratory thermometer can measure from -10 °C to 110 °C, beyond which the scale will not be able to register any readings. The expanding liquid column may even break the thermometer if the expansion is restrained beyond the maximum 110 °C.
The thermometer is filled with an inert gas such as argon or nitrogen above the mercury to reduce its volatilization
The accuracy of measurement depends mainly on the extent of immersion of the thermometer into the medium - not just the bulb but also the stem. As the temperature of the liquid in a thermometer increases, its volume increases. The liquid is enclosed in a tall, narrow glass (or plastic) column with a constant cross-sectional area. The increase in volume is thus due to a change in height of the liquid within the column. The increase in volume, and thus in the height of the liquid column, is proportional to the increase in temperature.

Clinical Thermometer

This is the form of mercury- in – glass thermometer used in the hospitals for measuring the temperature of the human body. Since the normal human body temperature varies from 35^0C to 43^0C, the range of the clinical thermometer is between these temperatures.

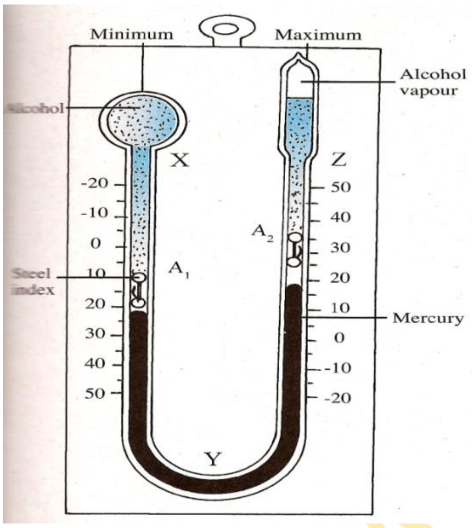


Clinical thermometer

The clinical thermometer consists of a short tube with a narrow bore through which the tube makes it possible for small temperature changes to cause large changes in the length of the mercury column, thus making the thermometer very sensitive to temperature changes. Also there is a narrow constriction or kink in the stem just above the bulb. The bulb itself is made of thin glass. When the thermometer is put under the person's tongue or armpit and left for some time the mercury thread expands along the tube, indicating the temperature, when the temperature is taken from the mouth, the mercury column does not contract into the bulb again. It breaks at the constriction and remains in the stem the position it was when it was in the mouth, the temperature can thus be read slowly and carefully, and recorded. Before being used again, the thermometer is shaken to force the mercury back also sterilised.

Note: it is not advisable to sterilize a clinical thermometer in boiling water at normal atmospheric pressure because the extreme high temperature of boiling water (100°C) is greater than the temperature of 43°C which a clinical thermometer can withstand. The thermometer then expands under the influence of this extreme high temperature and then crack.

Six's thermometer



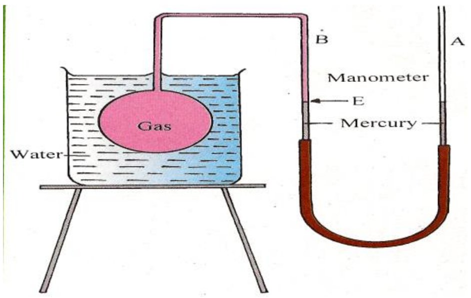
Six's thermometer is a thermometer which can measure the maximum and minimum temperatures reached over a period of time, usually during a day. It is commonly used wherever a simple way is needed to measure the extremes of temperature at a location, for instance in meteorology and horticulture. It is also commonly known as a **maximum minimum thermometer**, of which it is the earliest practical design and the most common type used. It is an example of a **registering thermometer** that is a thermometer that keeps a record of where the temperature has been in the past. It gives three readings:

It consists of a U-shaped glass tube with two separate temperature scales set along each arm of the U. One of these is for recording the maximum temperature encountered and the other for the minimum temperature. The arms of the U-shaped tube terminate in sealed glass bulbs. The bulb at the top of the minimum reading scale arm is full of alcohol, the other contains a vacuum (or low pressure alcohol vapour).

In the bend of the U is a section of mercury, a metal which is liquid at normal temperatures. This is pushed around the tube by the thermal expansion and contraction of the alcohol in the first bulb as it responds to the external temperature. The near vacuum in the other bulb allows free movement of the alcohol and mercury. It is the alcohol which measures the temperature; the mercury indicates the temperature reading on both scales. This is unlike a normal mercury thermometer, in which the expansion and contraction of mercury itself indicates temperature.

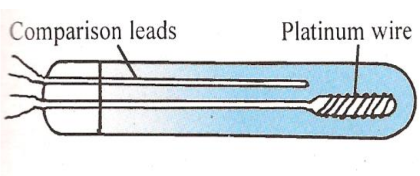
The thermometer shows a reading at the top of the mercury section on both the maximum and minimum scales; this shows the current temperature and should be the same on both scales. If the two reading are not the same, then the instrument scales are not correctly positioned or the instrument is damaged.

Constant -volume gas thermometer



A **gas thermometer** measures temperature by the variation in volume or pressure of a gas. One common apparatus is a constant volume thermometer. It consists of a bulb connected by a capillary tube to a manometer. The bulb is filled with a gas such that the volume of the gas in the bulb remains constant. The volume is related to temperature by k, known as Charles's Law . The pressure of the gas in the bulb can be obtained by measuring the level difference in the two arms of the manometer.
Uses: Gas thermometers are often used to calibrate other

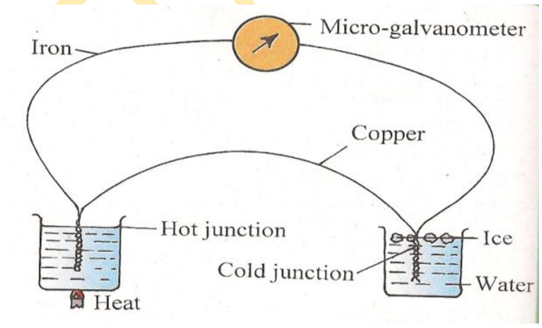
Resistance thermometer



Resistance thermometers are also called **resistance temperature detectors** or **resistive thermal devices** (**RTD**s). These are sensors used to measure temperature by correlating the resistance of the RTD element with temperature. Most RTD elements consist of a length of fine coiled wire wrapped around a ceramic or glass core. The element is usually quite fragile, so it is often placed inside a sheathed probe to protect it. The RTD element is made from a pure material whose resistance at various temperatures has been documented. The material has a predictable change in resistance

As they are almost invariably made of platinum, they are often called platinum resistance thermometers (PRTs). They are slowly replacing the use of thermocouples in many industrial applications below 600 °C, due to higher accuracy and repeatability.

Thermoelectric thermometer



A **thermocouple** is a device consisting of two different conductors (usually metal alloys) that produce a voltage proportional to a temperature difference between either ends of the pair of conductors. A thermoelectric is a type of metal thermometer that can measure a tremendously (high) wide range of different temperatures using the principle of thermocouple. They are inexpensive and interchangeable. In contrast to most other methods of temperature measurement, thermocouples are self-powered and require no external form of excitation. Properties such as resistance to corrosion may also be important when choosing a type of thermocouple.

The main limitation of thermocouples is accuracy since system errors of less than one degree Celsius (C) can be difficult to achieve. Though thermocouples are often not extremely precise, they can work in environments other thermometers can't. There are specially designed thermocouples that can measure temperatures to nearly absolute zero and others that can work in the hottest ovens.

How Thermocouples Work

A thermocouple does not measure absolute temperature, but rather the difference in temperature between two points. When two different metals (e.g copper and constantan) are joined at the ends and one end (hot junction) is heated, while (the cold junction) is kept constant in melting ice, electric current flows along the metals which creates a voltage between the two ends. This is thermoelectric effect and the setup is thermocouple

The greater the temperature difference, the greater the current. Different metals react at different rates, and a thermocouple actually makes use of two metals, joined at the sensor end. At the circuitry end, they are attached to a meter that uses the difference in voltages between the metals to calculate the temperature differential

Uses

- Thermocouples are widely used in science and industry
- Other applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes.
- Thermocouples are a widely used type of temperature sensor for measurement and control
- They can also be used to convert a heat gradient into electricity.

Molecular Explanation of Temperature

Kinetic theory of matter, explains that all matter is composed of tiny particles called molecules. These molecules are always in motion with varying velocities. When a substance is heated, the velocity of the molecules and hence their kinetic energy of the molecules appears as an increase in the temperature of the body. The temperature of a body is thus proportional to the average kinetic energy of its molecules. The average kinetic energy of molecules of a body becomes zero at absolute zero temperature (-273K). At this temperature the pressure of the gas is also zero.

ASSIGNMENT

1. Define Heat and temperature
2. Differentiate between Heat and temperature
3. List FIVE effects of heat on a substance
4. Use kinetic theory to explain TWO effects of heat on a substance
5. A thermometer with an arbitrary scale, S, of equal divisions registers -30^oS at ice point and $+90\,^oS$ at the steam point. Calculate the Celsius temperature corresponding to $60\,^oS$.
6. Give THREE reasons why water will NOT be a good choice of thermometric liquid
7. Describe how a simple thermometer can be constructed with the aid of a diagram.
8. Explain the working principle of thermoelectric thermometer.
9. Clinical thermometer is characterised by having a
   a. Constriction
   b. Wide range of temperature
   c. Wide bore
   d. Long stem

10. Which of the following cannot be used to measure the temperature?
    a. Variation of pressure with temperature
    b. Expansivity of a liquid
    c. Change in colour with temperature
    d. Change in resistance of a conductor

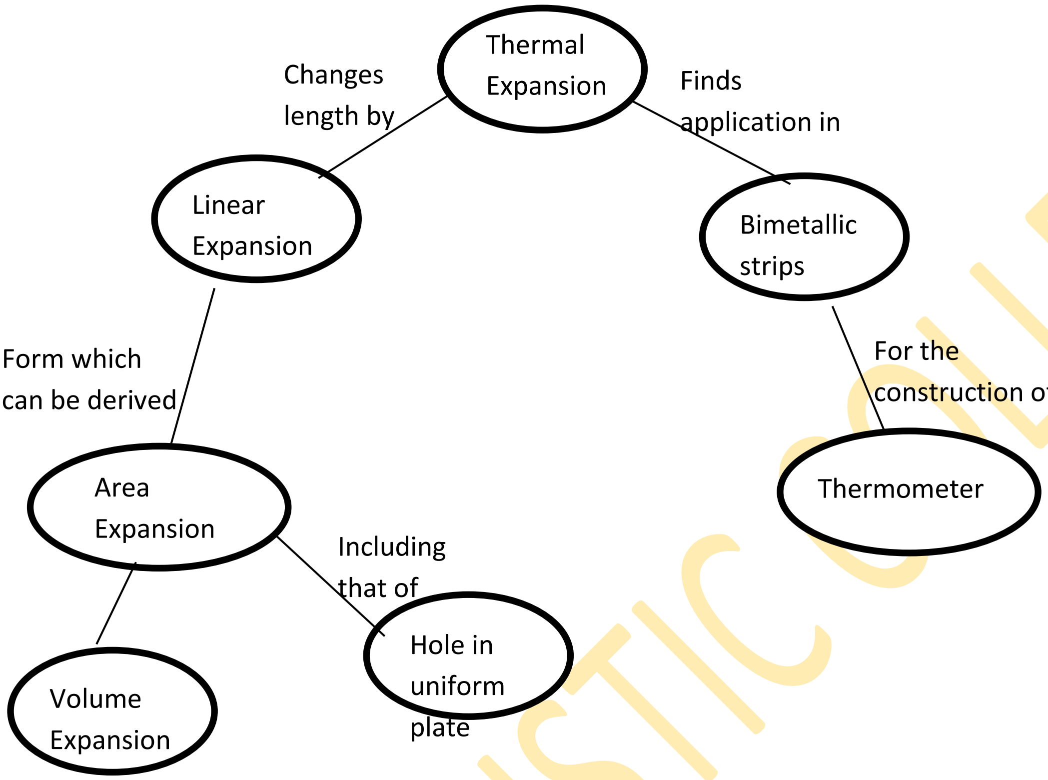
11. On what principle does the following thermometer operates
    a. Liquid –in-glass thermometer
    b. Constant-Volume gas thermometer
    c. Resistance thermometer
    d. Thermoelectric thermometer
12. Define upper and lower fixed points
13. The resistance in the element of a platinum resistance thermometer is 9.60Ω at 0°C, 12.10Ω at 100°C and 10.20Ω at room temperature. Calculate the room temperature on the scale of the resistance thermometer.
14. List THREE characteristics of a thermometer and explain three ways a thermometer can be made sensitive
15. A thermometer has its stem marked in millimetre instead of degree Celsius. The lower fixed point is 30 mm and the upper fixed point is 180 mm. Calculate the temperature in degree Celsius and Kevin when the thermometer reads 45 mm.
16. Define thermometer
17. List FOUR types of thermometer and their thermometric substances
18. Explain briefly the working principle of clinical and six's thermometers
19. Explain why it is NOT advisable to sterilize a clinical thermometer in boiling water at normal atmospheric pressure.
20. List TWO properties of mercury which makes it suitable thermometric liquid
21. State THREE physical properties of substances which may be used to measure temperature
22. Perform the appropriate temperature conversions in order to fill in the blanks in the table below.

	Celsius (°)	Fahrenheit (°F)	Kelvin (K)
a.	0		
b.		212	
c.			0
d.		78	
e.		12	
f		210	

WEEK TWO LESSON NOTE

THERMAL EXPANSION- Linear, Area and Volume Expansion

CONCEPTS OF EXPANSION

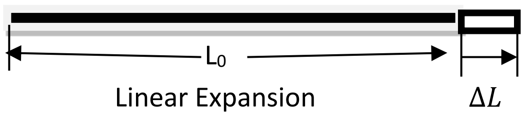


When heated most solids and liquids expand. They also contract when cooled. Expansion means increase in size of an object. Thermal expansion includes Linear, Area and Volume Expansion.

LINEAR EXPANSION:

Different solids expands by different amounts when heated over the same temperature range, the fractional thermal expansion of uniform linear object is proportional to the temperature change. Copper for example expands more than steel when both are heated through the same temperature. This is because they have different coefficient of linear expansion or linear expansivity. The relation governing the linear expansion of a long rod can be shown as follows

Length change = original Length x alpha x delta T



$\Delta L = \propto L_0 \, \Delta T$

L - $L_0 = \propto L_0 \, \Delta T$

$L = L_0(1 + \propto \Delta T)$ where

ΔL: is the fractional change in length $\frac{\Delta L}{L_0} = \propto \Delta T$

$\propto$: is the linear expansivity coefficient. Different substances expand by different amount. ΔT: is the fractional change in temperature. The change in temperature determines the fractional change in length. One would expect that 2°C change in temperature would lead to twice as much expansion as a 1°C change. L = increase in length and Lo = original length

Definition of Linear expansivity:

Linear Expansivity ∝ of a substance is defined as the increase in length per unit length per degree rise in temperature. In symbols, this is equivalent to:

$$\propto == \frac{Increase\ in\ length}{original\ length\ X\ \ temp\ rise} = \frac{l_2 - l_1}{l_1(\theta_2 - \theta_1)} = \frac{\Delta L}{l_1 \theta}$$

where

$\propto = linear\ expansivity,\ l_1 = length\ of\ metal\ at\ temperature\ \theta_1,$

$l_2 = length\ of\ metal\ at\ temperature\ \theta_2,$

θ = temperature rise which is given by $\theta_2 - \theta_1$,

$\Delta L = l_2 - l_1$ = expansion or increase in length.

The unit of ∝ is per ^{0}C or per K (K^{-1})

Example 1: Calculate the change in length for a steel rod of length 20m at 20^{o}C if the temperature after heating is 50^{o}C. Take ∝ of steel as 13x10^{-6} K^{-1}.

Solution

$L = L_0\ (1+ \propto\ \Delta T)$

= 20m $(1 + 13 \times 10^{-6} \times (50 - 20))$ = 20.0078m $\therefore \Delta L = L - L_0 = 20.0078m - 20m = 0.0078m$

$or\ \therefore \Delta L = \propto L_0\ \Delta T = 13 \times 10^{-6} \times 20 \times 30$ = 0.0078m

Example 2: Explain the statement that the linear expansivity of copper is 0.000017 K^{-1} or 0.000017^{o}C^{-1} .

The statement that the linear expansivity of copper is 0.000017 K^{-1} or 0.000017^{o}C^{-1} implies that a unit length of copper expands by 0.000017 units when it is heated through 1 K (or 1^{o}C) rise in temperature.

AREA EXPANSION:

Over small temperature ranges, the thermal expansion is described by of the coefficient of linear expansion. If the linear expansion is put in the form

$L = L_0\ (1+ \propto\ \Delta T)$ then $A = L^2 = L_0^2(1+ \propto\ 2\Delta$

In most cases the quadratic term above can be neglected since the typical expansion coefficient is on the order parts per million per degree C. the expression then becomes $A = A_0\ (1+ \propto\ 2\,\Delta T)$

Area Expansion

$$\frac{\Delta A}{A_0} = \propto 2\Delta T$$

Definition of Area or Superficial expansivity $\boldsymbol{\beta}$ is increase in area per unit area per degree Kelvin increase in temperature or fractional increase in area per Kelvin rise in temperature.

Area Expansivity $\beta = \frac{change\ in\ area}{original\ area\ X\ \ temp\ rise} = \frac{A_2 - A_1}{A_1 \theta}$

Where $A_2 = area\ at\ temp.\theta_2,\ A_1 = area\ at\ temp.\theta_1,\ \theta = \theta_2 - \theta_1,\ A_2 - A_1 = increase\ in\ area = A_1 \beta \theta$

$A_2 = A_1(1 + \beta\theta)$

$\beta = 2\alpha$

VOLUME or CUBIC EXPANSION:

Over small temperature ranges, the thermal expansion is described by the coefficient of linear expansion. If the linear expansion is put in the form

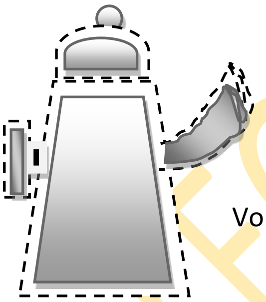
$L = L_0 \ (1 + \propto \ \Delta T)$ Then the expansion volume has the form

$V = L^3 = (L_0 \ (1 + \propto \ \Delta T))^3 = L_0^3 \ (1 + \propto 3\,\Delta T + 3 \propto^2 \Delta T^2 + \propto^3 \Delta T^3)$

In most cases the quadratic term above can be neglected Since the typical expansion coefficient is on the order parts per million per degree C. the expression then becomes

$V = V_0 \, (1 + \propto \ 3\,\Delta T)$

$$\frac{\Delta V}{V_0} = \propto 3\Delta T$$



Definition of Volume or Cubic expansivity γ: it is defined as increase in volume per unit volume per degree Kelvin increase in temperature or fractional increase in volume per Kelvin rise in temperature.

Volume Expansivity $\gamma = \frac{change\ in\ volume}{original\ area\ x\ temp\ rise} = \frac{V_2 - V_1}{V_1\theta}$

Where $V_2 = volume\ at\ temp.\theta_2$, $v_1 = volume\ at\ temp.\theta_1$, $\theta = \theta_2 - \theta_1$, $V_2 - V_1 = increase\ in\ volume = V_1\gamma\theta$

$V_2 = V_1(1 + \gamma\theta)$. Note $\gamma = 3\alpha$

Example 3:

The linear expansivity of the material of a cube is $12 \times 10^{-6}K^{-1}$. If the length of each side of the cube is 10cm, find the **area** of one face of the cube and the **volume** of the cube when its temperature is raised by 30K.

Solution:

Initial area of a face of cube $A_1 = 10cm \times 10cm = 100cm^2$

Initial volume of cube $V_1 = 10cm \times 10cm = 1000cm^3$

$\alpha = 12 \times 10^{-6}K^{-1}$.

$\beta = 2\alpha = 24 \times 10^{-6}K^{-1}$.

$\gamma = 3\alpha = 36 \times 10^{-6}K^{-1}$

$A_2 = A_1(1 + \beta\theta)$

$= 100(1 + 24 \times 10^{-6}K^{-1} \times 30)cm^2$

$= 100.072cm^2$

$V_2 = V_1(1 + \gamma\theta)$

$= 1000(1 + 36 \times 10^{-6}K^{-1} \times 30)cm^3$

$= 1001.08cm^3$

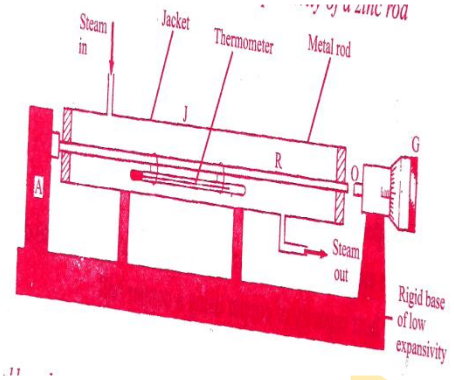
Kinetic molecular theory explanation that gas expands more than solid and liquid when heated

According to kinetic molecular theory, when an object is heated, the molecules acquire more kinetic energy which enables them to overcome their intermolecular forces therefore the vibration of the molecules increase and their displacement about their mean position increase. As a result of this, the average distance between the molecules of the substance becomes larger leading to an increase in size of the substance. This increase in the dimension of the heated object depends on the strength of the intermolecular forces. If these forces are strong, the expansion will be small and vice and vice versa. The intermolecular forces are stronger in solid than in liquid and weakest in gases, hence when heat is applied, gases expand more than liquids and liquid expands more than solids. Each particular substance has intermolecular forces peculiar to it. Therefore the addition of heat causes different expansion in different substances.

Experiment to determine the linear expansivity of a metal rod

Procedure:

The original length L_o of the metal rod is measured at room temperature. The room temperature θ_1 is measured by a thermometer while the original length is measured by a meter rule. The metal rod is then placed in a steam chamber. One end of the rod touches the pillar while the other end has the micrometre screw gauge tightened on it until contact is made. This is known when bulb in circuit shows light. The reading on the micrometre screw gauge is now recorded as x_1. The screw is now turned back to allow for expansion. Steam is then allowed into the chamber through the inlet. This steam heats the metal rod causing expansion of the rod when the temperature is close to 100°C . The new temperature is noted as the screw is adjusted forward to make contact again with the metal rod. The new micrometre reading x_2 is the noted and recorded



Result:

Original length of the = L_o initial temperature of the rod θ_1

Final temperature of the rod = θ_2 initial screw gauge reading = x_1

Final screw gauge reading = x_2

Calculations:

Increase in length = $x_2 - x_1$, increase in temperature = $\theta_2 - \theta_1$

Linear expansivity

$$\alpha = \frac{increase\,in\,length}{original\,length \times increase\,in\,temperature} = \frac{x_2 - x_1}{L_o(\theta_2 - \theta_1)}$$

Consequences and Applications of Expansion

Expansion in solid has many consequences and applications. They include

1. Expansion in buildings and bridges
2. Thermostat, the balance wheel of clocks/watches, the bimetallic strip thermometer and Electric fire alarm
3. The over-head cables causing sagging of telegraph wires
4. Railway lines ; buckling in railway lines

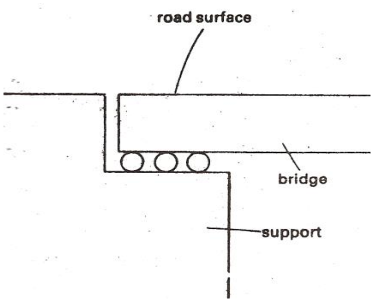
Expansion in buildings and bridges:

1. **Expansion in buildings**

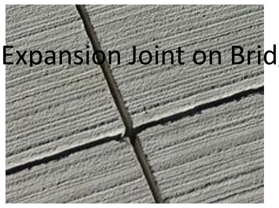
In hot weather, you can hear creaking noises if you are under a roof of a building made of galvanised iron sheets. This is due to the iron expanding as it gets hot. As the temperature comes down in the evening, creaking noise is repeated as the sheets contract.

2. **Expansion in bridges**

Metal structure such as a bridge expands when heated. Such expansion has to be allowed for during the design of a bridge so that the structure does not fracture under the action of the large force resulting from expansion. In order to allow for expansion one end of the bridge is fixed and another rest on rollers in an expansion joint or gap. Bridge expansion joints also allow



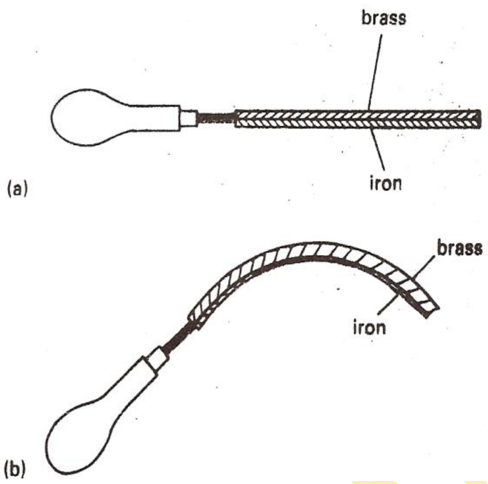
Expansion Joint on Bridge



Expansion Joint on Concrete

An **expansion joint** or **movement joint** is an assembly designed to safely absorb the heat-induced expansion and contraction of various construction materials, to absorb vibration, to hold certain parts together, or to allow movement due to ground settlement or earthquakes. They are commonly found between sections of sidewalks, bridges, railway tracks, piping systems, ships, and other structures. See aside examples of expansion joints; expansion joint on concrete.

The Bimetallic Strips:

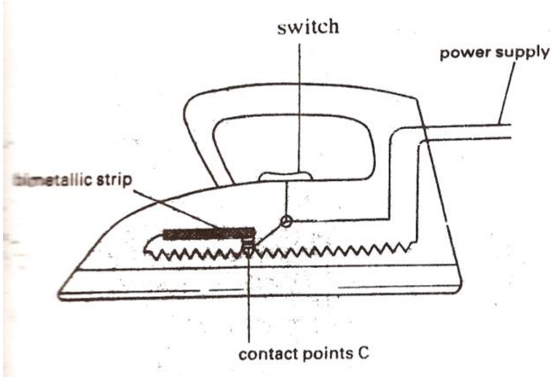


The bimetallic strip consists of two strips of different metals which expand at different rates as they are heated, usually steel and copper, or in some cases brass instead of copper. The strips are joined together throughout their length by riveting, brazing or welding. The different expansions force the flat strip to bend one way if heated, and in the opposite direction if cooled below its initial temperature. The metal with the higher coefficient of thermal expansion is on the outer side of the curve when the strip is heated and on the inner side when cooled. The sideways displacement of the strip is much larger than the small lengthways expansion in either of the two metals. This effect is used in a range of mechanical and electrical devices. In some applications the bimetal strip is used in the flat form. In others, it is wrapped into a coil for compactness. The greater length of the coiled version gives improved sensitivity

A. Thermostat

Thermostat is a device for maintaining a steady temperature. In the regulation of heating and cooling, thermostats that operate over a wide range of temperatures are used. In these, one end of the bimetal strip is mechanically fixed and attached to an electrical power source, while the other (moving) end carries an electrical contact. In adjustable thermostats another contact is positioned with a regulating knob or lever. The position so set controls the regulated temperature, called the **set point**. Thermostat is used in electric laundry irons, in refrigerators, hot water storage tanks, and electric fire alarm and gas ovens.

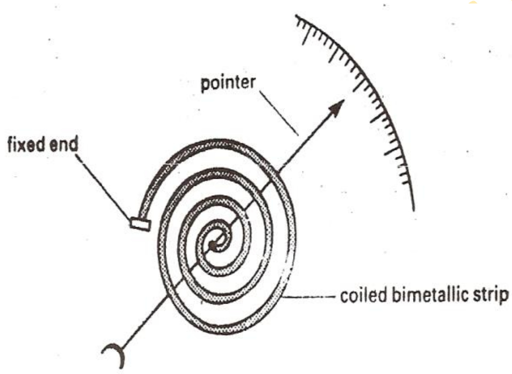
The bimetallic strip of an electric thermostat is used to control the temperature of an electric laundry iron. When the current is switch on, the temperature of the electric iron increases. When the electric iron reaches the desired temperature, the bimetallic strip which is now curved, separates from the contact point C, thereby switching off the current. As the iron cools, the strip strengthens up again and re-makes contact, thus switching on the electric current once more. This make- and-break device regulates the temperature of the electric iron.



Some thermostats use a mercury switch connected to both electrical leads. The angle of the entire mechanism is adjustable to control the set point of the thermostat. Depending upon the application, a higher temperature may open a contact (as in a heater control) or it may close a contact (as in a refrigerator or air conditioner).

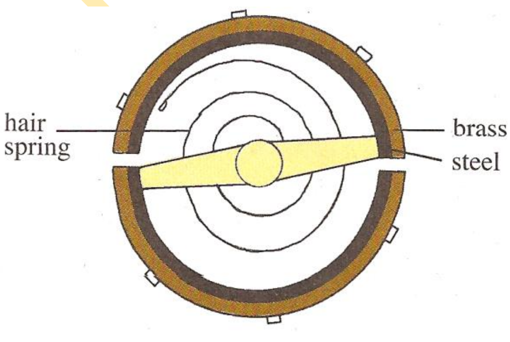
The electrical contacts may control the power directly (as in a household iron) or indirectly, switching electrical power through a relay or the supply of natural gas or fuel oil through an electrically operated valve. In some natural gas heaters the power may be provided with a thermocouple that is heated by a pilot light (a small, continuously burning, flame). In devices without pilot lights for ignition (as in most modern gas clothes dryers and some natural gas heaters and decorative fireplaces) the power for the contacts is provided by reduced household electrical power that operates a relay controlling an electronic ignitor, either a resistance heater or an electrically powered spark generating device.

B. Bimetallic strip thermometer:



A **bimetallic strip thermometer** is used to convert a temperature change into mechanical displacement. The thermometer consists of a spiral form of bimetallic strip made of invar (which hardly expands), and brass. The brass is on the outside of the strip and the invar inside. One end of the spiral strip is fixed and the other attached to the spindle of the pointer. Uneven expansion of metals of the strip due to rise in temperature causes it to curve in the clockwise direction. This curving movement makes the pointer to move over a scale and record the increase in temperature.

C. The balance wheel of clocks/watches:



The balance wheel of clocks and watches is made up of bimetallic strip usually of brass in steel. The strips bends inward on expansion and compensates both for the onward expansion of the spokes of the wheel and then reduced elasticity of the hairspring which occur when the temperature of the clock rises in hot weather. Without this bimetallic device an increase of temperature increases the diameter of the balance wheel and weakens the elasticity of the hairspring, thus causing the watch to lose time

D. Electric fire alarm:

Fire Alarm on a street

An automatic **fire alarm system** is designed to detect the unwanted presence of fire by monitoring environmental changes associated with combustion. It is made up of bimetallic strip usually of brass in steel. In general, a fire alarm system is classified as either automatically actuated, manually actuated, or both. Automatic fire alarm systems are intended to notify the building occupants to evacuate in the event of a fire or other emergency, report the event to an off-premises location in order to summon emergency services, and to prepare the structure and associated systems to control the spread of fire and smoke through the expansion of the strip.

Expansion in Railway Tracks:

To allow for expansion and contraction, gaps are left between sections of rail on the railway track. The ends held in line with fishplates, which are strips of metal bolted to the ends of the rails by slotted holes. Without the gaps, the railway will buckle and train would be derailed

Advantages of thermal expansion of solids:
i. To join steel structure in process called reverting
ii. To fit a wheel on a rim
iii. To fir a cork on a bottle

Disadvantages of thermal expansion of solids:

(i) The balance wheel of a wrist watch
(ii) The buckling of a railway track due to expansion in the hot afternoon and contraction on cold weather
(iii) Sagging of metal cable
(iv) The creaking sound made by corrugated iron sheet due to expansion

Expansion of glass:

Expansion of glass cup with hot water

If hot water is poured into a thick glass bottle or tumbler, it is liable to crack. This is due to the uneven expansion of the glass. The glass is a poor conductor of heat and so also water. When boiling water is poured into the glass cup, the inner layer/surface quickly expands while the outer layer/surface remains at room temperature. Resulting unequal expansion between these layers/surfaces generate thermal stress in the cup. This stress causes the glass to crack. A type of glass called **Pyrex** is therefore used for making laboratory beakers and flasks to avoid the above effects because Pyrex has a low thermal expansivity.

If on the other hand the cup is immersed in cold water that is heated from room temperature to boiling, the heating gradually raises the temperature of water and cup in succession and without the development of (applicable) thermal stress in the cup. The temperature gradient across the wall of the cup is (negligibly) small at any point in time hence cracking does not occur.

Removal of a glass cork or stopper

We can remove a tight glass stopper of a glass bottle without cracking either the bottle or the stopper by either standing the bottle in a hot water making sure that the stopper is not in the water or warming the neck of the bottle with a flame. As the bottle expand the stopper becomes lose

Thermal Expansion of Liquid:

We shall consider only the volume expansion of liquid in this lesson. The concept of thermal expansion of length or surface of a liquid is not meaningful as a liquid has no definite shape like that of a solid due to the following facts:

- The expansion in liquid is usually much more than in a solid for a same rise in temperature; on an average 10 times more.
- The rate of expansion of a same liquid sometimes differs greatly in different temperature ranges. Example: The amount of volume expansion of water in the range of 10ºC-11ºC is quite different from that in the range of 93ºC- 94ºC
- Anomalous expansion of water in the temperature range of 0ºC- 4º C

Apparent and Real Expansion of Liquids:

A liquid is heated while keeping it in a container. There occurs an expansion of the solid container along with the liquid. But the amount of expansion of the container is small compared to that of the liquid. Thus the expansion of a container is not usually noticeable.

When the expansion of liquid is considered ignoring the expansion of the container, it is called **apparent expansion**

When the expansion of liquid is considered alongside with the expansion of the container, it is the **real expansion** of liquid. It is calculated by adding the expansion of the part of the container containing liquid (before expansion) with the apparent expansion of liquid. That is; Real expansion = Apparent expansion + expansion of the container

Definitions of Coefficients of Apparent and Real expansions of Liquid:

We have two different coefficients of expansion for a liquid corresponding to apparent and real expansions.

Coefficient of apparent expansion for liquid:

The amount of apparent expansion of unit volume of a liquid for a unit change of temperature is called coefficient of apparent expansion of liquid.

If the initial volume of the liquid is V_0 and the final apparent volume which is observed to be V_a due to an increase in temperature $\Delta T = T - T_0$, the apparent expansion of volume of the liquid is

$$\Delta V = V_a - V_0$$

∴ The coefficient of apparent expansion of liquid can be written as

$\gamma_a = \frac{\Delta V}{V_0\, \Delta T}$ .... (1)

Thus we can write $V_a = V_0[1 + \gamma_a \Delta T] \;\; = V_0[1 + \gamma_a T - T_0]$.

It may be easily understood that the coefficient of apparent expansion of a liquid cannot be a characteristic property of a liquid as the apparent expansions will be different when containers of different materials are taken.

Definition of Apparent cubic expansivity/ Coefficient of apparent expansion (γ_a) of a liquid: It is defined as the increase in volume per unit volume per degree rise in temperature.

Coefficient of real expansion for liquid:
The amount of real expansion of unit volume of a liquid for a unit change of temperature is called coefficient of real expansion of liquid. If the initial volume of the liquid is V_0 and the final real volume which is calculated to be
V_r due to an increase in temperature ΔT = T - T_0 , the real expansion of the volume of liquid is $\Delta V = V_r - V_0$
∴ The coefficient of real expansion of liquid is

$$\gamma_r = \frac{\Delta V}{V_0\, \Delta T} \text{..........................(2)}$$

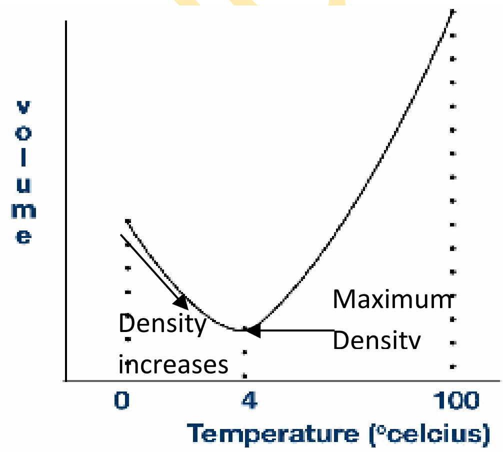
Thus we can write, $V_r = V_0[1 + \gamma \Delta T] = V_0[1 + \gamma_r T - T_0]$.
The coefficient of real expansion is a property of a liquid as the real expansion of volume of a liquid is not dependent on the expansion of the container.

Definition of Real cubic expansivity / Coefficient of Real expansion (γ_r) of a liquid: It is defined as the increase in volume per unit volume per degree rise in temperature when the liquid is heated in an expansible vessel.

The apparent expansivity depends on the cubic expansivity of the material of the vessel so the real expansivity of a liquid γ_r is always more than its apparent expansivity. It can be shown that the difference between the real and the apparent expansivity of a liquid is the cubic expansivity of the vessel. Hence $\gamma_r = \gamma_a + \gamma$
Example 1: The cubic expansivity of mercury is 1.8 x $10^{-4}k^{-1}$ and the linear expansivity of glass 8.0 x $10^{-6}K^{-1}$ Calculate the apparent expansivity of mercury in a glass container.

Solution
Data given:
Cubic expansivity of mercury(γ_r) = 1.8 x $10^{-4}k^{-1}$
Cubic expansivity of the glass $\gamma_g = 3\alpha_g = 3 \times 8.0 \times 10^{-4} K^{-1} = 2.4 \times 10^{-5} K^{-1}$
Formular: $\gamma_r = \gamma_a + \gamma_g$
∴ $\gamma_a = \gamma_r - \gamma_g = 1.8 \times 10^{-4} - 2.4 \times 10^{-5}$
$= 10^{-4}(1.8 - 2.4 \times 10^{-1})$
$= 10^{-4}(1.8 - 0.24)$
$= 10^{-4}(1.56)$
$\gamma_a = 1.56 \times 10^{-4} K^{-1}$

The Anomalous Expansion of Water:



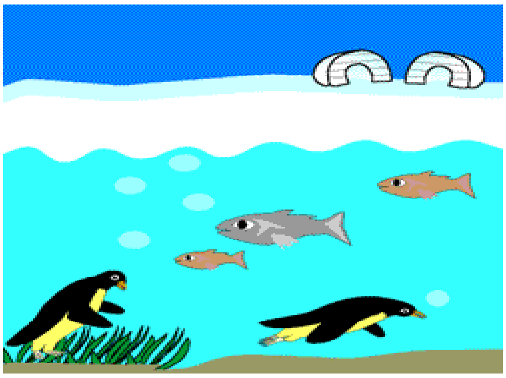
Most liquids contract when they solidify and expand when they are heated. The atoms in the liquid form bonds and move closer together. The molecules move faster, jostle each other more and are further apart on average. Water is strange in this respect. If water at 0 degrees Celsius is heated, it contracts and becomes less dense. It keeps contracting when heated until 4 degrees Celsius, and then it starts expanding. That is, its volume decreases (i.e. it contracts) as its temperature is raised from 0°C to 4°C. Beyond 4°C, the behaviour of water is normal in that its volume increases (i.e. expands) with temperature.

Most molecules, when they change their state from liquid to solid, contract and become more densely packed. When water changes its state gradually from liquid to solid, it contracts and becomes more buoyant. That is the reason why the ice floats in liquid instead of sinking. If water cools it shrinks until it reaches a temperature of four degrees centigrade. At four degrees Celsius, water expands and becomes denser until it reaches zero degrees Celsius. Pure water at 0 degrees Celsius has a density of 1000 Kg/m^3 but pure ice at 0 degrees Celsius has a density of 920 Kg/m^3.

- The anomalous behaviour of water between 0°C to 4°C is one of the reasons of water not being suitable as a thermometric liquid. Also the expansion of water is not regular even above 4°C.

- The anomalous expansion is useful in very cold climates for the preservation of aquatic life. It means the bottom of a lake is the last part to freeze, so fish can usually survive the winter.

How Do Fish Survive in Icy Waters?



In cold winter months, lakes and rivers freeze over forming ice. Yet, fish and other aquatic animals manage to survive. Do they also become blocks of ice? How do aquatic animals survive in frozen lakes and ponds? Animals like seals, penguins, walruses and a wide variety of sea birds are all fish eaters. They live in the Arctic and Antarctic Circle, amidst the icecaps. The land is completely frozen. Yet these animals manage to live in this region. How do they do it?

The icy waters of the Arctic and Antarctic Oceans support a great amount of marine life. For millions of years life has remained unchanged, making it possible for these animals to adapt themselves to these particular patterns of existence. But they do get some help from nature. All liquids have a boiling point and a freezing point.

When water boils at a certain temperature it turns into steam. When it is cooled to a certain temperature it freezes and becomes ice. Water boils at 100 degree Celsius (100 °C) and freezes at 0 °C. When the outside temperature falls below the freezing point of water, lakes and rivers get frozen. However, only the top layer of the lake or river freezes. Underneath the frozen upper layer, the water remains in its liquid form and does not freeze. Also, oxygen is trapped beneath the layer of ice. As a result, fish and other aquatic animals find it possible to live comfortably in the frozen lakes and ponds.

But why doesn't the entire body of water freeze, like a giant, lake-sized ice-cube? Generally, all liquids expand on heating, but water is an exception to this rule. If water is heated, its volume gradually decreases. (This decrease in volume continues till the temperature rises to 4°C.) At temperatures over 4°C water starts expanding. It then keeps expanding with the further rise in temperature, till finally at 100 °C it turns into steam.

In other words, at 4 °C, water has the least volume (occupies the least amount of space) and maximum density (is at its heaviest). This irregular expansion of water is called anomalous expansion. This anomalous expansion plays an important role by only freezing the upper layer in lakes and rivers.

During winter months in colder countries the outside or atmospheric temperature is very low - it drops to below freezing - and the upper layers of water in the lakes and ponds start cooling. When the temperature of the surface layers falls to 4 °C, the water body acquires maximum density and sinks down. The water that sinks down displaces water below, and the lower layers of water simultaneously rise up. This also gets cooled to 4 °C and again sinks down. When the temperature of the water body finally goes below 4 °C, the density or heaviness of water decreases and as a result water does not sink down. The surface water finally freezes at 0 °C while the lower part still remains at 4 °C. The light frozen layer of ice floats on top.

Ice does not allow heat to pass through it easily, so the freezing of the waters below is a very slow process. At depths below 30 metres, temperatures are cold and stable, but food is scarce. As a result animals have adapted to this situation by growing more slowly. There are other dangers that fish face in freezing waters - like death. The body fluid of an ordinary fish can solidify if the temperature of the surrounding water drops below -5 °C. So Arctic and Antarctic fish have adjusted to their surroundings in an interesting manner.

Assignment

1. The increase in volume of $10cm^3$ of mercury when the temperature rises by 100^oC is $0.182cm^3$. What is the cubic expansivity of mercury?
    A. 0.000182 K^{-1} B.0.000178 K^{-1} C. 0.00182 K^{-1} D. 0.0000182 K^{-1} E. 0.0000187 K^{-1}
2. A brass rod is 2 m long at a certain temperature. What is its length for a temperature rise of 100K? If the expansivity of brass is $18 \times 10^{-6}K^{-1}$?
    A. 2.00036 m B. 2.1800 m C. 2.0018 m D. 2.0360 m
3. On a cold morning, the metal blade of a cutlass feels colder to touch than the wooden handle because
    A. The blade is at a lower temperature than the handle.
    B. The hand is at a lower temperature than both blade and handle
    C. The blade is a better conductor of heat than the handle
    D. The handle contains some heat which is absent in the blade
    E. The handle is better conductor of heat than the blade
4. The following are effect of heat on matters Except _______
    A. Change of state and change in velocity
    B. Expansion of a body and change of state
    C. Change in electrical resistance and thermionic emission
    D. Chemical change and pressure
5. The S.I unit of temperature is _______
    A. Degree Fahrenheit B. Degree Kelvin C. Celsius D. Kelvin
6. Energy transferred from a hot object to cooler object as a result of their differences in the measure of average kinetic energy of matter is_______
    A. Light energy B. Thermometer C. Temperature D. Heat energy
7. The word thermometer is a _______ word
    A. French B. Latin C. German D. Greek
8. A measure of the ability of a substance to transfer heat energy to another physical system is known as____
    A. Thermometer B. Thermostat C. Pyrometer D. Temperature

9. A non-contacting device that intercepts and measures thermal radiation is called ________
   A. Pyrometr B. Pyrometer C. Pyrometric D. Pyromaths
10. Which of the following has the smallest temperature increment
   A. Degree Celsius B. Absolute Zero scale C. Degree Kelvin D. Degree Fahrenheit

Perform the appropriate temperature conversions in order to fill in the blanks in the table below

	Celsius (°)	Fahrenheit (°F)	Kelvin (K)
11.	0		
12.		212	
13.			0
14.		78	
15.		12	
16		210	

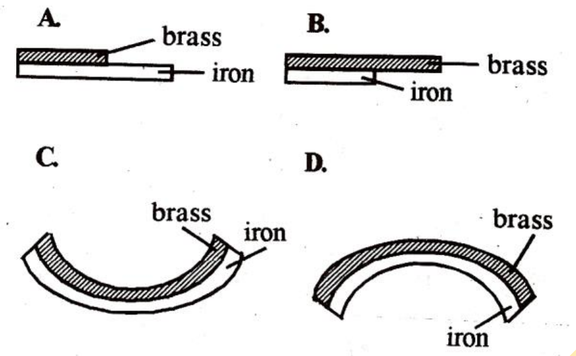
17. A thermocouple works on the principle of ________
   A. Variation of emf with temperature
   B. Variation of volume with temperature
   C. Variation of resistance with temperature
   D. Variation of pressure with temperature
18. A glass bottle of initial volume $2 \times 10^4\ cm^3$is heated from$20℃\ to\ 50℃$. If the linear expansivity of glass is $9 \times 10^{-6}K^{-1}$, the volume of the bottle at $50℃$ is ________
   A. $20,005.4cm^3$ $B. 20,008.1cm^3$ $C. 20,013.5cm^3$ $D. 20,016.2cm^3$
19. A brass measuring tape is correct at 20°C. The value obtained when the length of a field is measured with the rule at 50°C appears to be 70.5 m, what is the true length of the field? Linear expansivity of brass $= 1.8 \times 10^{-5}K^{-1}$,
   A. 70.5001 B. 70.5003 C. 70.4962 D. 70.4961

Find the values of A, B, C ,D E in the following table

S/N	Original length, area, or volume	Linear expansivity $10^{-6}K^{-1}$,	Rise in temperature in K	Increase in length, area, or volume
20	0.5 m	10	15	A
21	2.0 m	25	B	3.0 mm
22	0.6 m	C	80	1.0 mm
23	D	16.7	100	25 mm^2

24	500mm^2	18	E	0.36 mm^2

25. What is meant by the statement: the linear expansion of zinc is $2.6\times10^{-5}K^{-1}$?
26. Describe an experiment to determine the linear expansivity of a zinc rod
27. State TWO advantages and TWO disadvantages of thermal expansion of solids
28. A metal cube of volume V and linear expansivity α is heated through a temperature rise of T. The increase in volume of the cube is ____
    A. 3α VT B. 2α VT c. α VT D. α VT/3
29. A density bottle of volume 500 cm^3 is filled with a liquid and heated from 20^{o}C to 60 ^{o}C. if 7.5 cm^3 of liquid is expelled, the apparent cubic expansivity of the liquid is _____
    A. $7.5\times10^{-5}K^{-1}$ B. $3.75\times10^{-4}K^{-1}$ C. $3.75\times10^{-5}K^{-1}$ D. $7.5\times10^{-4}K^{-1}$
30. Which of the following diagram correctly illustrates the shape of a bimetallic strip made of brass and iron after heating?



31. Explain why a thick glass cup crack when boiling water is poured into it but the same cup would not crack when immersed in a bath of cold water which is then heated to boiling point.
32. When heat is added to a substance, this causes the following Except_______
    A. Rise in temperature B. Change in electrical reactance C. Change in electrical resistance D. Change in pressure
33. In which of the following is expansion of solids a disadvantage?
    A. The fitting of the wheel in rims B. Fire alarms C. The thermostat

    D. The balance wheel of a wrist watch

WEEK THREE LESSON NOTE

HEAT TRANSER

Heat transfer is a discipline of thermal engineering that is concerned with the generation, use, conversion, and exchange of thermal energy and heat between physical systems. Heat transfer is classified into various mechanisms/modes such as: conduction, convection and radiation.
Conduction or diffusion is the transfer of energy between objects that are in physical contact.
Convection is the transfer of energy between an object and its environment, due to fluid motion

Radiation is the transfer of energy to or from a body by means of the emission or absorption of electromagnetic radiation

Mass transfer: The transfer of energy from one location to another as a side effect of physically moving an object containing that energy. Engineers also consider the transfer of mass of differing chemical species, either cold or hot, to achieve heat transfer. While these mechanisms have distinct characteristics, they often occur simultaneously in the same system.

Concept of Thermal Conduction

If a metal spoon is used to fry some yams in hot oil, one notices that the handle of the spoon soon becomes very hot. Again if one uses an aluminium cup to transfer hot water from a cooking pot to a bucket, the handle of the cup soon becomes so hot that it is impossible to hold it. The heat of hot oil or boiling water has been transferred to the hand through the metal spoon or cup. This heat has travelled through the metal by the process of **conduction.**

Heat of conduction, also called diffusion, is the direct microscopic exchange of kinetic energy of particles through the boundary between two systems. In solids, the molecules are tightly packed together, held together by strong forces of attraction called cohesive force, are arranged in regular pattern and are not free to move about, but merely vibrate about their mean positions.

Conduction is the most significant means of heat transfer within a solid or between solid objects in thermal contact. Fluids especially gases are less conductive. Thermal contact conductance is the study of heat of conduction between solid bodies in contact, other types of conductions include:

Steady state conduction: is a form of conduction that happens when the temperature difference driving the conduction is constant, so that after an equilibration time, the spatial distribution of temperatures in the conducting object does not change any further. In steady state conduction, the amount of heat entering a section is equal to amount of heat coming out.

Transient conduction: occurs when the temperature within an object changes as a function of time. Analysis of transient systems is more complex and often calls for the application of approximation theories or numerical analysis by computer.

Definition of Conduction:

Conduction of heat is defined as the process by which heat is passed along a stationary solid material, the average or mean position of the heated particles of the material remaining the same.

Kinetic molecular theory explanation of conduction: Kinetic molecular theory of matter explains that heat transfer by conduction occurs as hot, rapidly moving or vibrating atoms and molecules interact with neighbouring atoms and molecules, transferring some of their energy (heat) to these neighbouring particles. In other words, heat is transferred by conduction when adjacent atoms of solid vibrate about their mean position continuously when heated; the molecules nearest to the source of heat receive the heat first and vibrate with an increase in velocity and kinetic energy. These molecules transfer the heat to the neighbouring molecules. This heat is the passed on gradually until the molecules at the other end of the solid receive it.

OR

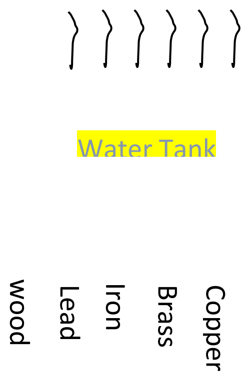
When one end of a material is heated, the molecules there gain energy and vibrate with increasing speed. They therefore bump against neighbouring molecules more than before and so transfer greater energy to them. This goes on all the way along the solid. All the molecules of the solid eventually vibrate more rapidly about their fixed or mean position. Therefore in this way thermal energy is transferred along the solid although the average or mean position of the molecules remain unchanged.

Most metals allow heat to pass through them and are said to be good conductors of heat. Non-metal such as wood, cotton and cork do not allow heat to pass through them and are said to be poor conductors or insulators.

Good conductors are metal such as	Poor conductors/ insulators are Non-metals such as:	Practical application of good conductors	Practical application of Poor conductors
Silver	Wood	Cooking Utensils- Pots, frying pans	Handle of cooking utensil
iron	Styrofoam	Tile/cemented floor conducts heat rapidly away from the one's foot hence cools.	Rug/carpet floor do not conduct heat rapidly away from the one's foot
steel	paper	Galvanised iron roof conducts heat from the sun into the room hence heats up the room	Thatched roof do not conduct heat from the sun into the room hence cools
Copper	Air	Silk/ nylon do not keep the body warm by holding air between the cloth and the body but conductors heat.	Woollen/fur clothing keeps the body warm by holding air between the cloth and the body

Though all metal are classed as good conductors, they differ in their ability to conductor heat. We can compare the ability of metals to conduct heat, or their thermal conductivity

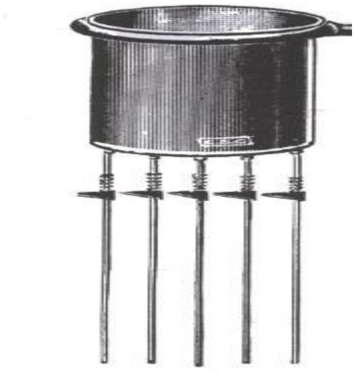
Experiment to compare the thermal conductivity of material:



The apparatus has a number of equal lengths of rods, each made of a different metal. The rods must be coated with wax. This can be done by one of the following methods:

i. Take the rods out of the water box and lay them in a chilled tin tray containing molten paraffin-wax. Remove quickly, hold vertically to allow the excess wax to drain off, and push them back into the water box.

ii. Keep the rods in the water box. Paint each rod with a paint brush dipped in very hot molten wax. This produces an uneven, thick coating of wax, which must then be thinned by blowing a Bunsen flame up and down the rod.

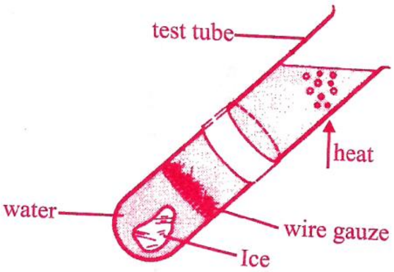


Equal length of rods of different metals such as copper, iron, aluminium, brass and one rod of a non-metal such as wood, all of equal cross-sectional are suck lightly into a small tank, so that a good length of the rods protrude outside the tank. The rods are coated with paraffin wax as explained above. Boiling water is then poured into the tank. After several minutes, it is noticed that different length of the wax has melted from the metal with the greatest length of copper and the least length of wood. More length of wax on the copper was melted than that of brass, iron and wood in that order. Thus copper has the greatest thermal conductivity and wood has least.

Thermal Conductivity in liquids

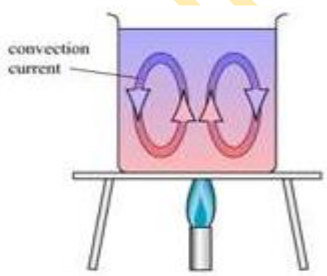
In general, liquids are poor conductors of heat, but metal in liquid form, such as mercury is a very good conductor. However, heat is transferred through liquids mainly by the process of convection.

Experiment to show that water is a bad conductor of heat



A piece of ice is wrapped with wire gauze and dropped into a tilted test tube containing water. The heat is applied near the top of the test tube using a Bunsen burner. It is observed that although the water at the top is boiling for sometimes, the ice at the bottom remains apparently unmelted. This is because only small amount of heat is conducted from the top to the bottom of the water showing that water is a poor conductor of heat.

Concept of Thermal

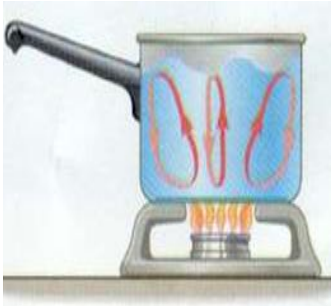


Convection is usually the dominant form of heat transfer in liquids and gases. Although sometimes discussed as a third method of heat transfer, convection is usually used to describe the combined effects of heat of conduction within the fluid (diffusion) and heat transference by bulk fluid flow streaming. Convection is the up and down movement of gases and liquids caused by heat transfer. As a gas or liquid is heated, it warms, expands, and rises because it is less dense and falls. As the gas or liquid warms and rises, or cools and falls, it creates convection current.

Convection is the primary method by which heat moves through gases and liquids. Examples of convections are: Warmer water at the surface of a lake or swimming pool, Wind currents, Hot air balloon, Lower floors of a building being cooler than the top floor.

Definition of Convection

Convection is defined as the process by which heat energy is transferred from the hotter region of a liquid or gas to the colder region of the fluid by the actual movement of the heated fluid.
Heat of convention can be of two types namely: Natural convection and forced convection.



Free, or natural, convection: occurs when bulk fluid motion (gas or liquid) are caused by buoyancy forces that result from density variations due to variations of temperature in the fluid. For instance when water is being heated on a stove, water in contact with hot base of the container rises because it is less dense than cold water. The cold, dense water moves down and convectional current is set up. Convectional currents are fluids that move due to temperature difference in the fluids

***Forced* convection:** is a term used when the streams and currents in the fluid are induced by external means such as fans, stirrers, and pumps creating an artificially induced convection current. The flow of fluid may be forced by external processes, or sometimes (in gravitational fields) by buoyancy forces caused when thermal energy expands the fluid (for example in a fire plume), thus influencing its own transfer.

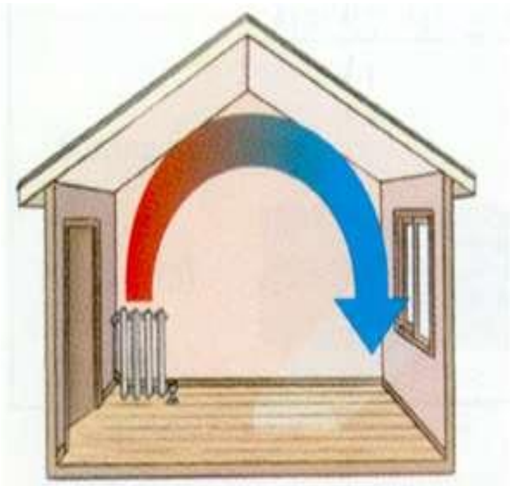
Kinetic molecular theory explanation of convention:

Convective heat transfer, or convection, is the transfer of heat from one place to another by the movement of fluid molecules, a process that is essentially transfer of heat via mass transfer. Bulk motion of fluid enhances heat transfer between the molecule of the liquid, as the liquid warms and rises, or cools and falls, it creates convection current. The molecules of liquid are not arranged in any regular pattern. The molecules are able to slide past one another because the cohesive force between molecules of liquids is not as strong as in solids. Therefore the molecules move with different speeds, some of the faster molecules escape from the surface of the liquid, giving rise to evaporation

PRACTICAL APPLICATION OF CONVECTION CURRENTS IN COOLING DEVICES

Ventilation of a Room

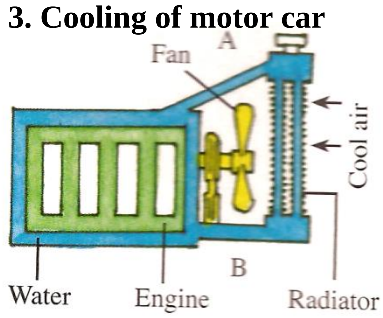
Good ventilation in houses relies on the continuous circulation of convection air currents. Air heated by respiration and fires, rises towards the ceiling and escapes through the ventilators placed near the ceiling. This is replaced by fresh air from outdoor which enters the rooms through the windows and other openings. In this way the room is ventilated.



Circulation of air in a room

The dense cool water from the main water supply C descends in the heating coil chamber A, when the water is heated it becomes less dense hence rises up in the chamber B where it comes out from the tap, some of the hot water moves up the while the cool water comes down hence creating a convectional current

3. Cooling of motor car



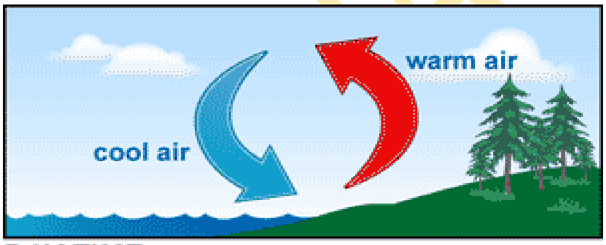
The motor car engine requires to be cooled to prevent overheating. Continuous convection currents are utilized in the cooling process of the car engine. Water circulates round the engine by convection currents. The heat generated by the engine is conducted by metal to the water in the jacket. The water itself is cooled by the draught of air created round the radiator by the motion of the car and the movement of the fan.

4. **Room air condition:** Air molecules near the ceiling get cooled becomes denser and sink. Warmer air molecules below being lighter rise to the top, get cooled, become denser and sink again; thus convectional current is set up.

Land and sea breeze

An example of a convection current in nature is the land and sea breeze observed near coastal area.

Sea breezes

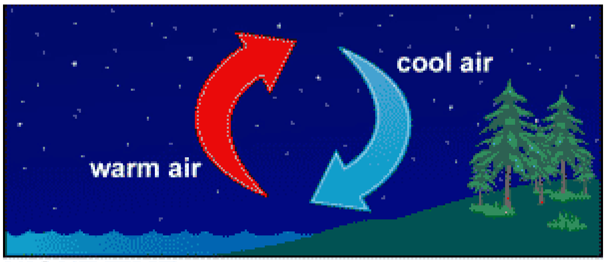


DAY TIME

SEA BREEZE

A **sea-breeze** (or **onshore breeze**) is a wind from the sea that develops over land near coasts. It is formed by increasing temperature differences between the land and water; these create a pressure minimum over the land due to its relative warmth, and forces higher pressure, cooler air from the sea to move inland. Generally, air temperature gets cooler relative to nearby locations as one move closer to a large body of water

During the day, the sun shines on both land and sea. The land gets heated up faster than the sea because the sea has a greater heat capacity than land and therefore the surface of the sea warms up slower than the land's surface. As the temperature of the surface of the land rises, the land heats the air above it. The warm air is less dense and so it rises. This rising air over the land lowers the sea level pressure by about 0.2%. The cooler air above the sea, now with higher sea level pressure, flows towards the land into the lower pressure; creating a cooler breeze near the coast thus convection current is created. The strength of the sea breeze is directly proportional to the temperature difference between the land and the sea. The cool breeze that blow inland from the sea is known as **Sea breeze**.



Land breezes

At night, the land is not being heated by the sun and cools off quicker than the ocean because the sea has a greater heat capacity than land and therefore the surface is more able to absorb and retain heat than the land, which forces the dying of the daytime sea breeze. If the land cools below that of the adjacent sea surface temperature, the pressure over the water will be lower than that of the land. This sets up a land breeze, which is a cool breeze now moving from the land to the sea.

If there is sufficient moisture and instability available, the land breeze can cause showers or even thunderstorms, over the water. Overnight thunderstorm development offshore due to the land breeze can be a good predictor for the activity on land the following day, as long as there are no expected changes to the weather pattern over the following 12–24 hours. This is mainly because the strength of the land breeze is weaker than the sea breeze. The land breeze will die once the land warms up again the next morning.

Thermal Radiation

The final major form of heat transfer is by radiation, which occurs in any transparent medium (solid or fluid) but may also even occur across vacuum (as when the Sun heats the Earth). When electromagnetic waves travel through space, it is called radiation. When electromagnetic waves come in contact with an object, the waves transfer the heat to that object. Thermal radiation therefore is energy emitted by matter as electromagnetic waves due to the pool of thermal energy that all matter possesses that has a temperature above absolute zero.

Thermal radiation propagates without the presence of matter through the vacuum of space. The sun warms the earth through the radiation of electromagnetic. It is a direct result of the random movements of atoms and molecules in matter. Since these atoms and molecules are composed of charged particles (protons and electrons), their movement results in the emission of electromagnetic radiation, which carries energy away from the surface.

Definition of Radiation

Radiation is defined as the process by which heat is transfer from a hotter to a cooler place without heating of the intervening medium. That is the transfer of energy through space by means of electromagnetic waves in much the same way as electromagnetic light waves transfer light. The same laws that govern the transfer of light govern the radiant transfer of heat.

Unlike conductive and convective forms of heat transfer, thermal radiation can be concentrated in a small spot by using reflecting mirrors, which is exploited in concentrating solar power generation. For example, the sunlight reflected from mirrors heats the PS10 solar power tower and during the day it can heat water to 285 °C (545 °F).

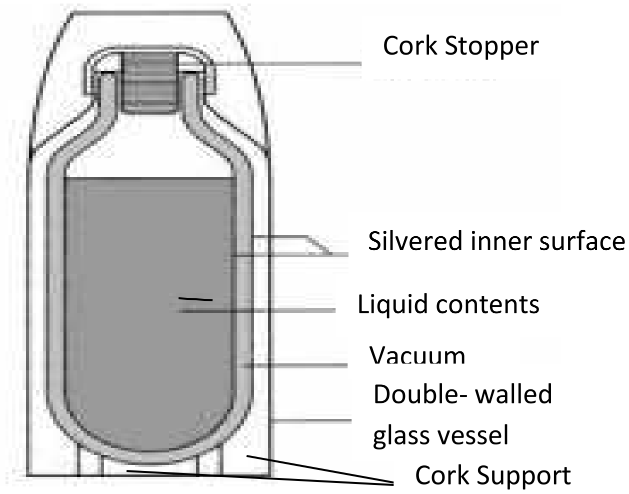
A red-hot iron objects transferring heat to the surrounding environment primarily through thermal radiation. Other examples of radiation heat transfer are; camp fire, microwave oven and a light bulb

The intensity of heat radiated by a surface increase with:

1. The area of the surface
2. The absolute temperature of the surface
3. The colour and brightness of the surface: black, dull surfaces are generally better radiator/absorber of radiant heat than silvery and shiny surfaces.

PRACTICAL CONSEQUENCES OF RADIATION

The Thermos flask



A vacuum-flask (popularly known as a Thermos flask, which is a trade name) is a double-walled vessel with the space between the two walls exhausted of air as completely as possible. It was originally devised by Sir James Dewar for preserving liquefied gases at very low temperatures from evaporation. The nature of heat transference means that the substance contained in a vacuum-flask remains at its temperature for very much longer than if it were in an ordinary single walled vessel. That is it is used to keep the temperature of its contents constant. If we put hot water in the flask it will remain hot, if we put ice cold water it will remain ice cold.

The essential features of a vacuum flask consist of

i. a double- walled glass vessel with the inside coated with silver,
ii. a vacuum between the walls,
iii. the stopper is made of an insulating material, such as cork or plastic. The bottom of the glass vessel is supported with insulating cork.

The functions of various features are as follows:

a) The vacuum prevents heat losses by conduction and convection, since a material medium is require for these two processes
b) The silvered wall prevents heat loss by radiation. Silver is a poor radiator, and any heat from one wall tends to be reflected back by the other
c) The insulating cork or plastic stopper reduces heat loss by convection from the contents upwards to the outside. The stopper is a poor conductor of heat so it prevents heat loss by conduction.

Because of all these features, heat lost or gained by the flask from the surrounding is very small. Hence the flask keeps cold liquids cold and hot liquids hot, for a long time.

Other practical consequences of radiation include:

1. An electric pressing iron has a silvered surface at the base. The bright surface reduces the heat loss from the iron by radiation
2. Factory roof are brightly painted with aluminium to keep the interior cool, since the bright surface will not absorb much heat from the sun.

3. A brightly painted car is preferred to a black- painted car in Nigeria and other hot tropical countries. The black-painted car can absorb and retain heat from the sun and inside the car will be very hot.
4. On the bases of the above it is easy to see why it is not advisable to wear a dark coloured jacket or shirt in a hot afternoon. The dark cloth will absorb the radiant heat of the sun and cause the wearer to feel hot and uncomfortable. It is preferable to wear a white cloth which will not absorb the heat but will rather reflect it away from the body
5. The outer surface of a teapot is brightly polished. Such a surface radiates less heat than an unpolished one and will therefore retain heat inside the teapot for a longer period.

Exercises:

1. Explain convectional current
2. State TWO practical application of convectional currents in cooling devices
3. Give TWO modes of heat transfer other than conduction
4. Use kinetic theory of matter to explain the mechanism by which heat is transmitted through solids and liquids
5. Describe an experiment to show that water is a bad conductor of heat.
6. Draw and label a diagram showing the essential parts of a thermos flask
7. Explain how a flask can retain heat for a very long time
8. Which of the following is a reason why a concrete floor feels colder to the bare feet than a mat on the same floor during the rainy season?
   A. Mat is a better conductor of heat than the feet
   B. Mat loses heat to the bare feet at a faster rate than concrete floor.
   C. Mat loses heat to the bare feet than concrete while the concrete floor extracts heat from them
   D. Concrete floor is better conductor of heat than the concrete floor
9. Cooking pots are usually made of metals because metals
   A. Have high coefficient of expansion
   B. Have low specific heat capacity
   C. Are poor conductor of heat
   D. Are good conductor of heat
10. A house whose roof is painted white feels cooler on a hot day than one whose roof is painted black because
   A. White is a better conductor of heat than black
   B. Black is a better conductor of heat than white.
   C. White is a better reflector of heat than black
   D. Black is a better reflector of heat than white
11. Which of the following is NOT suitable method for reducing heat from hot metal ball?
   A. Placing it in a vacuum B. Painting it black
   B. Placing it on a rubber support D. Wrapping it with cotton wool
12. In an electric kettle the heating element is usually located near the bottom of the kettle because
   I. Cold water is denser than hot water

II. Heat is transmitted to all parts of water primarily by convection
III. Heat is quickly conducted to all parts of the water
IV. Loss to the surroundings is minimized

A. I and II only
B. B. III and IV only
C. C. I, II and III only
D. D. I, II and IV only

13. The heat of the sun reaches the earth's surface by the process of
    A. Convection
    B. B. Conduction
    C. Radiation
    D. D. Precipitation
14. Two identical kettles X and Y are filled with water at 100°C. The outer surface of X is painted black while that of Y is polished
    A. X cools faster because a blackened surface radiates faster than a polished surface
    B. X cools faster because it is a better conductor of heat
    C. Y cools faster because it is a better reflector of heat
    D. Y cools faster because a polished surface is a better radiator of heat than a blackened surface.
15. A thermos flask has a double-walled glass container in which heat losses are minimized by

    I. Evacuating the space between the glass walls
    II. Silvery the surface on either side of the evacuated space
    III. Covering the container with cork of low thermal conductivity

    Which of the above measure minimize(s) heat loss by conduction?

    A. I only
    B. B. II only
    C. C. I and II only
    D. D. I and III only
16. Which of the following attire is most comfortable on a hot sunny day?
    A. Black
    B. white
    C. Red
    D. Blue
17. The heat from a fire in a room is transmitted to various parts of the room primarily by
    A. Convection
    B. B. Conduction
    C. Diffusion
    D. D. radiation

WEEK FOUR LESSON NOTE

DESCRIPTION AND PROPERTIES OF FIELD

Concept of Field:

Fields can be defined as a region or space in which the influence of some physical agency such as gravitation, magnetism and electricity is detected or felt. If the physical agency is magnet, the field is known as magnetic field. If it is gravity, the field will be gravitational field. If it is electricity, the field is electric field. Fields creates a force known as force fields.

Force field is defined as force whose sources do not require contact with the body to which they are applied. Such force fields are identified as gravitational force, electric force, magnetic force and electromagnetic force.

There are two classes of force fields; scalar and vector force fields. A scalar field is one that has only magnitude but no direction, e.g. temperature, energy and density. A vector field is a field that has both magnitude and direction, e.g. gravitational, magnetic and electric fields.

Field lines:

A **field line** is an imaginary line or locus that is defined by a vector field and a starting location within the field. A vector field line is the tangent line to the path at which each point is required to be parallel to the vector field at that point. It defines a direction at all points in space.

Field lines are useful for visualizing vector fields, which are otherwise hard to depict. Note that, like longitude and latitude lines on a globe, or topographic lines on a topographic map, these lines are not physical lines that are actually present at certain locations; they are merely visualization tools.

Field lines start at sources and end at sinks of the vector field. (A "source" is wherever the divergence of the vector field is positive; a "sink" is wherever it is negative.) In physics, drawings of field lines are mainly useful in cases where the sources and sinks, if any, have a physical meaning, as opposed to e.g. the case of a force field of a radial harmonic.

For example, Gauss's law states that an electric field has sources at positive charges, sinks at negative charges, and neither elsewhere, so electric field lines start at positive charges and end at negative charges. (They can also potentially form closed loops, or extend to or from infinity). A gravitational field has no sources, it has sinks at masses, and it has neither elsewhere, gravitational field lines come from infinity and end at masses. A magnetic field has no sources or sinks (Gauss's law for magnetism), so its field lines have no start or end: they can *only* form closed loops, or extend to infinity in both directions.

Types of fields:

There three types of vector fields, they include: Gravitational field, Electric field and magnetic field

Concept of Gravitational field:

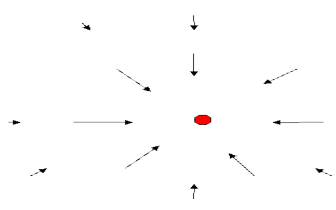
If we throw up massive object, it is our common observation that they move up to their highest points, stationary very briefly and eventually move downward, falling faster until they hit the ground level or the lowest level on their path. The up and down movement of objects on the earth's surface are subject to the influence of the Gravitational field of the earth.

Gravity is a force that exists between the Earth and the objects that are near it. As you stand upon the Earth, you experience this force. We have become accustomed to calling it the **force of gravity** and have even represented it by the symbol $\mathbf{F_{grav}}$.

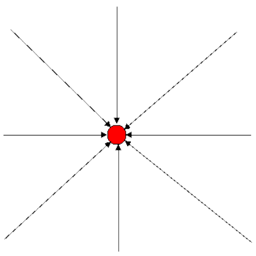
Definition of gravitational field:

The gravitational field at any point P in space is defined as the gravitational force felt by a tiny unit mass placed at P.

Field from a Single Point Mass



Field from a single point mass has field strength of $\frac{GM}{r^2}$. The points are towards the mass, that is, the direction of the attraction. If we draw a few vectors showing its strength at various points it shows rather inadequate representation because there is a lot of blank space, and, besides, the field attracts in three dimensions, there should be vectors pointing at the mass in the air above (and below) the paper. But the picture does convey the general idea.

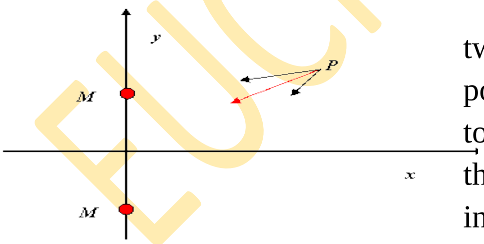


A different way to represent a field is to draw "field lines", curves such that at every point along the curve's length, that is, its direction is the direction of the field at that point. Of course, for our single mass, the field lines add little insight:

The arrowheads indicate the direction of the force, which points the same way all along the field line. A shortcoming of the field lines picture is that although it can give a good general idea of the field, there is no precise indication of the field's *strength* at any point. However, as is evident in the diagram above, there *is* a clue: where the lines are closer together, the force is stronger. Obviously, we could put in a spoke-like field line anywhere, but if we want to give an indication of field strength, we would have to have additional lines equally spaced around the mass.

Gravitational Field for Two Masses

The next simplest case is two equal masses. Let us place them symmetrically above and below the *x*-axis:



Recall Newton's Universal Law of Gravitation states that any two masses have a mutual gravitational attraction Gm_1m_2/r^2. A point mass $m = 1$ at P will therefore feel gravitational attraction towards both masses M, and a *total* gravitational field equal to the *vector sum of these two forces*, illustrated by the red arrow in the figure

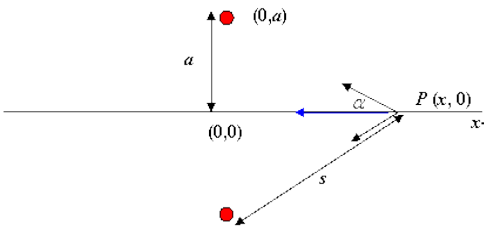
The Principle of Superposition

The fact that the total gravitational field is just given by adding the two vectors together is called the *Principle of Superposition*. This may sound

really obvious, but in fact it is not true for every force found in physics: the strong forces between elementary particles do not obey this principle, neither do the strong gravitational fields near black holes. But just adding the forces as vectors works fine for gravity almost everywhere away from black holes, and, as you will find later, for electric and magnetic fields too. Finally, superposition works for any number of masses, not just two: the total gravitational field is the vector sum of the gravitational fields from all the individual masses. Newton used this to prove that the gravitational field outside a solid sphere was the same as if all the mass were at the centre by imagining the solid sphere to be composed of many small masses.

Field Strength at a Point Equidistant from the Two Masses

It is not difficult to find an exact expression for the gravitational field strength from the two equal masses at an equidistant point *P*. Choose the *x,y* axes so that the masses lie on the *y*-axis at (0, *a*) and (0,-*a*). By symmetry, the field at *P* must point *along* the *x*-axis, so all we have to do is compute the strength of the *x*-component of the gravitational force from one mass, and double it.



If the distance from the point *P* to one of the masses is *s*, the gravitational force towards that mass has strength $\frac{GM}{s^2}$. This force has a component along the *x*-axis equal to $\left(\frac{GM}{s^2}\right)\cos\alpha$, where α is the angle between the line from *P* to the mass and the *x*-axis, so the total gravitational force on a small unit mass at *P* is $2\left(\frac{GM}{s^2}\right)\cos\alpha$ directed along the *x*-axis.

From the diagram, $\cos\alpha = \frac{x}{s}$, so the force on a unit mass at *P* from the two masses *M* is $2\left(\frac{GM}{s^2}\right)\frac{x}{s}$

Concept of Electric field:

The concept of the electric field was introduced by Michael Faraday. Surrounding any object with charge, or collection of objects with charge, is an electric field. Any charge placed in an electric field will experience an electrical force. In physics, an **electric field** surrounds electrically charged particles and time-varying magnetic fields. It depicts the force that is exerted on other electrically charged objects by the electrically charged particle the field is surrounding.

An electric field is created by a charged body in the space that surrounds it which results in a force exerted on any other charges placed within the field. The electric field acts between two charges in a similar manner to the way that the gravitational field acts between two masses, and like it, extends towards infinity and shows an inverse square relationship with distance.

This suggests similarities between the electric field **E** and the gravitational field **g**, so sometimes mass is called "gravitational charge".

Similarities between electrostatic and gravitational forces:

1. Both act in a vacuum.
2. Both are central and conservative.
3. Both obey an inverse-square law (both are inversely proportional to square of r).
4. Both propagate with finite speed c, the speed of light.

[Electric charge](#) and [relativistic mass](#) are conserved; note, though, that [rest mass](#) is not conserved. However, there is an important difference. Gravity always acts in attraction, drawing two masses together, while the electric field can result in either attraction or repulsion.

Differences between electrostatic and gravitational forces:

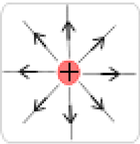
1. Electrostatic forces are much greater than gravitational forces (by about 10^{36} times).
2. Gravitational forces are attractive for like charges, whereas electrostatic forces are repulsive for like charges and attractive for unlike charges
3. There are no negative gravitational charges (no [negative mass](#)) while there are both positive and negative electric charges. This difference combined with previous implies that gravitational forces are always attractive, while electrostatic forces may be either attractive or repulsive.

Since large bodies such as planets generally carry no net charge, the electric field at a distance is usually zero. Thus gravity is the dominant force at distance in the universe, despite being much weaker.

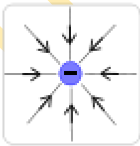
Electric Field lines:

The electric field lines are the paths that a point (isolated small) positive charge would follow if placed in the field. OR, they are imaginary lines drawn in an electric field in such a way that the direction at any point (or direction of the tangent) gives the direction of the electric field at such a point. It has no physical existence. The field permeates all the intervening space between the lines.

For example, consider the electric field arising from a single, isolated [point charge](#).



Field lines emanating



Field lines emanating

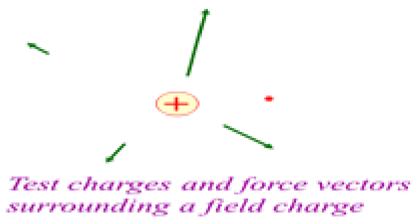
Properties of lines of force/ field lines:

Field lines emanating from stationary charges have several key properties which include

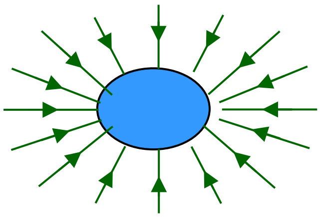
1. They originate from positive charges and terminate at negative charges. The number of lines starting or ending is proportional to the magnitude of the charge
2. They must enter any good conductor at right angles. A hollow conducting body carries all its charge on its outer surface. The field is therefore zero at all places inside the body.
3. They may never cross nor close in on themselves.
4. They are continuous in any region with free charges
5. They are drawn such that the electric field is proportional to the number of lines crossing unit area perpendicular to the lines.
6. The closer the lines are together, the stronger the electric field in that region
7. They indicate the direction of the electric field.

Electric lines of force-around isolated positive charge:

Let us use the idea of a test charge to produce the **E** field for an isolated positive field charge. We place small, positive test charges in the vicinity of the field and draw the force vector on each. Note that the closer the test charge is to the field charge, the greater the force, but all force vectors are directed radially outward from the field charge. At any point near the field charge, the force vector points in the direction of the electric field. Thus we have a field that looks like a sea urchin, with field lines radiating

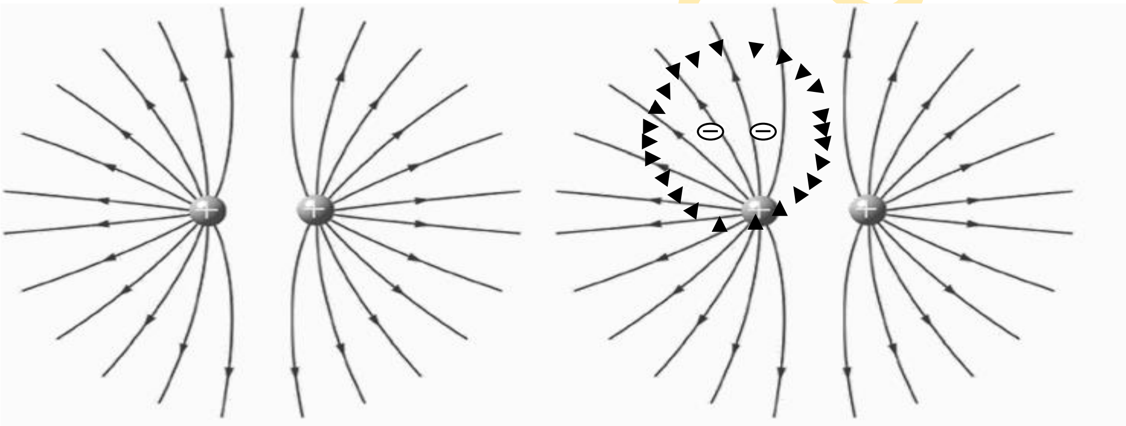


Electric lines of force-around isolated –ve charge:



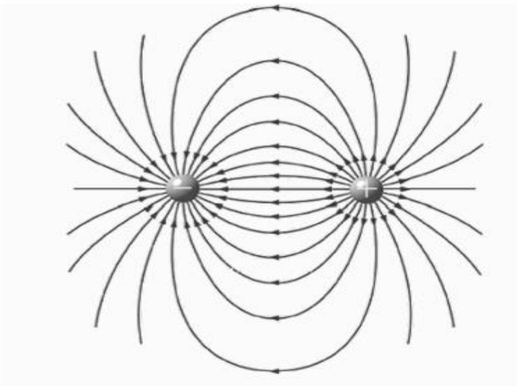
The opposite is true for an isolated negative field charge. No matter how complex the field is, the electric force on a test charge is always tangent to the field line at that point.

Electric lines of force-around two like equal charges placed near each other:

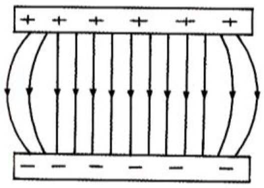


With two equal identical field charges, the field is symmetric but all field lines go to infinity (if the charges are positive) or come from infinity (if the charges are negative). As with any field the net force on a test charge is tangent to the field. Here, each field charge repels a positive or negative test charges. The forces are shown as well as the resultant vectors, which are tangent to the field lines.

Electric lines of force-around two unlike equal charges placed near each other:



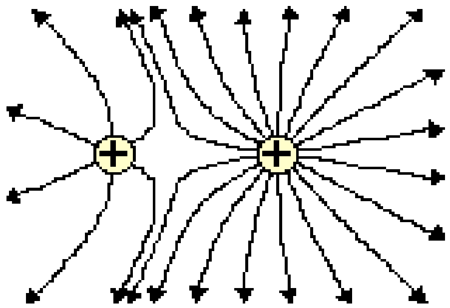
For two equal unlike field charges, the positive and negative charges have the same magnitude as shown above. The field lines move out from the positive charge than land on the negative. Those that do not land on the negative charge go to infinity. As always, net force on a test charge is the vector sum of the two forces and it is tangent to the field.

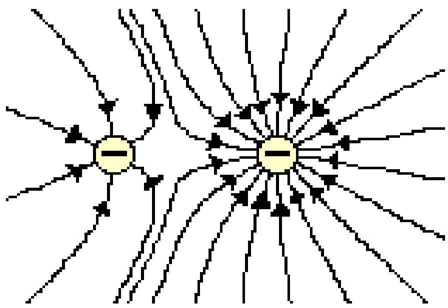


Between a pair of parallel conducting plates

Electric line between two parallel plates carries unlike charges of equal magnitude

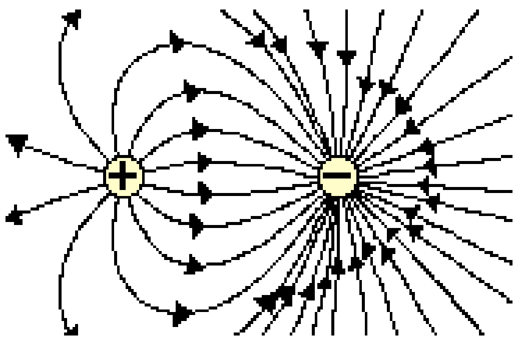
Electric lines of force-around, two like Unequal amount charges placed near each other

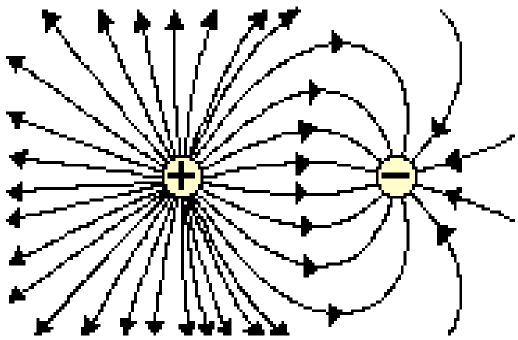




With two like unequal field charges, more field lines emanate from the greater charge; none of the field lines cross and they all go to infinity. The field lines of the greater charge look more like that of an isolated charge, since it dominates the smaller charge. If you looked at the field from a great distance, it would look like that of an isolated point charge due to one combined charge.

Electric lines of force-around, two unlike Unequal amount charges placed near each other





For unequal unlike field charges, the positive charge has a greater magnitude than the negative charge. This explains why the field is as shown above. More field lines come from the positive charge than land on the negative. Those that do not land on the negative charge go to infinity. Since the positive charge has greater magnitude, it dominates the negative charge, forcing the "turning points" of the point to be closer to the negative charge. If you were to observe the field from a distance, it would look like that of an isolated, positive point with a charge equal to the net charge of the system.

Second Law of Electrostatics or Coulomb's law:

The fundamental equation of electrostatics is Coulomb's law, which describes the force between two point charges.

Coulomb's law states that the magnitude of the electrostatic force between two point electric charges Q_1 and Q_2 is directly proportional to the product of the magnitudes of each charge and inversely proportional to the surface area of a sphere whose radius is equal to the distance between the charges: $F_C = \frac{Q_1 Q_2}{4\pi r^2 \varepsilon_0} = \frac{K Q_1 Q_2}{r^2}$

Where, ε_0 is a constant called the vacuum permittivity or permittivity of free space, has a unit of $C^2N^{-1}m^{-2}$ or $F\ m^{-1}$

$Q_1\, and\, Q_2$ = point charges have unit of coulomb (C)

r = distance between the charges has unit of metre (m)

$k = \frac{1}{4\pi\varepsilon_0}$ has unit of $Nm^2C^2\ OR\ F^{-1}$

Definition of Electric Field strength or Intensity:

We defined electric field strength or intensity as the electric force per unit (positive) charge on any "test charge" placed in the field:

$\vec{E} = \frac{\vec{F}}{q}$ where

F is the electric force experienced by the test charge, a vector

q_t is the charge of the test charge in the electric field, a scalar

E is the electric field wherein the particle or charge is located. It defines the direction of the net electric force on a positive charge; its units are N / C.

E and F are only parallel if the test charge is positive.

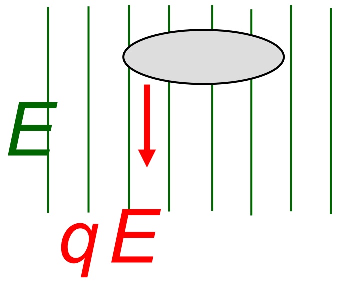
From the definition of electric field intensity and Coulomb's law, it follows that the magnitude of the electric field *E* created by a single point charge *Q* is: $E(\vec{r}) = \frac{Q}{4\pi r^2 \varepsilon_0}$

As is clear from the definition, the direction of the electric field is the same as the direction of the force it would exert on a positively-charged particle, and opposite the direction of the force on a negatively-charged particle. Since like charges repel and opposites attract (as quantified below), the electric field tends to point away from positive charges and towards negative charges.

Electric potential:

The concept of electric potential is closely linked to that of the electric field. A small charge placed within an electric field experiences a force, and to have brought that charge to that point against the force requires work.

Definition of Electric potential:



The electric potential at any point is defined as the energy required in bringing a unit test charge from an infinite distance slowly to that point. It is usually measured in

.

In a uniform field V $= E\,d$. Where V is electric potential, E is electric field; d is the distance from a charged surface in a uniform field. Electric potential is a scalar quantity, that is, it has only magnitude but no direction. Concept of magnetism and Magnetic field

A bar magnet consist of two poles North and South poles. The poles of a magnet are the portion of the magnet where its magnetic attraction appears to be strongest. Like or similar poles of magnets repel each other but unlike or dissimilar poles attract each other.

Properties of a Magnet

Magnets attract objects of iron, cobalt and nickel.
2. The force of attraction of a magnet is greater at its poles than in the middle.
3. Like poles of two magnets repel each other.
4. Opposite poles of two magnets attracts each other.
5. If a bar magnet is suspended by a thread and if it is free to rotate, its South Pole will move toward the North Pole of the earth and vice versa.

Magnetic field

The region or space around a magnet in which the influence of the magnet can be felt of detected is called magnetic field.

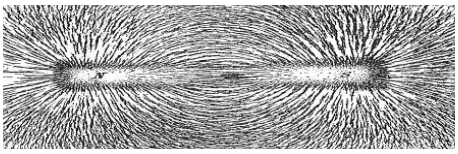
Magnetic line of force

The magnetic line of force of a magnetic field is the line along which a free N-pole would tend to move in the field or a line such that the tangent to it at any point gives the direction of the field at that point.

Characteristics of Magnetic line of force

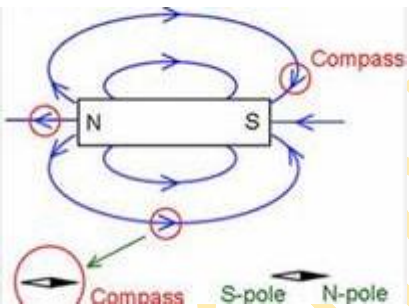
1. Magnetic lines of force start from the North Pole and end at the South Pole.
2. They are continuous through the body of magnet
3. Magnetic lines of force can pass through iron more easily than air.
4. Two magnetic lines of force cannot intersect each other; otherwise the magnetic field would have two possible directions at the point of intersection.
5. They tend to contract longitudinally.
6. They tend to expand laterally.

Field pattern with iron fillings



If a tiny sheet of glass is placed over a bar magnet, and some iron sprinkle on the glass and taped gently, it is observed that the filings are spread evenly over the magnetic field but all aligned in the direction of the field. Then, based on the scale and ferromagnetic properties of the filings they damp the field to either side, creating the apparent spaces between the lines that we see.

Field pattern with a Compass needle



The *magnetic field* of a bar magnet can be investigated with a compass needle. The magnetic poles of both bar magnet and compass needle are symbolized by the following colors:

north pole **red**

south pole **green**

If you move the magnetic needle with pressed mouse button, the magnetic field line through the centre of the compass needle will be drawn with blue colour.

The blue arrows mark the direction of the magnetic field which is defined as the direction indicated by the north pole of the compass needle. If you turn the magnet by using the red button, the direction of the field lines will reverse. The left button makes it possible to clear all field lines.

Exercises

1. Explain what is meant by a field as used in physics
2. Mention THREE types of field you know
3. Distinguish between scalar fields and vector fields. Give TWO examples of each.
4. Draw the lines of force associated with the following situations:
   (i) Two unlike point charges of equal magnitude
   (ii) A positive charge in isolation
   (iii) Two parallel plate carrying unlike charges of equal magnitude
5. What do you understand by the poles of a magnet?
6. Explain the following term: magnetic field, magnetic lines of force

WEEK FIVE LESSON NOTE

GRAVITATIOANAL FIELD AND LAW

Concept of Gravitational field

Recall that surrounding any object with mass, or collection of objects with mass, is a gravitational field. Any mass placed in a gravitational field will experience a gravitational force.

Definition of gravitational field strength:

We defined the field strength as the gravitational force per unit mass on any "test mass" placed in the field given as

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

Where g is a vector that points in the direction of the net gravitational force; its units are N / kg.

F is the vector force on the test mass,

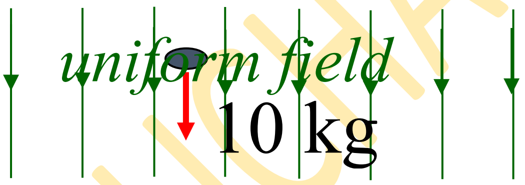
m is the test mass, a scalar. g and F are always parallel.

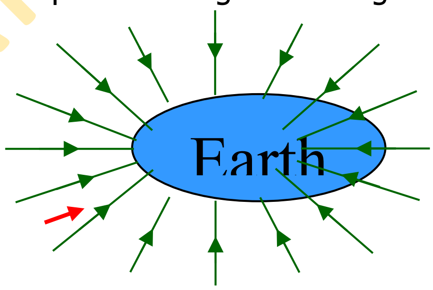
The strength of the field is independent of the test mass. For example, near Earth's surface $mg / m = g = 9.8$ N / kg for any mass.

Types of fields:

There are two types of fields: Uniform and Nonuniform/variable fields

- Some fields are uniform (parallel, equally spaced fields lines) such as the field on the left formed by a sheet of negative charge.
- Non-uniform/variable fields are stronger where the field lines are closer together, such as the field on the right produced by a sphere of negative charge.



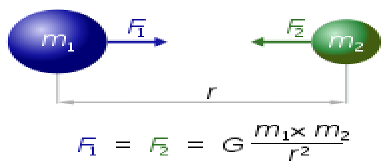


Gravitational Force between two masses

Gravitation is the force of attraction exerted by a body on all other bodies in the universe. Hence a gravitational force exists between a body and all other bodies around it. Gravitational forces act between all masses and hold together planets, stars and galaxies. Each mass has a gravitational field around it. The relationship between the gravitational force F, between two masses m_1 , m_2 and distance r, between two masses is known as Newton's Law of universal gravitation.

Newton's law of universal gravitation

Newton's law of universal gravitation states that every point mass in the universe attracts every other point mass with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.



(Separately it was shown that large spherically symmetrical masses attract and are attracted as if all their mass were concentrated at their centres.)

Every point mass attracts every single other point mass by a force pointing along the line intersecting both points. The force is proportional to the product of the two masses and inversely proportional to the square of the distance between them:

Newton's Law of universal gravitation can be stated in equation form $F \alpha \frac{m_1 m_2}{r^2}$ the magnitude of this force can be written as;

$$F = \frac{G m_1 m_2}{r^2}$$

Where:

- F is the force between the masses,
- G is the gravitational constant,
- m_1 is the first mass,
- m_2 is the second mass, and

Assuming SI units, F is measured in Newton (N), m_1 and m_2 in kilograms (kg), r in meters (m), and the constant G is approximately equal to 6.674×10^{-11} N m^2 kg^{-2}.

Example 1

Calculate the force of attraction between two small objects of mass 10kg and 50kg respectively separated at distance of 10 cm. Take G as 6.67×10^{-11} Nm^2 Kg^{-2}.

$$Formula: F = \frac{G m_1 m_2}{r^2} ---------(1)$$

$$m_1 = 10kg,\ m_2 = 50kg,\ r = 10cm = 0.1m,\ G = 6.67 \times 10^{-11} Nm^2 kg^{-2}$$

Substituting in (1)

$$F = \frac{6.67 \times 10 \times 50 \times 10^{-11} Nm^2 kg^{-2}}{(0.1)^2 m^2} = 6.67 \times 5 \times 10^{-11+4} N = 33.35 \times 10^{-7} N \quad = 3.33 \times 10^{-6} N$$

Acceleration due to gravity:

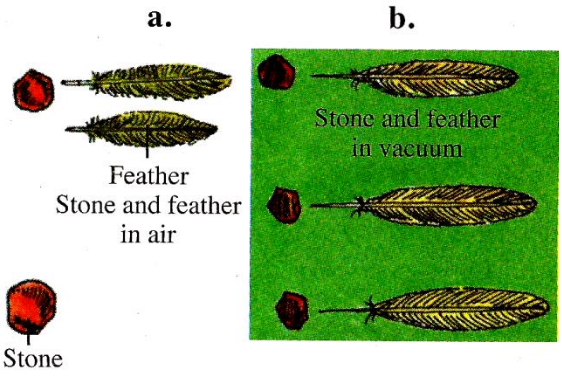
The earth attracts every object existing in the earth's gravitational field. The attraction is called gravitational attraction and its effect is to change the velocity of objects under its influence, that is, to accelerate such object. The force of gravity acts upon our bodies as we jump upwards from the Earth. As we rise upwards after our jump, the force of gravity slows us down. And as we fall back to Earth after reaching the peak of our motion, the force of gravity speeds us up. In this sense, the force gravity causes an acceleration of our bodies during this brief trip away from the earth's surface and back.

The gravitational acceleration at a point in space is given by:

$$\hat{g} = -\frac{GM}{r^2}\hat{r}$$

Where: M is the mass of the attracting object. It is the unit vector from centre of mass of the attracting object to the centre of mass of the object being accelerated, r is the distance between

the two objects, and *G* is the gravitational constant. Neglecting friction such as air resistance, all small bodies accelerate in a gravitational field at the same rate relative to the centre of mass.
It is because the acceleration due to gravity is the same for all bodies in the same locality that all objects whatever their masses, when released from rest at the same point above the ground fall to the ground simultaneously (at the same time). The force of gravitational attraction is given by F = mg, where g is the acceleration due to gravity and m is the mass of the object. When m = 1, F = g. This is known as the Acceleration of free fall.



Bodies falling freely under gravity

Facts about the acceleration of a falling object due to gravity:

i. Its magnitude decreases with altitude (height)
ii. It varies with latitude
iii. Its value is about 10 ms^{-2} at the equator
iv. Its value on earth is about 6 time that on the moon/greater than the moon
v. It is a vector quantity

In fact, many students of physics have become accustomed to referring to the actual acceleration of such an object as the **acceleration of gravity**. Not to be confused with the force of gravity ($\mathbf{F_{grav}}$), the acceleration of gravity (**g**) is the acceleration experienced by an object when the only force acting upon it is the force of gravity. The acceleration of objects due to the earth's gravitational attraction is called the acceleration due to gravity. It is represented by the symbol g whose average value is about $9.81ms^{-2}$

Relationship between the Gravitational Constant 'G' and the acceleration due to gravity at the earth surface 'g'

The gravitational constant is a universal number that applies equally in all places, at all times, and upon all objects. It is expressed as: 6.674×10^{-11} N m^2 kg^{-2}. Acceleration due to gravity is the phenomenon in which all masses are attracted to all other masses.

The earth is supposed to be a sphere of radius, r_e , with its mass, m_e concentrated at the earth's centre. The distance of any object on the earth's surface to the centre of the earth is r_e the earth radius. The gravitation force of attraction of the earth on any mass, m, on the earth surface is given by $F = \frac{Gm_e m}{r_e^2}$

This force is equivalent to the weight of the object, mg, where 'g' is the acceleration due to gravity

$$F = \frac{Gm_e m}{r_e^2} = mg -----------(1)$$

$$\text{The force per unit mass, } \frac{F}{m} \text{ is given by}$$

$$\frac{F}{m} = \frac{Gm_e}{r_e^2} = g ----------(2)$$

$$g = \frac{Gm_e}{r_e^2} -------------(3)$$

This means that the acceleration due to gravity 'g' can be considered as the force per unit mass on the earth's surface. From (3) we see that 'g' at the surface of the earth is dependent on $\mathbf{m_e}$ (mass of the earth) and $\mathbf{r_e}$ (radius of the earth). With this we expect 'g' to be slightly less on the top of the mountain than at the sea level since $\mathbf{r_e}$ the distance from the centre of the earth is slightly greater at the top of the mountain than at the sea level. The mass of the earth $\mathbf{m_e}$ is given by

$$m_e = \frac{g r_e^2}{G}$$

Example 2

If g = 9.8ms^{-2} , G = 6.7 x 10^{-11} Nm^{2}kg^{-2} . Calculate the mass of the earth if the radius of the earth is taken as approximately 6400km.

$$\text{Formula } m_e = \frac{g r_e^2}{G} ------------(1)$$

$$g = 9.8ms^{-2}, G = 6.7\times10^{-11} Nm^2kg^{-2}, r_e = 6400km = 6.4\times10^6 m$$

Substituting in (1)

$$m_e = \frac{9.8ms^{-2} \times 4.096\times10^{13} m^2}{6.7\times10^{-11} Nm^2kg^{-2}} = \frac{9.8\times4.096\times10^{13+11}}{6.7kg^{-1}} = 5.99\times10^{24} kg$$

$$m_e = 6.0\times10^{24} kg$$

Shape and dimension of the earth:

On and near Earth's surface, the value for the acceleration of gravity is approximately 9.81 m/s/s. The acceleration due to gravity g is uniform at a given place and is the same for all bodies irrespective of their masses (and assuming that the only significant force is gravity). However g varies from place to place. It is minimum (9.83ms^{-2}) at the poles of the earth. Hence it is less in Lagos than in London

The value of g is dependent upon location. There are slight variations in the value of g about earth's surface. These variations result from:

1. The varying density of the geologic structures below each specific surface location.

2. They also result from the fact that the earth is not truly spherical; the earth's surface is further from its centre at the equator than it is at the poles. This would result in larger g values at the poles. As one proceeds further from earth's surface - say into a location of orbit about the earth - the value of g changes still.

The **gravitational potential** at a location is equal to the work (energy transferred) per unit mass that is done by the force of gravity as an object moves to that location from a reference location. It is analogous to the electric potential with mass playing the role of charge. By convention, the gravitational potential is defined as zero infinitely far away from any mass. As a result it is negative elsewhere. It depends on height, h, or the relative position of the body from the ground or zero level where the P.E is considered to be zero.

Gravitational potential:

Thus potential is independent on mass. If $M > m$ and they are at the same height then M will have more potential energy than m, but both are at the same potential

Definition of Gravitational Potential:

Gravitational potential (V) is defined as the gravitational potential energy (U) per unit mass. At any given height above Earth's surface, the gravitational potential is a constant since.

$$V = \frac{U}{m} \qquad But\, U = F_g \times d,\ \frac{Gm_1m_2}{r^2} \times r\ if\ m_1 = m_2\ then\, F_g = \frac{Gm^2}{r^2} \times r \qquad \therefore V = \frac{Gm^2}{r^2 \times m} r = -\frac{Gm}{r}$$

where m is the mass of the object producing gravitational field and r is the distance of the point from mass. The potential energy is the negative of the work done by the gravitational field moving the body to its given position in space from infinity. If the body has a mass of 1 unit, then the potential energy to be assigned to that body is equal to the gravitational potential. So the potential can be interpreted as the negative of the work done by the gravitational field moving a unit mass in from infinity.

The potential V at a distance x from a point mass of mass M is

$$V = \frac{GM}{x}$$

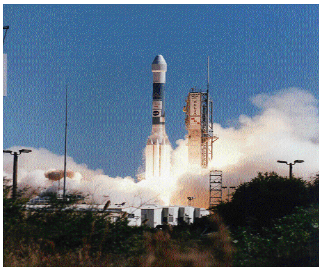
where G is the gravitational constant. The potential has units of energy per unit mass, e.g., J/kg in the MKS system. By convention, it is always negative where it is defined, and as x tends to infinity, it approaches zero.

Properties of force of gravity

i. Gravity can bend space-time
ii. Gravity occurs with an object with mass
iii. Gravity can attract objects through barriers
iv. Gravity attracts each unit mass of an object with the same force

Escape velocity

Escape velocity is the speed that an object needs to be travelling to break free of a planet or moon's gravity well and leave it without further propulsion. For example, a spacecraft leaving the surface of Earth needs to be going 7 miles per second, or nearly 25,000 miles per hour to leave without falling back to the surface or falling into orbit. If the kinetic energy of an object launched from the Earth were equal in magnitude to the potential energy, then in the absence of friction resistance it could escape from the Earth.



Definition of Escape Velocity

Escape velocity is defined as the speed at which the kinetic energy plus the gravitationa potential energy of an object is zero. It is the speed needed to "break free" from a gravitational field without further propulsion.

Suppose a rocket of mass m is fired from the Earth's surface so that it just escapes from gravity. Then work done = kinetic energy of the rocket.

$$But\ work\ done = m \times \frac{GM}{r}$$

$$and\ kinetic energy of\ rocket\ E_k = \frac{1}{2}mv^2$$

$$\therefore \frac{1}{2}mv^2 = m \times \frac{GM}{r}$$

$$\therefore v_e = \sqrt{\frac{2GM}{r}}$$

where *G* is the universal gravitational constant (G = 6.67×10^{-11} m^3 kg^{-1} s^{-2}), M the mass of the planet, star or other body, and r the distance from the centre of gravity.

In this equation atmospheric friction or air drag, is not taken into account. A rocket moving out of a gravity well does not actually need to attain escape velocity to do so, but could achieve the same result at walking speed with a suitable mode of propulsion and sufficient fuel. Escape velocity only applies to ballistic trajectories.

For a spherically-symmetric body, escape velocity is calculated by the formula

$$v_e = \sqrt{\frac{2Gm_e}{r_e}} \quad \text{but} \quad m_e = \frac{g\,r_e^2}{G}$$

$$v_e = \sqrt{\frac{2Ggr_e^2}{r_eG}} = \sqrt{2gr_e}\ or\ \sqrt{2gR}$$

How to Calculate Escape Velocity

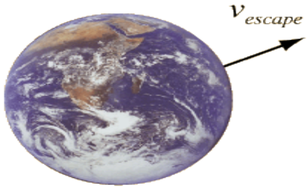
1. Determine the mass and radius of the planet you are on. For Earth, assuming that you are at sea level, the radius is 6.38x10^6 meters and the mass is 5.97x10^{24} kilograms. You will need the gravitational constant (G), which is 6.67x10^{-11} N m^2 kg^{-2}. It is required to use S.I units for this equation.

2. Using the above data, calculate the required velocity needed to exceed the planet's gravitational potential.

The object must have greater energy than the planet's gravitational energy to escape, so $\frac{1}{2}mv^2 = \frac{GMm}{r}$ can be used for the escape velocity as follows: $V(escape) = \sqrt{\frac{2GM}{r}}$ where "M" is the mass of the earth, "G" is the gravitational constant(6.67x10^{-11}) and "r" is the radius from the centre of the planet(6.378x10^6 m).

3. **The escape velocity of Earth comes to about** 11.2 kilometres per second from the surface.

Escape velocity from the Earth



$$v_{escape} = 11.2 \ km/s$$

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

$$v_{escape} = \sqrt{\frac{2GM}{r}}$$

Therefore with an initial velocity greater than 11.2km/s, an object or a rocket will completely escape from the gravitational attraction of the earth

$$Formula \quad V_e = \sqrt{\frac{2GM}{r}}$$

$$if \ r = R \therefore V_e = \sqrt{\frac{2GM}{R}}$$

$$but \ M = \frac{gR^2}{G}, V_e = \sqrt{\frac{2G}{R} \times \frac{gR^2}{G}} = \sqrt{2gR}$$

$$V_e = \sqrt{2gR}$$

$$\therefore R = \frac{V_e^2}{2g} ------------(1)$$

$$g = 9.8m/s^2, V_e = 11km/s = 1.1 \times 10^4 m/s$$

Substituting in (1)

$$R = \frac{1.2544 \times 10^8 m^2/s^2}{2 \times 9.8 \ m/s^2} = 0.064 \times 10^8 m = 6.2 \times 10^6 m \quad = 6400km$$

Assignment

1. What is the gravitational potential due to a molecule of mass at a distance r from it? (G = gravitational constant).
2. Calculate the escape velocity for a rocket fired from the earth's surface at a point where the acceleration due to gravity is 10m/s^2 and the radius of the earth is 6.0 x 10^6m.
3. Define force field.
4. List TWO types of fields
5. State Newton's Law of Universal gravitation
6. State the conditions necessary for a satellite to be in motion in a circular orbit
7. Calculate the gravitational potential at a point on the earth's surface. (Radius of the earth = $6.4 \times 10^6 m$ mass of the earth = $6.4 \times 10^{24} kg$, G = $6.7 \times 10^{-11} Nm^2 kg^{-2}$)
8. Explain why '**g**' is slightly less on the top of the mountain than at the sea level
9. List THREE facts about the acceleration of a free falling object due to gravity.
10. Derive an expression for the relationship between **G** and **g**

11. A ball is dropped from a height, at the same time as another ball is projected horizontally from the same height
    i. Would the balls hit the ground at the same time?
    ii. Explain your answer in (i)

WEEK SIX LESSON NOTE

ELECTRIC CHARGES, ELECTROSTATICS AND GOLD LEAF ELECROSCOPE

Electric Charge is the fundamental conserved property of a matter such as some subatomic particles, which determines their electromagnetic interaction and causes it to experience a force when near to other electrically charged matters. Electrically charged matter is influenced by, and produces, electromagnetic fields. The interaction between an electromagnetic field and a moving charge is the source of the electromagnetic force, which is the one of the four fundamental forces in nature.

Types of electric charges:

Fig 1a A positive electric charge

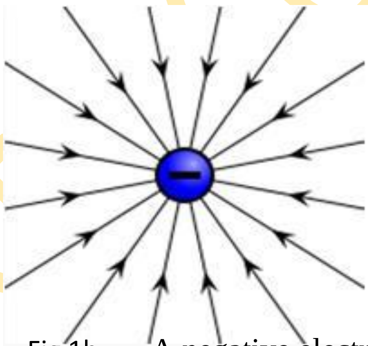


Fig 1b A negative electric charge

There are two types of electric charges namely: Positive and Negative charges. By convention, the charge of an electron is −1, while that of a proton is +1. Charged particles whose charges have the same sign repel one another (Force of repulsion), and particles whose charges have different signs attract (Force of attraction). This is referred to as the first law of electrostatics

Units of Charge:

The SI unit of quantity of electric charge is coulomb denoted by (C), which is equivalent to about 6.242×10^{18} e (e is the charge of a proton), although in electrical engineering it is also common to use the ampere-hour (Ah). Hence, the charge of an electron is approximately -1.602×10^{-19}C. The symbol Q is often used to denote a quantity of electricity or charge. The quantity of electric charge can be directly measured with an **ELECTROMETER**, or indirectly measured with **BALLISTIC**

Definition of Coulomb

The coulomb is defined as the quantity of charge that has passed through the cross section of an electrical conductor carrying one ampere within one second.

Electrostatics or static Electricity:

Since classical antiquity, it was known that some materials such as amber attract lightweight particles after rubbing. The Greek word for amber, ἤλεκτρον *electron*, was the source of the word 'electricity'. Electrostatics involves the building up of charge on the surface of objects due to contact with other surfaces. Electrostatic phenomena arise from the forces that electric charges exert on each other. Such forces are described by Coulomb's law. Even though electrostatically induced forces seem to be rather weak, the electrostatic force between e.g. an electron and a proton, that together make up a hydrogen atom, is about 40 orders of magnitude stronger than the gravitational force acting between them.

Definition of Electrostatics

Electrostatics is defined as the branch of physics that deals with the phenomena and properties of stationary or slow-moving (without acceleration) electric charges. It is a phenomenon in which the net electric charge of an object is non-zero and motionless.

Electrostatic phenomena include:

- the attraction of the plastic wrap to your hand after you remove it from a package,
- the apparently spontaneous explosion of grain silos,
- the damage of electronic components during manufacturing,
- the operation of photocopiers.

Production of electrostatic charges:

Charging means gaining or losing electron. There are three methods in which an uncharged body can be charged, namely:

- charging by friction,
- charging by contact (conduction)
- Charging by Electrostatic induction.

Charging by Friction:

When you rub one material to another, they are charged by friction. Material losing electron is positively charged and material gaining electron is negatively charged. Amount of gained and lost electron is equal to each other. In other words, we can say that charges of the system are conserved. Charging by friction can easily be produced by rubbing two dissimilar materials together, such as rubbing amber (ebonite or hard rubber) with fur or glass with silk as shown in fig. 2.

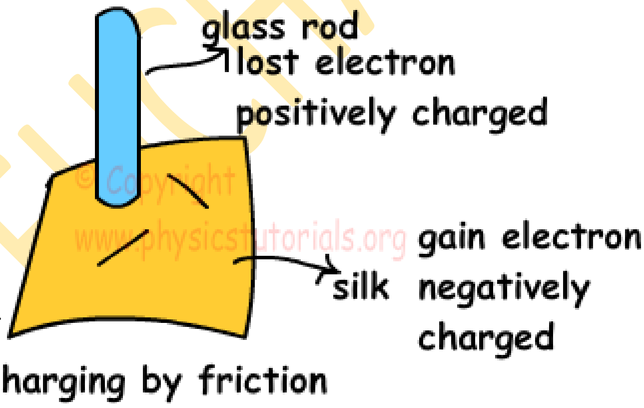


Fig 2

1. When you rub glass rod with a silk (rub silk on glass rod), friction brings about a net transfer of surface electrons from glass to the silk. Glass becomes positively charged while silk gain electron and becomes negatively charged.

2. Rubbing amber (ebonite or hard rubber) with fur a negative charge is gained by an ebonite rod due to a net transfer of electrons from the atoms of fur. The ebonite is negatively charged and fur positively charged.

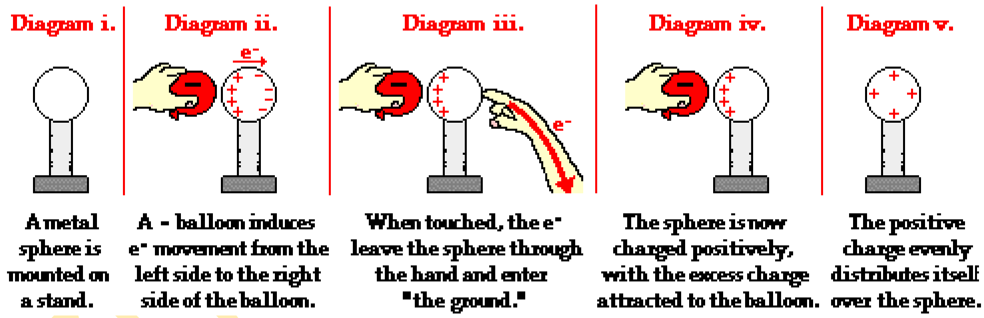
In this way non-conductive materials can be charged to a significant degree, either positively or negatively. Of course, charge taken from one material is simply moved to the other material, leaving an opposite charge of the same magnitude behind. The law of conservation of charge always applies, giving the object from which a negative charge has been taken a positive charge of the same magnitude, and vice-versa.

The Law of Conservation of Charge:
The law of conservation of charge states that Charge is neither created nor destroyed during this charging process; it is simply transferred from one object to the other object in the form of electrons.

Charging by Electrostatic Induction
This method is used to charge an object without actually touching the object to any other charged object. An understanding of charging by induction requires an understanding of the nature of a conductor and an understanding of the polarization process. In the context of electricity, **polarization** is the **process** of separating opposite charges within an object. The positive charge becomes separated from the negative charge within an object.

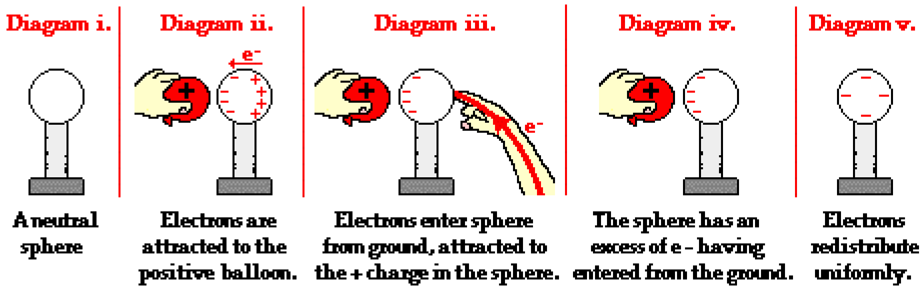
Definition of Electrostatic induction
Electrostatic Induction is the process by which an uncharged body acquires charge when it is brought near a charged body. Electrostatic induction is a redistribution of electrical charge in an object, caused by the influence of nearby charges. Electrostatic induction should not be confused with electromagnetic induction; both are often referred to as 'induction'.

Charging a Single Sphere by Induction using a negatively charged object:



Suppose a negatively charged rubber balloon is brought near a single sphere as shown in (Diagram ii). The presence of the negative charge will induce electron movement in the sphere. Since like charges repel, negative electrons within the metal sphere will be repelled by the negatively charged balloon. There will be a mass migration of electrons from the left side of the sphere to the right side of the sphere causing charge within the sphere to become polarized (Diagram ii). Once charge within the sphere has become polarized, the sphere is touched. The touching of the sphere allows electrons to exit the sphere and move through the hand to "the ground" (Diagram iii). It is at this point that the sphere acquires a charge. With electrons having left the sphere, the sphere acquires a positive charge (Diagram iv). Once the balloon is moved away from the sphere, the excess positive charge redistributes itself (by the movement of remaining electrons) such that the positive charge is uniformly distributed about the sphere's surface.

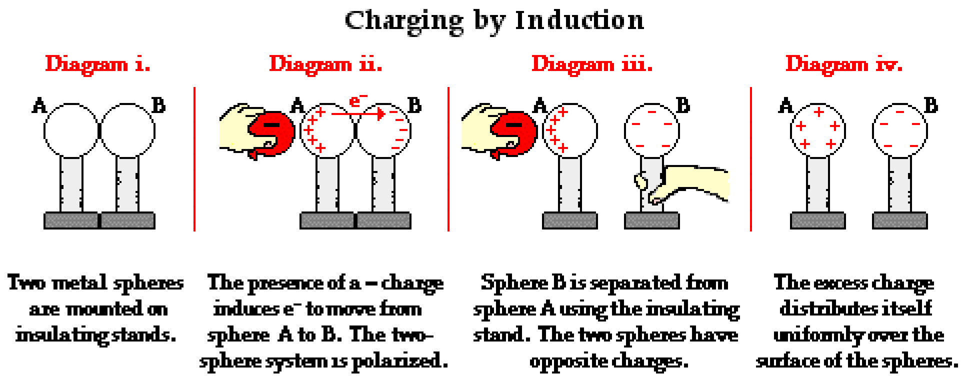
Charging a Single Sphere by Induction using a positively charged object:



If a positively charged object is used to charge a neutral object by induction, then the neutral object will acquire a negative charge. If you understand the induction charging process, you can see why this would always be the case. The charged object that is brought near will always repel like charges and attract opposite charges. Either way, the object being charged acquires a charge that is opposite the charge of the object used to induce the charge. To further illustrate this, the diagram above shows how a positively charged balloon will charge a sphere negatively by induction

Charging a Two-Sphere System by induction using a Negatively Charged Object

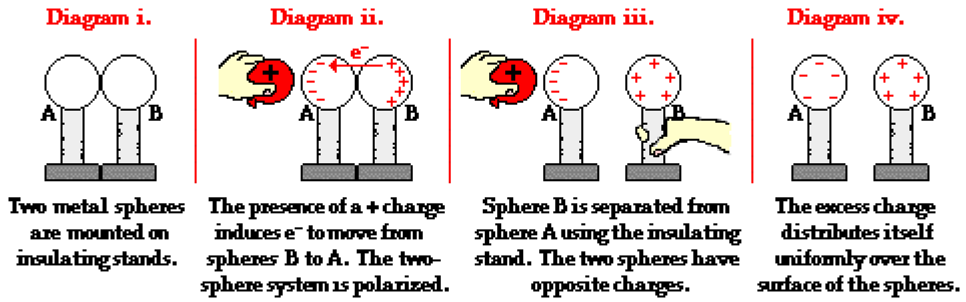
One common demonstration in a physics class involves the induction charging of two metal spheres. The metal spheres are supported by insulating stands so that any charge acquired by the spheres cannot travel to the *ground*. The spheres are placed side by side (see diagram i) so as to form a two-sphere system.



Being made of metal (a conductor), electrons are free to move between the spheres from sphere A to sphere B and vice versa. If a negatively charged rubber balloon is brought near the spheres, electrons within the two-sphere system will be induced to move away from the balloon. This is simply the principle that like charges repel. Being charged negatively, the electrons are repelled by the negatively charged balloon. Subsequently, there is a *mass migration* of electrons from sphere A to sphere B. This electron migration causes the two-sphere system to be polarized (see diagram ii. below). Overall, the two-sphere system is electrically neutral. Yet the movement of electrons out of sphere A and into sphere B separates the negative charge from the positive charge. Looking at the spheres individually, it would be accurate to say that sphere A has an overall positive charge and sphere B has an overall negative charge. Once the two-sphere system is polarized, sphere B is physically separated from sphere A using the insulating stand. Having been pulled further from the balloon, the negative charge likely redistributes itself uniformly about sphere B (see diagram iii. below). Meanwhile, the excess positive charge on sphere A remains located near the negatively charged balloon, consistent with the principle that opposite charges attract. As the balloon is pulled away, there is a uniform distribution of charge about the surface of both spheres (see diagram iv. below). This distribution occurs as the remaining electrons in sphere A move across the surface of the sphere until the excess positive charge is uniformly distributed.

Charging a Two-Sphere System by induction using a Positively Charged Object

The above examples show how a negatively charged balloon is used to polarize a two-sphere system and ultimately charge the spheres by induction. But what would happen to sphere A and sphere B if a positively charged object was used to first polarize the two-sphere system?



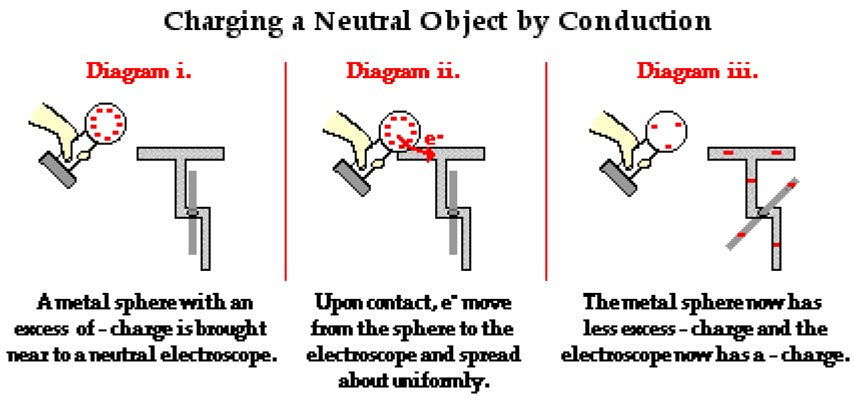
How would the outcome be different and how would the electron movement be altered? The same result will be obtained

Charging by conduction (Contact)

The process of charging by friction and charging by induction have been described and explained above. In this paragraph a third method of charging which is **charging by conduction** involves the contact of a charged object to a neutral object. Suppose that a positively charged aluminium plate is touched to a neutral metal sphere. The neutral metal sphere becomes charged as the result of being contacted by the charged aluminum plate. Or suppose that a negatively charged metal sphere is touched to the top plate of a neutral needle electroscope. The neutral electroscope becomes charged as the result of being contacted by the metal sphere. In contrast to induction, where the charged object is brought near but never contacted to the object being charged, conduction charging involves making the physical connection of the charged object to the neutral object. Because charging by conduction involves contact, it is often called **charging by contact.**

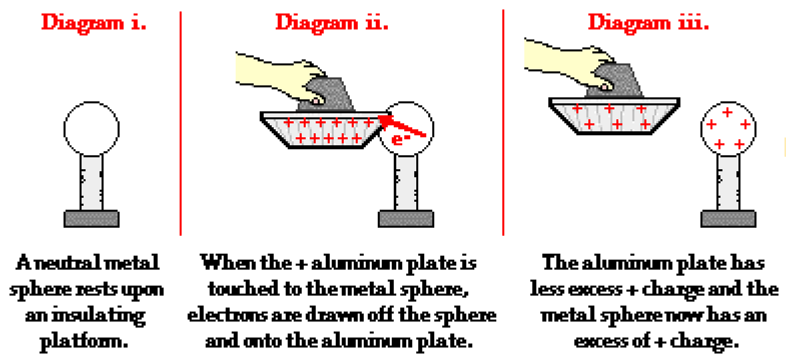
Charging by Conduction Using a Negatively Charged Object

Let's consider the case of using a negatively charged metal sphere to charge a neutral needle electroscope. To understand this process demands that you understand that like charges repel and have an intense desire to reduce their repulsions by spreading about as far as possible.



A negatively charged metal sphere has an excess of electrons; those electrons find each other repulsive and distance themselves from each other as far as possible. Once the contact of the sphere to the electroscope is made, a countless number of excess electrons from the sphere move onto the electroscope and spread about the sphere-electroscope system. When the process of charging by conduction is complete, the electroscope acquires an excess negative charge due to the movement of electrons onto it from the metal sphere. The metal sphere is still charged negatively, only it has less excess negative charge than it had prior to the conduction charging process.

Charging a neutral object by Conduction Using a Positively Charged Object



What happens if a positively charged object is touched to a neutral object? To investigate this question, we consider the case of a positively charged aluminum plate being used to charge a neutral metal sphere by the process of conduction. A positively charged aluminum plate has an excess of protons. When looked at from an electron perspective, a positively charged aluminum plate has a shortage of electrons. It is not satisfied until it has found a negatively charged electron with which to co-habitat. However, since a proton is tightly bound in the nucleus of an atom, it is incapable of leaving an atom in search of that longed-for electron. It can however attract a mobile electron towards itself. And if a conducting pathway is made between a collection of electrons and an excess proton, one can be certain that there is likely an electron that would be willing to take the pathway. So when the positively charged aluminum plate is touched to the neutral metal sphere, countless electrons on the metal sphere migrate towards the aluminum plate. There is a mass migration of electrons until the positive charge on the aluminum plate-metal sphere system becomes redistributed. Having lost electrons to the positively charged aluminum plate, there is a shortage of electrons on the sphere and an overall positive charge. The aluminum plate is still charged positively; only it now has less excess positive charge than it had before the charging process began.

Properties of Charging by Conduction or contact:

1. When charged object touches to a neutral object, they both have same charge.
2. When two charged matter touch each other, total charge of the system is conserved and they share the total charge according to their capacities. If they have same amount of different charges, when we touch one another they become neutral. If the amount of charges is different then, after flow of charge they are both negatively or positively charged. Having opposite charges after contact is impossible.
3. If the touching objects are spheres, they share the total charge according to their radii, because their capacities are directly proportional to their radius. When the spheres are identical then they share total charge equally.

Grounding - the Removal of a Charge

We have discussed the three common methods of charging - charging by friction, charging by induction, and charging by conduction. A discussion of charging would not be complete without a discussion of *uncharging*. Objects with an excess of charge - either positive or negative - can have this charge *removed* by a process known as grounding. A **ground** is simply a large object that serves as an almost infinite source of electrons or sinks for electrons. A ground contains such vast space from which the ideal object either receive electrons or supply electrons to whatever objects needs to get rid of them or receive them. A **ground** is simply an object that serves as a seemingly infinite reservoir of electrons; the ground is capable of transferring electrons to or receiving electrons from a charged object in order to neutralize that object.

Definition of Grounding

Grounding is the process of *removing* the excess charge on an object by means of the transfer of electrons between it and another object of substantial size. When a charged object is grounded, the excess charge is balanced by the transfer of electrons between the charged object and a ground.

Distribution of charges:

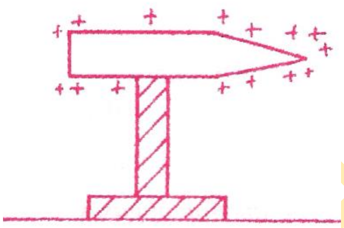


Fig 3

1. The distribution of charges on a conductor is generally concentrated at places where the surface is sharply curved. Thus the surface charged density or charge per unit area is very high at sharp points with very small areas. This is the case with the pear-shaped conductor as shown in fig. 3.

2. It is also found that charge reside only on the surface of the conductor not inside, this occurs due to repulsion of similar charges. For uniformly curved surface such as a sphere, the charge is distributed uniformly on the surface

Fig 4

Storage of charges - Electrophorus

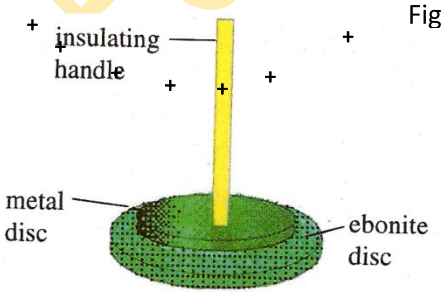


Fig 5.1

The electrophorus is a device for transferring and storing charges. It produces electrostatic charge via the process of electrostatic induction. The electrophorus consists of a dielectric plate and a metal disc with an insulating handle. The dielectric plate is first charged by rubbing it with fur or cloth. The metal disc is then placed onto the dielectric plate (ebonite). The dielectric does not transfer a significant fraction of its surface charge to the metal because the microscopic contact is poor. Instead the electrostatic field of the charged dielectric causes the charges in the metal disc to separate. It develops two regions of charge. The positive charges in the plate are attracted to the side facing down toward the dielectric, charging it positively, while the negative charges are repelled to the side facing up, charging it negatively, with the plate remaining electrically neutral as a whole.

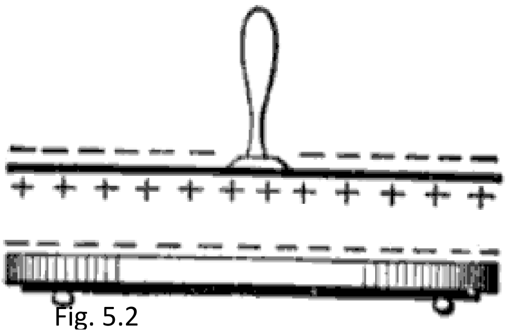


Fig. 5.2

Then, the side facing up is momentarily grounded (which can be done by touching it with a finger), draining off the negative charge. Finally, the metal disc, now carrying only one sign of charge (positive in our example), is lifted. These charges are then stored in the disc when the handle is lifted from the ebonite. The amount of the charge stored can be built up by repeating the above process.

Example 1: When a positively charged conductor is placed near a candle flame, it spread out as shown in the diagram above, explain this observation.

The candle ionizes the air around the conductor that is striping electrons from the air. The positively charged conductor attracts the negative charges but repel positive charges which make the flame to spread.

GOLD LEAF ELECTROSCOPE

What is an Electroscope?

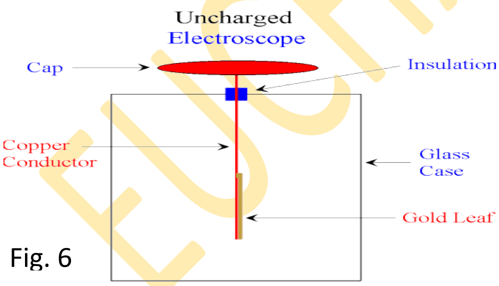


Fig. 6

An electroscope is an instrument for detecting the presence of static electricity. It consists of two thin metal leaves suspended from a metal hook. When the hook is brought near a source of static electricity, some of the electrons in the hook are pushed to the leaves (if the source is negative) or pulled up to the hook from the leaves (if the source is positive), either way, the leaves are now charged the same way as each other and so they repel each other. The amount they open up (divergence of the leaf) is proportional to the charge of the source (if the sources are always held at the same distance from the hook).

Type of Electroscope:
There are various types of electroscope which include:

- A pivoted needle called the **versorium** the first electroscope invented by British physician William Gilbert around 1600.
- Straw blade electroscope

- The pith-ball electroscope
- Gold-leaf electroscope.

Uses of an Electroscope:

- An electroscope is used to detect the presence and magnitude of electric charge on a body.
- It is used to illustrate electrostatic principles of charging and charge interactions. The electroscope is most commonly used for detection and testing of small electric charge.
- It is used for testing the conducting and insulating properties of materials.

Gold leaf electroscope:

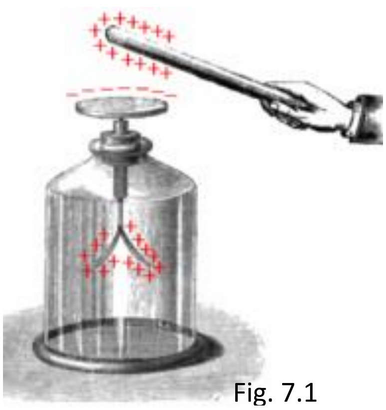


Fig. 7.1

The gold-leaf electroscope was developed in 1787 by British clergyman and physicist Abraham Bennet, as a more sensitive instrument than pith ball or straw blade electroscopes then in use. It is a very thin piece of gold foil (called gold leaf) fixed at the top to a piece of copper/ brass. It consists of a vertical metal rod, usually copper/ brass, from the end of which hang two parallel strips of thin flexible gold leaf. A large round disk or ball terminal is attached to the top of the rod, where the charge to be tested is applied. To protect the gold leaves from drafts of air they are enclosed in a glass bottle, usually open at the bottom and mounted over a conductive base, That is, the piece of copper/ brass goes through insulation in the top of the glass case, so that any charge on the gold leaf cannot escape.

Charging of an Electroscope:

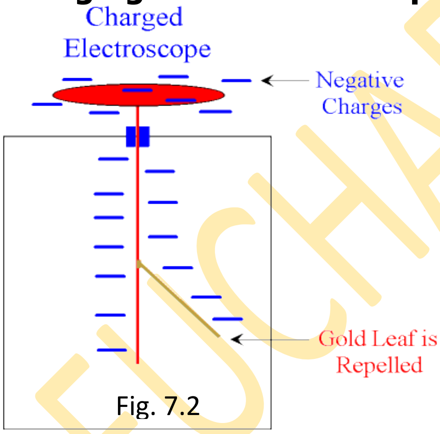


Fig. 7.2

Charges can be transferred to the electroscope by wiping the charged object across the cap. The charge flows over the conducting copper/brass and gold, and the gold leaf rises as it is repelled by having the same charge as the copper/ brass.

When the metal terminal of an electroscope is touched with a charged object, the gold leaves spread apart in a 'V' form. This is because some of the charge on the object is conducted through the terminal and metal rod to the leaves. Since they receive the same sign charge they repel each other and thus diverge. If the terminal is grounded by touching it with a finger, the charge is transferred through the human body into the earth and the gold leaves close

When the materials are brought near the cap, if the material is a good insulator there will be no leakage of charge and the leaf divergence will not be altered. If the material is a good conductor, the leaf collapses instantly. Poor insulators like wood will produce a slow collapse of the leaf.

Lightning:

The atmosphere is known to contain ions, or charged particle, which have been produced by radiation from the sun, and by what is known as cosmic radiation, which enters the atmosphere from outer space. Lightning is a giant atmospheric electrostatic discharge (spark) or neutralization of electric charge that occurs when charges build up in a cloud. It is being accompanied by thunder, which typically occurs during thunderstorms, and sometimes during volcanic eruptions or dust storms. From this discharge of atmospheric electricity, a leader of a bolt of lightning can travel at speeds of 220,000 km/h (140,000 mph), and can reach temperatures approaching 30,000 °C (54,000 °F). This extreme heating causes the air to expand at an explosive rate. The expansion creates a shock wave that turns into a booming sound wave, better known as thunder. This explains why it has the name thunderstorm.

What is the cause and mechanism associated with lightning strikes?

The precursor of any lightning strike is the polarization of positive and negative charges within a storm cloud. The second mechanism that contributes to the polarization of a storm cloud involves a freezing process. These two mechanisms are believed to be the primary causes of the polarization of storm clouds. In the end, a storm cloud becomes polarized with positive charges carried to the upper portions of the clouds and negative portions gravitating towards the bottom of the clouds. The polarization of the clouds has an equally important effect on the surface of the Earth. The cloud's electric field stretches through the space surrounding it and induces movement of electrons upon Earth. Electrons on Earth's outer surface are repelled by the negatively charged cloud on the bottom surface. This creates an opposite charge on the Earth's surface. Buildings, trees and even people can experience a build-up of static charge as electrons are repelled by the cloud's bottom. The attraction increases steadily until a huge spark or discharge is produced as the charges come together. This spark is seen as a very bright flash which we call lightning. Lightning can also occur within the ash clouds from volcanic eruptions, or can be caused by violent forest fires which generate sufficient dust to create a static charge. Thunder and lightning occur at roughly the same time, although you see the flash of lightning before you hear the thunder. This is because light travels much faster than sound

The irrational fear of lightning (and thunder) is astraphobia. The study or science of lightning is called **fulminology**, and someone who studies lightning is referred to as a **fulminologist**.

Usefulness of Lightning:
Lightning causes ionisation in the air through which it travels; leading to the formation of nitric oxide and ultimately, nitric acid is of great benefit to plant life.

Lightning conductor:
Lightning, in discharging to the earth, tends to strike the highest part of a building, such as the chimney, and the charge passes to the earth through the path of least resistance. A considerable heat is produced by the passage of the current and this can sometimes set a building on fire, hence the need of a lightning conductor on a building.

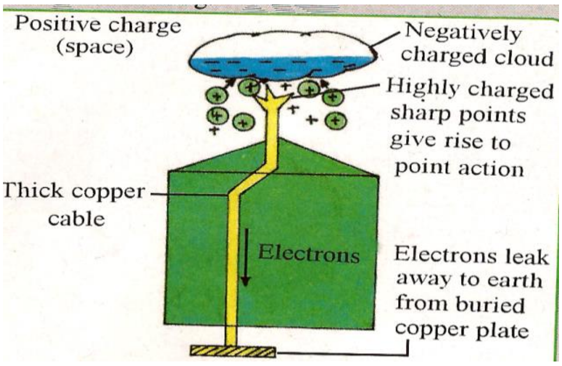
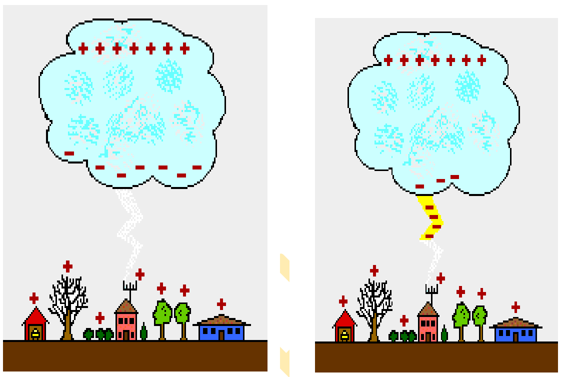


Fig. 8

A **lightning rod** (US) or **lightning conductor** (UK) is a metal rod or conductor mounted on top of a building and electrically connected to the ground through a wire, to protect the building from being damaged by lightning. It consist of a metallic rod, taller than the building, is being installed in the walls of the building during its construction. One end of the rod is kept out in the air and the other is buried deep in the ground. If lightning strikes the building it will preferentially strike the rod, and be conducted harmlessly to ground through the wire, instead of passing through the building, where it could start a fire or cause electrocution

Lightning rod working Principle:



How lightning rods serve to protect buildings from the devastating effects of a lightning strike

When a strongly charged cloud passes above the conductor, a large opposite charge is attracted to the points of the conductor. The two large charges exert very large forces on the electrons and positive nuclei of the air molecules between the cloud and the lightning conductor. The forces are so large that the electrons are torn off the molecules, leaving them positively charged. Ions or charged particles are thus formed.

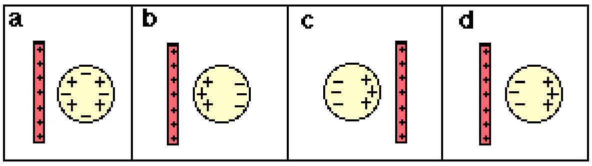
Fig. 9

If the cloud is negatively charged, positive ions are attracted to the cloud. The negative charge flows to the cloud, so that it loses its charge without any lightning taking place. The air above the conductor now contains many positive charges. This charge makes it less likely that lightning will strike the building. If the lightning does strike, the charge is attracted towards the spikes and is carried safe away to the earth through the conducting strip.

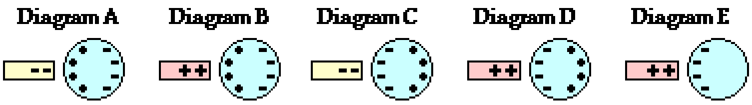
Exercises:

1. A rubber balloon possesses a positive charge. If brought near and touched to the door of a wooden cabinet, it sticks to the door. This does not occur with an uncharged balloon. These two observations can lead one to conclude that the wall is _____
A. electrically neutral B. negatively charged C. a conductor D. lacking electrons

2. Which of the diagrams below best represents the charge distribution on a metal sphere when a positively charged plastic tube is placed nearby?



3. Charged rubber rods are placed near a neutral conducting sphere, causing a redistribution of charge on the spheres. Which of the diagrams below depict the proper distribution of charge on the spheres? List all that apply.



4. In the above situation, the conducting sphere is ____. List all that apply.
A. charged B. uncharged C. polarized D. Non-polarized

5. A neutral metal sphere is touched by a negatively charged metal rod. As a result, the sphere will be ____ and the metal rod will be ____. Select the two answers in their respective order.

A. positively charged Negatively charged C. neutral D. much more massive

6. A neutral metal sphere is touched by a negatively charged metal rod. During the process, electrons are transferred from the _____ to the _____ and the sphere acquires a _____ charge.

A. neutral sphere, charged rod, negative
B. neutral sphere, charged rod, positive
C. charged rod, neutral sphere, negative
D. charged rod, neutral sphere, positive
E. ... Nonsense! None of these describe what occurs.

7. A metal sphere is electrically neutral. It is touched by a positively charged metal rod. As a result, the metal sphere becomes charged positively. Which of the following occur during the process? List all that apply.

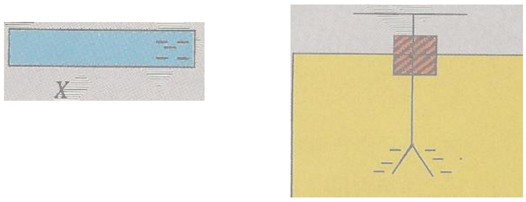
A. The metal sphere gains some protons.
B. Electrons are transferred from the sphere to the rod.
C. The metal sphere loses electrons.
D. The overall charge of the system is conserved.
E. Protons are transferred from the rod to the sphere.

8. a. Explain electrostatic induction
b. How would you charge a rod through this method?
c. Mention TWO other methods of producing electrostatic charges order than electrostatic induction

9. A short chain is usually attached to the back of a petrol tanker trailing behind it to ensure that
A. petrol tanker is balanced on the road
B. heat generated by friction in the engine can be conducted to the floor
C. charges generated by friction in the tanker is conducted on the floor
D. chain produces sound for the resonance of the tanker

10. Explain why the following occur
a. an ebonite rubbed with fur attracts small pieces of paper
b. nylon undergarments crackle in dry weather
c. the upper end of a lightning conductor is pointed
d. when a polythene rod which has been rubbed with dry cloth is held above small pieces of paper on a table, the pieces of paper jump up and down repeatedly between the table and rod.

12. Draw a labelled diagram of a gold-leaf electroscope



13. In the above figure, when the negatively charged rod X is brought near the cap of the electroscope
A. the leaves will open further
B. the leaves will close up
C. the leaves will become positively charged
D. the cap will become negatively charged

14. If a gold leaf electroscope is charged and left, the leaves gradually collapse. Give TWO possible reasons for this.

WEEK SEVEN LESSON NOTE

CAPACITORS

A **capacitor** (originally known as **condenser**) is two-terminal electrical component or device used for storing electric charge or electricity. It consists of two electrical conductors (metal plates) of opposite charges. The metallic plates are separated through a small distance, d, by a dielectric (insulator). This device is used to regulate the flow of current. When there is a potential difference (voltage) across the conductors, a static electric field develops across the dielectric, causing positive charge to collect on one plate and negative charge on the other plate thereby storing energy in the electrostatic field. When there is a big drop of voltage, electricity stored by capacitor is released so there is no voltage drop after that.

Capacitors are widely used as parts of electrical circuits in many common electrical devices. Example; it is used in digital circuit such as computer memories. Computer memories can be lost during electric power failure, so the capacitor provides power to maintain information from temporarily loss of power. It can also regulate a big increase of voltage.

The Isolated metallic sphere capacitor

A very simple capacitor is an isolated metallic sphere. The potential of a sphere with radius R and charge Q is equal to

$$\Delta V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R} \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_(1)}$$

Equation (1) shows that the potential of the sphere is proportional to the charge Q on the conductor. This is true in general for any configuration of conductors. This relationship can be written as

$$Q = CV \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_(2)}$$

where C is called the **capacitance** of the system of conductors. The capacitance of the metallic sphere is equal to

$$C = \frac{Q}{V} = \frac{Q}{\frac{1}{4\pi\varepsilon_0}\frac{Q}{R}} = 4\pi\varepsilon_0 R \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (3)}$$

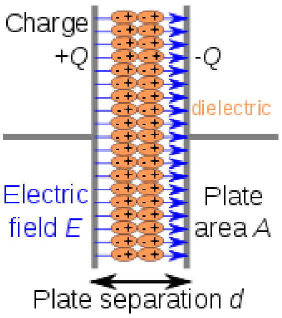
$$C = \frac{Q}{V} \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_(4)}$$

Definition of Capacitance of a capacitor

The Capacitance (C) of a capacitor is defined as the ratio of the electric charge Q on each conductor to the potential difference V between them. Quantitatively, the capacitance of a capacitor is a measure of the ability to store electricity. The capacitance increases with the area between the plates, decreases with increasing distance, and increases with diaelectric constant. The unit of capacitance is the farad (F). The sub-units are 1 Microfarad (µF) = 10^{-6} Farad (F), 1 Picofarad (pF) = 10^{-12} Farad. The Capacitance of a capacitor is one Farad if one coulomb of charge is transferred from one conductor to the other per unit volt of potential difference between the conductors.

$$Farad = \frac{Coulomb}{Volt} \qquad (5)$$

The parallel-plate capacitor



Another example of a capacitor is a system consisting of two parallel metallic plates. The potential difference between two plates of area A, separation distance d, and with charges +Q and -Q, is given by

$$\Delta V = \frac{Qd}{\varepsilon_0 A} \qquad (6)$$

Using the definition of the capacitance (eq.(4)), the capacitance of this system can be calculated:

$$C = \frac{Q}{\Delta V} = \frac{Q\varepsilon_r\varepsilon_0 A}{Qd} = \frac{\varepsilon_r\varepsilon_0 A}{d}\ if\ \varepsilon_r = 1 \therefore C = \frac{\varepsilon_0 A}{d} \qquad (7)$$

where

C is the capacitance; *A* is the area of overlap of the two plates; ε_r is the relative static permittivity (sometimes called the dielectric

constant) of the material between the plates (for a vacuum, $\varepsilon_r = 1$);

ε_0 is the diaelectric constant ($\varepsilon_0 \approx 8.854\times10^{-12}$ F m^{-1}); and *d* is the separation between the plates.

Equation (4) shows that the charge on a capacitor is proportional to the capacitance C and to the potential V. To increase the amount of charge stored on a capacitor while keeping the potential (voltage) fixed, the capacitance of the capacitor will need to be increased. Since the capacitance of the parallel plate capacitor is proportional to the plate area A and inversely proportional to the distance d between the plates, this can be achieved by increasing the surface area A and/or decreasing the separation distance d.

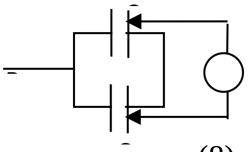
Factors upon which the Capacitance of a Capacitor depends are:

1. Distance between the plates
2. Dielectric constant (relative permittivity) between the plates
3. The area of the plates

ARRANGMENTS OF CAPACITORS

Capacitor in Parallel

Capacitors can be connected together either in series or in parallel. Figure (1) shows two capacitors, with capacitance C_1 and C_2, connected in parallel. The potential difference across both capacitors must be equal and therefore



(8)

$$V_{eff} = V_1 = V_2 = \dots V_n \quad (8)$$

Figure (1). Two

Using the relation below to calculate the total charge on both capacitors

$$Q_{eff} = Q_1 + Q_2 + \dots\dots + \dots Q_n$$

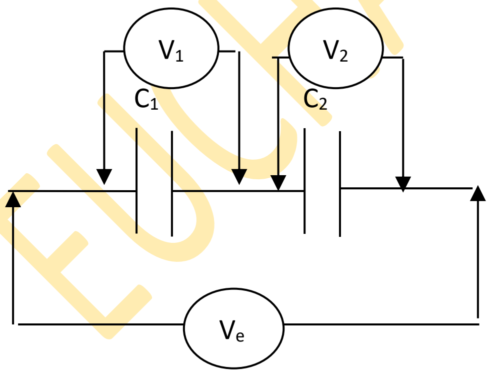
$$Q_{eff} = C_1V + C_2V + C_3V \therefore Q_{eff} = (C_1 + C_2 + C_3)V \therefore \frac{Q}{V} = C = C_1 + C_2 + C_3 \quad (9)$$

Equation (9) shows that the total charge on the capacitor system shown in Figure (1) is proportional to the potential difference across the system. The two capacitors in Figure (1) can be treated as one capacitor with a capacitance C where C is related to C_1 and C_2 in the following manner

$C_{eff} = C_1 + C_2 + \dots\dots + \dots C_n$ is effective capacitance in parallel (10)

Capacitor in Series

Figure (2) shows two capacitors, with capacitance C_1 and C_2, connected i



Suppose the potential difference across C_1 is V_1 and the potential difference across C_2 is V_2. A charge Q on the top plate will induce a charge -Q on the bottom plate of C_1. Since electric charge is conserved, the charge on the top plate of C_2 must be equal to Q. Thus the charge on the bottom plate of C_2 is equal to -Q.

The voltage difference across C_1 is given by

$$V_1 = \frac{Q_{eff}}{C_1} \qquad (11)$$

Figure (2). Two

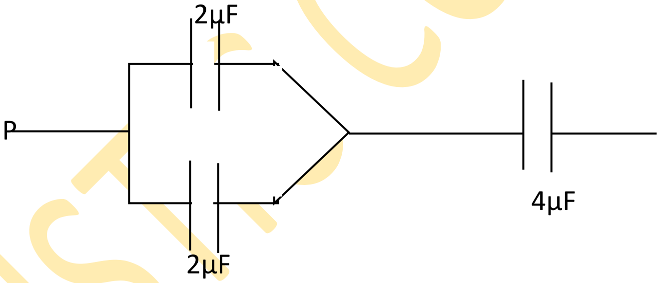
And the voltage difference across C_2 is equal to $V_2 = \frac{Q_{eff}}{C_2}$ (12)

The total voltage difference across the two capacitors is given by

$$V_{eff} = V_1 + V_2 = \frac{Q}{C_1} + \frac{Q}{C_2} = \left(\frac{1}{C_1} + \frac{1}{C_2}\right)Q \qquad (13)$$

Equation (13) again shows that the voltage across the two capacitors, connected in series, is proportional to the charge Q. The system acts like a single capacitor C whose capacitance can be obtained from the following formula of combining the capacitance as reciprocals

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots\ldots \frac{1}{C_n} \; \textit{Capacitance in series} \qquad (14)$$



Examples 1:

Calculate the net Capacitance in this diagram

For Parallel combination

$$C_{eq} = C_1 + C_2 = 2\mu F + 2\mu F = 4\mu F$$

For series combination

$$\frac{1}{C_{eq}} = \frac{1}{C_3} + \frac{1}{C_4} = \frac{1}{4\mu F} + \frac{1}{4\mu F} = 2\mu F$$

Example 2

A capacitor of charge, 2.4×10^{-4} Coulomb has a potential difference of 100 V. Calculate the Capacitance of the Capacitor

$Formular\ C = \frac{Q}{V}$

$= \frac{2.4\times10^{-4}}{10^{2}} = 2.4\times10^{-4-2}F = 2.4\times10^{-6}F$

$= 2.4\times \mu F$

Examples 3:
Three Capacitors of capacitances 1.0μF, 1.5 μF and 2 μF containing charges 1.0 x 10^{-3} C, 2 x 10^{-3}, 3.0 x 10^{-3} respectively are connected in parallel. Calculate the P.d across the combination.

$Parallel\ Combination$

$C_{effective} = C_1 + C_2 + C_3$

$C_{effective} = (1.0 + 1.5 + 2.0)\mu F = 4.5\mu F$

$Q_{effective} = Q_1 + Q_2 + Q_3$

$Q_{effective} = (1.0 + 2.0 + 3.0)mC = 6mC$

Using the relation $V = \frac{Q_{effective}}{C_{effective}} = \frac{6mC}{4.5\mu F} = \frac{6C}{4.5F}\times10^{-3+6} = 1.3\times10^{3}V \ = 1300V$

The same voltage passes through the three capacitors since they are in parallel

Examples 4:
What does the statement that the capacitance of a parallel is 2μF capacitor mean? The statement simply means that the ratio of the quantity of charge to the voltage between parallel plate capacitors id 2μF

Functions of a Capacitor

1. It is used for storing energy or electrical charges
2. It is used to separate a.c from d.c by coupling or blocking d.c
3. It is used to regulate or control current in an a.c circuit
4. It is used in radio circuit for tuning
5. It is used in ignition system of motor vehicles
6. It is used in elimination of sparks when a circuit containing inductance is suddenly opened e.g induction coil

Energy stored in a capacitor

The energy (measured in joules) stored in a capacitor is equal to the *work* done to charge it. Consider a capacitor of capacitance *C*, holding a charge +*q* on one plate and −*q* on the other. Moving a small element of charge d*q* from one plate to the other against the potential difference *V* = *q/C* requires the work d*W*:

$$dw = \frac{q}{c}dq \qquad (15)$$

The energy stored in a capacitor is found by integrating this equation. Starting with an uncharged capacitance ($q = 0$) and moving charge from one plate to the other until the plates have charge $+Q$ and $-Q$

$$W_{charging} = \int_0^Q \frac{q}{C}\,dq = \frac{1}{2}\frac{Q^2}{C} = W_{stored} \text{------}(16)$$

$$but\; Q = CV$$

$$substituting\; in\; (1)$$

requires the work W: $= \frac{1}{2}\frac{C^2V^2}{C} = \frac{1}{2}CV^2$

This work done in charging a capacitor is the energy stored in the capacitor. Hence

$$W = \frac{1}{2}qv = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}CV$$

where W is the work measured in joules, q is the charge measured in coulombs and C is the capacitance, measured in farads.

Example 5. The Net charge on a capacitor which is charged to P.d of200V is 1.0×10^{-4} C. What is the capacitance of the capacitor and the energy stored in the capacitor?

Using the relation

$$W = \frac{1}{2}qv \text{--------------}(17)$$

$$q = 1.0\times 10^{-4}\,C, V = 200V$$

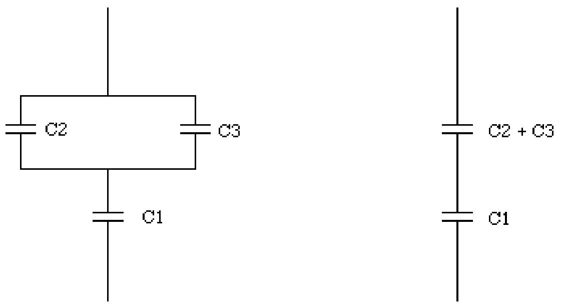
$$Substituting\; in\; (1)$$

$$W_{stored} = \frac{1}{2}\times 1.0\times 10^{-4}\,C\times 200V = \frac{1}{2}(1\times 2)\times 10^{-4+2} = \frac{1}{2}\times 2\times 10^{-2}\,J$$

$$= 0.01J$$

Example 6: Problem

Three capacitors are connected as shown in Figure (3) Their capacitances are C_1 = 2.0 uF, C_2 = 6.0 uF, and C_3 = 8.0 uF. If a voltage of 200 V is applied to the two free terminals, what will be the charge on each capacitor? What will be the electric energy of each ?



Suppose the voltage across capacitor C_1 is V_1, and the voltage across capacitor ($C_2 + C_3$) is V_2. If the charge on capacitor C_1 is equal to Q_1, then the charge on the parallel capacitor is also equal to Q_1. The potential difference across this system is equal to $V_{eff} = \frac{Q_1}{C_1} + \frac{Q_1}{C_2 + C_3}$. since the same current flows in

$C_1,\; C_2 + C_3$

$$C_1 = 2.0\mu F = 2\times 10^{-6} F$$

For parallel combination $C_{23} = C_2 + C_3 = 6\mu F + 8\mu F = 14\mu F$

For series combination $\frac{1}{C_{eff}} = \frac{1}{C_1} + \frac{1}{C_2 + C_3} = \frac{1}{2.0\mu F} + \frac{1}{14uF} = \frac{8}{14}uF$

$$C_{eff} = \frac{14}{8}uF$$

$$Q_1 = \frac{V_{eff}}{\frac{1}{C_1} + \frac{1}{C_2 + C_3}} = \frac{2\times 10^2 V}{\frac{8}{14}\times 10^{-6} F} = \frac{2\times 14\times 10^{2-6}}{8} C = 3.5\times 10^{-4} C = 0.35mc$$

The charge on capacitor 1 is Q_1, thus the potential difference V_1 is determined as

$$V_1 = \frac{Q_1}{C_1} = \frac{0.35mC}{2.0\mu F} = \frac{3.5\times 10^{-4+6}}{2.0} = 1.75\times 10^2 V$$

The electricpotential energy storedcapacitor1is equal to

Substituting in (1)

$$U_1 = \frac{1}{2} q_1 V_1 = \frac{1}{2}\times 3.5\times 1.75\times 10^{-4+2} = 30.625\times 10^{-2} J = 0.0306J$$

The voltage V_{23} across the capacitor ($C_2 + C_3$) is related to the charge Q_1

$$V_{23} = \frac{Q_1}{C_2 + C_3} = \frac{0.35mC}{14\mu F} = \frac{3.5\times 10^{-4+6}}{14} = 0.25\times 10^2 V = 25V$$

$$Q_2 = C_2 V_{23} = 6\times 25\times 10^{-6} = 150\times 10^{-6} = 0.15mC$$

The electric potential energy stored capacitor 2 is equal to

Substituting in (2)

$$U_2 = \frac{1}{2} q_2 V_{23} = \frac{1}{2}\times 0.15\times 25\times 10^{-3} = 1.875\times 10^{-3} J = 0.00188J = 0.0019J$$

The charge on capacitor C_3 is equal to

$$Q_3 = C_3 V_{23} = 8\times 25\times 10^{-6} = 200\times 10^{-6} = 0..2mC$$

The electric potential energy stored capacitor 3 is equal to

Substituting in (3)

$$U_3 = \frac{1}{2} q_3 V_{23} = \frac{1}{2}\times 0.2\times 25\times 10^{-3} = 2.5\times 10^{-3} J = 0.0025J$$

Exercises:

1. Define the Capacitance of a capacitor.

2. What does the statement that the capacitance of a parallel is 2μF capacitor mean?
3. List THREE factors which can affect the capacitance of a parallel plate capacitor
4. State THREE applications of a capacitor
5. A capacitor with air between its plates has capacitance 3.0μF. What is the capacitance when wax of dielectric constant 2.8 is placed between the plates?
6. Determine the charge on each plate of a 0.05μF capacitor when the potential difference between the plates is 200V.
7. A capacitor is charged with 9.6nC and has a 120V potential difference between its terminals. Compute its capacitance and the energy stored in it.
8. Compute the energy stored in a 60pF capacitor (a) when it is charged to potential difference of 2.0kV and (b) when the charge on the plate is 30nC.
9. Three capacitor, each of capacitance 120pF, are each charged to 0.5kV and then connected in series; Determine (a) the potential difference between the ends of the plates, (b) the charge on each capacitor, and (c) the energy stored in the system
10. Three capacitors (2.00 μF, 5.00 μF, and 7.00 μF) are connected in series. What is their equivalent capacitance?
11. The capacitors in problem (6) are connected in parallel. What is their equivalent capacitance?
12. The capacitor combinations in problem (6) are connected in series with the combination in problem (7). What is the capacitance of the new combination?
13. Two capacitors (0.30 and 0.50 μF) are connected in parallel. (a) What is their equivalent capacitance? A charge of 200 μC is now on the parallel combination. (b) What is the potential difference across it? (c) What are the charges on the capacitors?
14. (a) Calculate the capacitance of a capacitor consisting of two parallel plates separated by a layer of paraffin wax 0.5cm, the area of each plate being 80cm^2. The dielectric constant for the wax is 2.0. (b) If the capacitor is connected to a 100V source, calculate the charge on the capacitor and energy stored in the capacitor.
15. A parallel plate capacitor consists of two identical plate of area 1.00 x 10^{-2} m^2 placed at a distance of 2.00 x 10^{-2} m in air. The capacitor is charged so that the potential difference between the plates is 1000V, Calculate the

(i) Magnitude of the electric field strength between the plates
(ii) Capacitance of the capacitor
(iii) Energy stored in the capacitor [Neglect edge effect $\varepsilon_0 = 8.854 \times 10^{-12} Fm^{-1}$]