Electricity
TEST -8

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6thStd (Term- II)
Unit – 2. Electricity

Introduction

- We use electricity in our day to day life. Have we ever wondered from where do we get this electricity? How does this electricity work? Can we imagine a day without electricity? If you ask your grandfather, you can come to know a period without electricity. They used oil lamps for light, cooked on fires of wood or coal. By the advent of electricity, our day to day works are made easy and the world is on our hands. What are the appliances those work on electricity? What are the materials those allow electricity to flow through? What are electric circuits? What are electric cells and batteries? Come on, let us descend into this lesson to know more about electricity.

Sources of Electricity

- Selvan and Selvi are twins. They are studying in sixth standard. They visited their grandparent's village during summer vacation. At 6 O'clock in the evening Selvan's Grandfather switched on the light. The whole house was illuminated. Seeing this Selvan asked his grandfather "How do we get light by switching on the switch?" So, his grandfather took him to the nearest electricity board and enquired about the electricity.

- The Major Electric power stations in Tamilnadu are: Thermal stations (Neyveli in Cuddalore District, Ennore in ThiruvallurDistrict), Hydel power stations (Mettur in

Salem District, Papanasam in Tirunelveli District), Atomic power stations (Kalpakkam in Kanchipuram District, Koodankulam in Tirunelveli District), and Wind mills (Aralvaimozhi in Kanyakumari District Kayatharu in Tirunelveli District). Apart from these Solar panels which are prevalent in many places are used to produce electricity.

- Let us discuss in shortly about working power stations.

Thermal Power stations

- In thermal power stations, the thermal energy generated by burning coal, diesel or gas is used to produce steam. The steam thus produced is used to rotate the turbine. While the turbine rotates, the coil of wire kept between the electromagnet rotates. Due to electromagnetic induction electricity is produced. Here heat energy is converted into electrical energy.

Hydel power stations

- In hydel power stations, the turbine is made to rotate by the flow of water from dams to produce electricity. Here kinetic energy is converted into electrical energy. Hydel stations have long economic lives and low operating cost.

Atomic power stations

- In atomic power stations, nuclear energy is used to boil water.The steam thus produced is used to rotate the turbine. As a result, electricity is produced. Atomic power stations are also called as nuclear power stations. Here nuclear energy is converted into mechanical energy and then electrical energy.

Wind mills

- In wind mills, wind energy is used to rotate the turbine to produce electricity. Here kinetic energy is converted into electrical energy.

Cell

- A device that converts chemical energy into electrical energy is called a cell.

- A chemical solution which produces positive and negative ions is used as electrolyte. Two different metal plates are inserted into electrolyte as electrodes to form a cell. Due to chemical reactions, one electrode gets positive charge and the other gets negative charge producing a continuous flow of electric current.
- Depending on the continuity of flow of electric current cells are classified in to two types. They are primary cells and secondary cells.

Primary Cells

- They cannot be recharged. So they can be used only once. Hence, the primary cells are usually produced in small sizes.

Examples

- cells used in clocks, watches and toys etc., are primary cells.

Secondary Cells

- A cell that can be recharged many times is called secondary cell. These cells can be recharged by passing electric current. So they can be used again and again. The size of the secondary cells can be small or even large depending upon the usage. While the secondary cells used in mobiles are in the size of a hand, the cells used in automobiles like cars and buses are large and very heavy.

Examples

- Secondary Cells are used in Mobile phones, laptops, emergency lamps and vehicle batteries.

Battery

- Often, we call cells as 'batteries'. However only when two or more cells are combined together they make a battery. A cell is a single unit that converts chemical energy into electrical energy, and a battery is a collection of cells.

Electric Circuits

- Grandfather asked Selvi to bring torchlight. While taking the torchlight, it fell down and the cells came out. She puts the cells back and switched it on (Fig. A)

- The torchlight did not glow. She thought the torchlight was worn out. She was afraid that grandfather might scold her. She started crying. Her uncle came there and asked the reason for crying. She conveyed the matter. Her uncle removed the cells and reversed them (Fig B)

- Now, the torch glows. Selvi's face also glows. Uncle told her the reason and explained her about electric circuits.

Inside view of torch

· An electric circuit is the continuous or unbroken closed path along which electric current flows from the positive terminal to the negative terminal of the battery. A circuit generally has:

v A cell are battery- a source of electric current

- v Connecting wires- for carrying current
- v A bulb- a device that consumes the electricity
- v A key or a switch- this may be connected anywhere along the circuit to stop or allow the flow of current.

a. Open Circuit

- In a circuit if the key is in open (off) condition, then electricity will not flow andthe circuit is called an open circuit. The bulb will not glow in this circuit.

b. Closed Circuit

- In a circuit if the key is in closed (on) condition, then electricity will flow and the circuit is called a closed circuit. The bulb will glow in this circuit.

- Can you make a simple switch own by simple things available to you?

Types of Circuits

- **v** Simple Circuit
- **v** Series Circuit
- **v** Parallel Circuits

1. Simple Circuit

- A circuit consisting of a cell, key, bulb and connecting wires is called a simple circuit.

2. Series Circuit

- If two or more bulbs are connected in series in a circuit, then that type of circuit is called series circuit. If any one of the bulbsisdamaged disconnected, the entire circuit will not work.

3. Parallel Circuit

- If two or more bulbs are connected in parallel in a circuit, then that type of circuit is called parallel circuit.

Symbols of Electric Components

- In the circuits discussed above, we used the figures of electric components. Using electric components in complicated circuits is difficult. So, symbols of the components are used instead of figures. If these symbols used in electric circuits, even complicated circuits can be easily understood.

- If any one of the bulb is damaged or disconnected the other part of the circuit will work. So parallel circuits are used in homes.

- Electric Eel is a kind of fi sh which is able to produce electric current. This fish can produce an electric shock to safeguard itself from enemies and also to catch its food.

More to Know

- Ammeter is an instrument used in electric circuits to find the quantity of current flowing through the circuit. This is to be connected in series.

Conductors and Insulators

Will electric current pass throw all materials?

- If an electric wire is cut, we could see a metal wire surrounded by another material. Do you know why it is so?

Conductors

- The rate of flow of electric charges in a circuit is called electric current. The materials which allow electric charges to pass through them are called conductors. Examples: Copper, iron, aluminium, impure water, earth etc.

Insulators (Non-Conductors)

The materials which do not allow electric charges to pass through them are called insulators or non- conductors.

Safety measures to safeguard a person from electric shock

- Switch off the power supply.
- Remove the connection from the switch.
- Push him away using non - conducing materials.
- Give him first aid and take him to the nearest health centre.

More to Know
Thomas Alva Edison (February 11, 1847 – October 18, 1931) was an American inventor. He invented more than 1000 useful inventions and most of them are electrical appliances used in homes. He is remembered for the invention of electric bulb.

7th std (Term –II)
Unit - 2. Electricity

Introduction

- In 1882, when it was sun set in the west thatmiracle happened in New yorkcity. WhenThomas Alva Edison gently pushed the switchon 14,000 bulbs in 9,000houses suddenly gotlighted up. It was the greatest invention tomankind. Fromthen the world was under thelight even in the night.

- Many countries began using electricityfor domestic purposes. Seventeen yearsafterthe New York, in 1899 electricity first came toIndia. The Calcutta ElectricSupply CorporationLimited commissioned the first thermal powerplant in India on17 April 1899Around 1900s, a thermal power stationwas set up at Basin Bridge inMadras city andpower was distributed to the government press,general hospital,electric tramways and certainresidential areas in Madras. Today electricity isacommon household commodity.

- In your class 6, we learned about electricityand their sources. From operatingfactories,running medical equipment's like ventilator, communications like mobile, radio and TV,drawing water to the agricultural field andlight up homes electricityis important. Whatis electricity? We can see that. it is a form ofenergy, like heat andmagnetism.We have learnt that all materials are madeup of small particles calledatoms. The centre of the atom is called the nucleus. The nucleus consists of protons and neutrons. Protons are positively charged. Neutrons have no charge. Negatively charged electrons revolve around the nucleus in circular orbits. Electricity is a form of energy that is associated with electric charges that exists inside the atom

- Electric charge is measured in a unit calledcoulomb. One unit of coulomb ischarge ofapproximately 6.242×10^{18} protons or electrons.Electrical charges aregenerally denoted bythe letter \`q\`

Electric Current

- The flows of electric charges constitute anelectric current. For an electricalapplianceto work, electric current must flow through it.An electric current ismeasured by the amountof electric charge moving per unit time at anypoint in thecircuit. The conventional symbolfor current is 'I'.

Unit of Electric Current

- The SI unit for measuring an electric current isthe ampere, which is the flowof electric chargeacross a surface at the rate of one coulomb persecond.

$$I = q / t$$

Where I ⇒ current (in Ampere - A)

q ⇒ charge (in coulomb - c)
t ⇒ time taken (in seconds - s)

Conventional Current and Electron Flow

- Before the discovery of electrons, scientists believed that an electric current consisted of moving positive charges.

- This movement of positive charges is calledconventional current.After the electrons were discovered, itwas known that electron flow actuallytakesplace from the negative terminal to the positiveterminal of the battery. Thismovement isknown as electron flow.Conventional current is in thedirection opposite to electron flow.

Measurement of electric current

- Electric current is measuredusing a device called ammeter.The terminals ofan ammeterare marked with + and -sign. An ammeter must beconnected in seriesin a circuit.Instruments used to measure smallercurrents, in the milli ampere ormicro ampererange, are designated as milli ammeters ormicro ammeters.

1 Milliampere (mA) = 10^{-3} ampere.
= 1/1000 ampere
1 Microampere (µA) = 10^{-6} ampere
= 1/1000000 ampere

Potential difference (v)

- Electrical charges need energy to push themalong a circuit.Water alwaysflows fromhigher to lower ground.Similarly an electric chargealways flows from apoint athigher potential to a point atlower potential.

- An electric current can flow only when there isa potential difference (V) or P.D.

- The potential difference between anytwo points in the circuit is the amount ofenergy needed to move one unit of electriccharge from one point to the other.

Unit of potential difference

- Did you ever notice the precautionaryboard while crossing the railway trackand the electrical transformer? What does theword high voltage denotes?

- The term mentioned in the board volt isthe measurement for the electricpotentialdifference.

- The SI unit of potential difference is volt (V).Potential difference between twopoints ismeasured by using a device called voltmeter.

· The electric current flow from the higher potential level to the lower potential level is just like the water flow.

Electrical conductivity and Resistivity
Resistance (R)

- An electrical component resists or hinders theflow of electric charges, when itis connected ina circuit. In a circuit component, the resistanceto the flow of chargeis similar to how a narrowchannel resists the flow of water.

- The higher the resistance in a component, thehigher the potential difference neededto moveelectric charge through the component. We canexpress resistance as a ratio.

- Resistance of a component is the ratio of thepotential difference across it to thecurrentflowing through it. R=$\frac{V}{I}$

- The S.I unit of resistance is ohmGreater the ratio of V to I, the greater is theresistance

Electrical conductivity (σ)

- Electrical conductivity or specific conductanceis the measure of a material'sability to conductan electric current. It is commonly representedby the Greek letterσ (sigma) The S.I Unit ofelectrical conductivity is Siemens / meter(S / m)

Electrical resistivity (ρ)

- Electrical resistivity (also known as specificelectrical resistance or volumeresistivity)is a fundamental property of a material thatquantifies how strongly thatmaterial opposesthe flow of electric current. The SI unit ofelectrical resistivity is the ohm-metre (Ω m).

Material	Resistivity (ρ) ($\Omega\, m$) at 20°C	Conductivity (σ) (S/m) at 20°C
Silver	1.59x10-8	6.30×10^{7}
Copper	1.68x10-8	5.98x107
Annealed copper	1.72×10^{-8}	5.80×10^{7}
Aluminium	2.82×10^{-8}	3.5×10^{7}

Analogy of Electric Current with Water Flow

- An electric current is a flow of electrons througha conductor (like a copperwire). We can't seeelectrons; however, we can imagine the flow ofelectric current ina wire like the flow of waterin a pipe.

- Let us see the analogy of flow of electric current with the water flow. Water flowing through pipes is pretty good mechanical system that is a lot like an electrical circuit. This mechanical system consists of a pump pushing water through a closed pipe.

- Imagine that the electrical current is similar to the water flowing through the pipe. The following parts of the two systems are related

  - The pipe is like the wire in the electric circuit and the pump is like the battery.

  - The pressure generated by the pump drives water through the pipe.

  - The pressure is like the voltage generated by the battery which drives electrons through the electric circuit.

  - Suppose, there are some dust and rust that plug up the pipe and slow the flow of water, creating a pressure difference from one end to the other end of the pipe. In similar way, the resistance in the electric circuit resists the flow of electrons and creates a voltage drop from one end to the other. Energy loss is shown in the form of heat across the resistor.

Sources of Electric current -Electro chemical cells or electric cells

- An electric cell is something that provideselectricity to different devices thatare not fed directly or easily by the supplyof electricity.

- In addition to electro chemical, we use electrothermal source for generatingelectricity forlarge scale use.It has two terminals. When electric cells areused, achemical reaction takes place inside thecells which produces charge in the cell.

Types of cell – primary cell and secondary cell

- In our daily life we are using cells and batteriesfor the functioning of aremote, toys cars, clock,cellphone etc. Event Hough all the devicesproduceselectrical energy, some of the cellsare reusable and some of them are of single use.Do you know the reason why? Based on theirtype they are classified into two types namely –primary cell and secondary cell.

Primary cell

- The dry cell commonly used in torches is anexample of a primary cell. Itcannot be rechargedafter use.

Secondary cells

- Secondary cells are used in automobiles andgenerators. The chemical reactionin themand be reversed, hence they can be recharged.Lithium cylindrical cells,button cells andalkaline cells are the other types that are in use.

PRIMARY CELL	SECONDARY CELL
1. The chemical reaction inside the primary cell is irreversible.	The chemical reaction inside the secondary cell is reversible
2. It cannot be recharged	It can be recharged
3. Examples of secondary cells are lead accumulator, Edison accumulator and Nickle – Iron accumulator	It is used to operate devices such as mobile phones, cameras, computers and emergency lights
4. Example – Simple Voltalic cell, Daniel cell, and Lechananche cell and dry cell	Examples of secondary cells are lead accumulator, Edison accumulator and Nickle – Iron accumulator.

Primary cell – simply Dry cell

- A dry cell is a type of chemical cellcommonly used in the common formbatteriesfor many electrical appliances. It is a convenientsource of electricityavailable in portable andcompact form. It was developed in 1887 by YeiSakizo ofJapan.

- Dry cells are normally used in small devicessuch as remote control for T.V., torch, cameraand toys.
- A dry cell is a portable form of a leclanche cell.It consists of zinc vessel whichacts as a negativeelectrode or anode. The vessel contains a moistpaste of saw dustsaturated with a solution ofammonium chloride and zinc chloride.The ammoniumchloride acts as an electrolyte.Electrolytes are substances that becomeions insolution and acquire the capacityto conduct electricity.

- The purpose of zinc chloride is to maintainthe moistness of the paste beinghighlyhygroscopic. The carbon rod covered with abrass cap is placed in the middleof the vessel. Itacts as positive electrode or cathode.

- It is surrounded by a closely packed mixtureof charcoal and manganese dioxide (MnO2) ina muslin bag. Here MnO2 acts as depolarizer.The zinc vessel issealed at the top with pitch orshellac. A small hole is provided in it to allowthegases formed by the chemical action toescape. The chemical action inside the cell is thesame as in leclanche cell.

Batteries

- Batteries are a collection of one or more cellswhose chemical reactions create aflow ofelectrons in a circuit. All batteries are made upof three basic components: ananode (the ‘+’side), a cathode (the ‘–’ side), and some kindof electrolyte. Electrolyteis a substance thatchemically reacts with the anode and cathode.

Invention of the Battery

- One fateful day in 1780,Italian physicist, physician,biologist, andphilosopher, LuigiGalvani, was dissecting a frogattached to a brass hook. As hetouched the frog's leg with an iron scapel, theleg twitched.

- Galvani theorized that the energy came fromthe leg itself, but his fellow scientist,AlessandroVolta, believed otherwise.Volta hypothesized thatthe frog's legimpulses wereactually caused by differentmetals soaked in a liquid.He repeated the experiment using cloth soakedin brine instead of a frog corpse, whichresultedin a similar voltage. Volta published his findingsin 1791 and later createdthe first battery, thevoltaic pile, in 1800.The invention of the modernbattery isoften attributed toAlessandro Volta. It actuallystarted with a surprising accidentinvolving the dissection of a frog.

ELECTRIC SWITCH

- Our country faces a shortage of electricity. Sowastage of electricity means youare deprivingsomeone else of electricity. Your electricitybill goes up. So, we mustuse electricity verycarefully and only when it is needed we mustuse the electricityas long as we need it in ourhouse hold activities.Can you remember what you didlast year toturn the current on or off?This time, we shall usea switch to turn thecurrent on or off. Youmay have used differentkinds of switches to turnyourhousehold electricappliances on or off. Switches help us to start orstop theappliances safely and easily.

Electric circuit

- It is difficult to draw a realistic diagram of thiscircuit. The electricalappliances you use at homehave even more difficult circuits. Can you drawrealisticdiagrams of such circuits which containmany bulbs, cells, switches and othercomponents?Do you think it is easy? It is not easy.Scientists have tried to make thejob easier.They have adopted simple symbols for differentcomponents in a circuit.We can draw circuitdiagrams using these symbols.

Do you know?
All muscles of our bodies move in response to electrical impulses generated naturally in our bodies

Types of electrical circuits

- In the above experiment, we make a circuit witha bulb and a cell. We makeonly one kind of thecircuit with a cell and a bulb. But we can makemany types ofcircuits if we have more than onebulb or cells by connecting these components indifferent ways.

Series circuit

- Two kinds of circuits can be made with twobulbs and a cell. In thisexperiment we shallmake one of them and study it.

Parallel Circuit

- Figure - shows a circuit in which two bulbsare connected indifferent places.Thisis a second type ofcircuit. Two bulbs inthis circuit are said tobe connected inparallel and such circuits arecalled parallel circuits.

Do you know?
Short circuit

- You mighth a v eobserved thespark in the electric polelocated nearby yourhouse. Do you knowthe cause of this electric spark? This is dueto the shortcircuiting of electricity along itspath.A short circuit is simply a low resistanceconnection between the two conductorssupplying electrical power to any circuit.Arc welding is a common example of thepractical application of the heating due toashort circuit.

- Conductors and Insulators
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- Based on the property ofconductance of electricity,substances are classifiedinto two types, namely,Conductors and Insulators(or) bad conductors of electricitythe electrons of different types of atoms havedifferent degrees of freedom to movearound.With some types of materials, such as metals,the outermost electrons in theatoms are looselybound and they chaotically move in the spacebetween the atomsof that material. Becausethese virtually unbound electrons are free toleave theirrespective atoms and float aroundin the space between adjacent atoms, they areoften called as free electrons.

- Let’s imagine that we have a metal in the form ofa wire. When a voltage isconnected across theends of the metal wire, the free electrons drift inone direction.

- So, a really good conductor is one that has lots offree charges while those whodon’t have enough‘free charges’ would not be good at conductingelectricity or wecan say that they would be‘poor conductors’ of electricity.

Conductors

- Conductors are the materials whose atoms haveelectrons that are looselybound and are free tomove through the material. A material that is agoodconductor gives very little resistance to theflow of charge (electron) on theapplication ofexternal voltage. This flow of charge (electron)is what constitutes anelectric current. A goodconductor has high electrical conductivity inthe aboveactivity.In general, more the free electrons, the betterthe material will conduct (for acertain appliedvoltage).

Insulators

- Those materials which don't have enough'free electrons' are not good atconductingelectricity or we can say that they would be'poor conductors' ofelectricity and they are called insulators

Do you know?

- This is the material used in SIM Cards, Computers, and ATM cards. Do you know by which material I am made up off?
- The chips which are used in SIM Cards, Computers, and ATM cards are made up of semiconductors namely, silicon and germanium because of their electrical conductivity lies between a conductor and an insulator.

- An insulator gives a lot of resistance to the flowof charge (electron). Duringthe drift of theelectrons in an object when an external voltageis applied, collisionsoccur between the freeelectrons and the atoms of the material alsoaffect themovement of charges. These collisionsmean that they get scattered. It is acombinationof the number of free electrons and how muchthey are scattered thataffects how well themetal conducts electricity. The rubber eraserdoes not allowelectric current to pass throughit. So rubber is a non-conductor of electricity.Rubber is an insulator Most of the metals are good conductors of electricity while most of the non-metals are poor conductors of electricity.

Do you know?

- Wires made of copper, anelectrical conductor, havevery low resistance. Copperwires are used to carrycurrent in households. These wires are inturn enclosed inelectrical insulators, ormaterials of highelectrical resistance.These materials areusually made offlexible plastic.

Effects of Electric Current

- You performed manyexperiments with electricityin Class 6 and learned quitea few interesting facts. Forexample, you saw that abulb can be made to light up bymakingelectricity flow through it. The light of thebulb is thus one of the effects ofelectricity.There are several other important effectsof electricity. We shall studysome of theseeffects in this chapter. There are 3 maineffects of electricity as,

  - Heating effect
  - Magnetic effect (Magnetism)
  - Chemical effect

Heating effect

- When an electric current passes through a wire,the electrical energy is converted to hear. Inheating appliances, the heating element is madeup ofmaterials with high melting point. An example of such a material is nichrome (an alloy of nickel, iron and chromium).

- The heating effect of electric current has manypractical applications. Theelectric bulb, geyser,iron box, immersible water heater are based onthis effect.These appliances have heating coilsof high resistance.Generation of heat due toelectriccurrent is known as the heating effect ofelectricity.

Factors affecting Heating Effect of current

1. Electric Current
2. Resistance
3. Time for which current flows

Electric Fuse

- Electric fuse isa safety devicewhich is usedin householdwiring andin manyappliances. Electric fuse has a body made ofceramic and two points for connectingthe fusewire. The fuse wire melts whenever there isoverload of the current in thewire. This breaksthe circuit and helps in preventing damage tocostly appliancesand to the wiring. In electricaldevices, a glass fuse is often used. This is a smallglasstube, in which lies the fuse wire.

MCBs (Miniature Circuit Breaker)

- MCBs have been replacing electric fuse fromwirings at most of the places. Theelectric fusehas a big practical problem. Whenever the wirefuses, one needs toreplace the wire to resumeelectric supply. More often than not, this provesto be acumbersome task. Miniature circuitbreakers break the circuit automatically. Onejust needs to switch it on to resume the electricsupply. Many models of MCBs havea built inmechanism by which the electric supply isautomatically resumed.

Magnetic Effect of electricity

- The next effect of electric current is Magnetism.In 1819, Hans ChristianOersted discoveredthe electricity that has a magnetic effect.The experiment inactivity-5 will help youunderstand the magnetic effect of electriccurrent.

Application of magnetic effect of electric current - Electromagnet

- Magnetic effect of electric current has beenused in making powerfulelectromagnets.Electromagnets are also used to removesplinters of steel or iron inhospitals dealingwith eye injuries.Electro magnets are used in many appliancesthat we use in our day to day life, namely, electricbell, cranes and telephone. Let usknow how themagnetic effect of electric current is applied intelephones.

Telephone

- In telephones, a changing magnetic effect causesa thin sheet of metal(diaphragm) to vibrate.The diaphragm is made up a metal that can beattracted tomagnets.

1. The diaphragm is attached to spring that isfixed to the earpiece.

2. When a current flows through the wires, thesoft – iron bar becomes anelectromagnet.

3. The diaphragm becomes attracted to theelectromagnet.

4. As the person on the other end of the linespeaks, his voices cause the current inthecircuit to change. This causes the diaphragmin the earpiece to vibrate,producing sound.

Chemical Effects of Electricity

- Chemical reactions happen, when electricitypasses through variousconducting liquids. Thisis known as chemical effects of electricity. Youwill learnchemical effect of electricity in yourhigher classes.

8th std (Term – 2)
Unit –2 Electricity

Introduction

- All things we use in our life are made up of elements. Each element is made up of atoms which is the smallest unit. John Dalton, the scientist considered that atoms cannot be divided further. But, it was found out later through Rutherford's gold foil experiment that atoms are made up of particles like proton, electron and neutron. Movement of electrons in a material constitutes electric current and generates an energy called electric energy or electricity. We use this energy in our life for various needs. Electric bulbs, fans, elctric iron box, washing machines and refrigirators are some of the appliances which work with the help of electricity. In this lesson we will study about electric charges and how they are transferred. This lesson will also cover electric circuits and the effect of electric current.

Atoms

- Atom consists of proton, electron and neutron which are called sub-atomic particles. Proton and neutron are found inside the nucleus which is at the centre of an atom. Electrons revolve around the nucleus indifferent paths called orbits. In an atom, the number of protons and the number of electrons will be equal. There is a force of attraction between the protons in the nucleus and the electrons in the orbits. Electrons in the inner orbits are strongly attracted by the protons and they cannot be removed from the atom easily. But, the electrons in the outermost orbits are loosely bound and they can be easily removed from the atom.

Charges

- Charge or electric charge is the basic property of matter that causes objects to attract or repel each other. It is carried by the subatomic particles like protons and electrons. Charges can neither be created nor be destroyed. There are two types of charges: positive charge and negative charge. Protons carry positive charge and the electrons carry negative charge. There is a force of attraction or repulsion between the charges. Unlike charges attract each other and like charges repel each other.

- Electric charge is measured in coulomb (C). Small amount of charge that can exist freely is called elementary charge (e). Its value is 1.602 × 10-19 C. This is the amount of charge possessed by each proton and electron. But, protons havepositive elementary charge (+e) and electrons have negative elementarycharge (-e). Since protons and electrons are equal in number, an atom is electrically neutral.

Transfer of Charges

- As we saw earlier, electrons (negative electric charges) in the outermost orbit of an atom can be easily removed. They can be transferred from one substance to another.

The substance which gains electrons become negatively charged and the substance which looses electrons becomes positively charged. Transfer of charges takes place in the following three ways.

- o Transfer by Friction
- o Transfer by Conduction
- o Transfer by Induction

Transfer by Friction

- Comb rubbed with hair gains electronsb from the hair and becomes negatively charged. These electrons are accumulated on the surface of the comb. When a piece of paper is teared into bits, positive and negative charges are present at the edges of the bits. Negative charges in the comb attract positive charges in the bits. So, the paper bits are moving towards the comb. While combing hair charges are transferred from the hair to comb due to friction. If the hair is wet, the friction between the hair and the comb reduces which will reduce the number of electrons transferring from hair to comb. Hence, rubbing certain materials with one another can cause the build-up of electrical charges on the surfaces. From this it is clear that charges are transferred by friction.

- A neutral object can become positively charged when electrons get transferred to another object; not by receiving extra positive charges.

- Similar effect can be seen when we rub few materials with one another. When a glass rod is rubbed with a silk cloth the free electrons in the glass rod are transferred to silk cloth. It is because the free electrons in the glass rod are less tightly bound as compared to that in silk cloth. Since the glass rod looses electrons, it has a deficiency of electrons and hence acquires positive charge. But, the silk cloth has excess of electrons. So, it becomes negatively charged.

- When an ebonite rod (rod made by vulcanized rubber) is rubbed with fur, the fur transfers electrons to the ebonite rod because the electrons in the outermost orbit of the atoms in fur are loosely bound as compared to the ebonite rod. The ebonite rod which has excess electrons becomes negatively charged and the fur which has deficiency of electrons is positively charged.

- From these we know that when two materials are rubbed together, some electrons may be transferred from one material to the other, leaving them both with a net electric charge.

- If a negatively charged glass rod is brought near another glass rod, the rods will move apart as they repel each other. If a positively charged glass rod is brought close to a negatively charged ebonite rod, the rods will move toward each other as they attract. The force of attraction or repulsion is greater when the charged objects are closer.

Transfer by Conduction

- When the ebonite rod is rubbed with woollen cloth, electrons from the woolen cloth are transferred to the ebonite rod. Now ebonite rod will be negatively charged. When it is brought near the paper cylinder, negative charges in the rod are attracted by the positive charges in the cylinder. When the cylinder is touched by the rod, some negative charges are transferred to the paper. Hence, the negative charges in the rod are repelled by the negative charges in the cylinder. Thus, we can say that charges can be transferred to on object by bringing it in contact with a charged body. This method of transferring charges from one body to other body is called transfer by conduction.

- The materials which allow electric charges to pass through them easily are called conductors of electricity. For example, metals like aluminium, copper are good conductors of electricity. Materials which do not allow electric charges to pass through them easily are called insulators. Rubber,wood and plastic are insulators

Transfer by Induction

- We saw that we can charge an uncharged object when we touch it by a charged object. But, it is also possible to obtain charges in a body without any contact with other charges. The process of charging an uncharged body by bringing a charged body near to it but without touching it is called induction. The uncharged body acquires an opposite charge at the near end and similar charge at the farther end.

- Bring a negatively charged plastic rod near a neutral rod. When the negatively charged plastic rod is brought close to the neutral rod, the free electrons move away due to repulsion and start piling up at the farther end. The near end becomes positively charged due to deficit of electrons. When the neutural rod is grounded, the negative charges flow to the ground. The positive charges at the near end remain held due to attractive forces and the electrons inside the metal is zero. When the rod is removed from the ground, the positive charge continues to be held at the near end. This makes the neutral rod a positively charged rod

- Similarly, when a positively charged rod is brought near an uncharged rod, negatively charged electrons are attracted towards it. As a result there is excess of electrons at nearer end and deficiency of electrons at the farther end. The nearer end of the uncharged rod becomes negatively charged and far end is positively charged.

Flow of Charges

- Suppose you have two metallic spheres; one having more negative charge (excess of electrons) and the other having more positive charge (deficiency of electrons). When you connect them both with the help of a metallic wire, excess electrons from the negatively charged sphere will start flowing towards the positively charged sphere. This flow continues till the number of electrons in both the sphere is equal. Here, the positively charged sphere is said to be at higher potential and the negatively charged sphere is said to be at lower potential. Hence, electrons flow from lower potential to higher potential. This is known electric current (flow of electrons). The difference between these potentials is known as potential difference, commonly known as voltage.

- Before the discovery of electrons it was considered that electric current is due to the flow of positive charges. Flow of positive charge is called conventional current. Conventional current flows from higher potential to lower potential.

Electroscope

- An electroscope is a scientific instrument used to detect the presence of electric charge on a body. In the year 1600, British physician William Gilbert invented the first electroscope. It is the first electrical instrument. There are two types of electroscope: pith-ball electroscope and gold leaf electroscope. An electroscope is made out of conducting materials, generally metal. It works on the principle that like charges repel each other. In a simple electroscope two metal sheets are hung in contact with each other. They are connected to a metal rod that extends upwards, and ends in a knob at the end.

- The first electroscope developed in 1600 by William Gilbert was calledversorium. The versorium was simply a metal needle allowed to pivot freely on a pedestal. The metal would be attracted to charged bodies brought near.

- If you bring a charged object near the knob, electrons will either move out of it or into it. This will result in charges on the metal leaves inside the electroscope. If a negatively charged object is brought near the top knob of the electroscope, it causes free electrons in the electroscope to move down into the leaves, leaving the top positive. Since both the leaves have negative charge, they repel each other and move apart.If a positive object is brought near the top knob of the electroscope, the free electrons in theelectroscope start to move up towards the knob. This means that the bottom has a net positive charge. The leaves will spread apart again.

Gold leaf electroscope

- The gold-leaf electroscope was developed in 1787 by a British scientist named Abraham Bennet. Gold and silver are used in electroscope because they are the best conductors of electric current.

Structure of Electroscope

- It is made up of a glass jar. A vertical brass rod is inserted into the jar through a cork. The top of the brass rod has a horizontal brass rod or a brass disc. Two gold leaves are suspended from the brass rod inside the jar.

Working of Electroscope

- When the brass disc of the electroscope is touched by a charged object, electric charge gets transferred to the gold leaf through the rod. This results in the gold leaves moving away from each other. This happens because both the leaves have similar charges.

Charging

- Transfer of charge from one object to another is called charging. In case of the gold leaves charge is transferred through the brass rods.

Electrical Discharge

- The gold leaves resume their normal position after some time. This happens because they lose their charge. This process is called electrical discharge. The gold leaves would also be discharged when someone touches the brass rod with bare hands. In that case, the charge is transferred to the earth through the human body.

Lighting and Thunder

- Getting a shock from a doorknob after rubbing your foot on a carpet floor, results from discharge. Discharge occurs when electronson the hand are quickly pulled to the positively charged doorknob. This movement of electrons, which is felt as a shock, causes the body to lose negative charge. Electric discharge takes place in a medium, mostly gases. Lightning is another example of discharge that takes place in clouds.

- Lightning is produced by discharge of electricity from cloud to cloud or from cloud to ground. During thunderstorm air is moving upward rapidly. This air which moves rapidly carries small ice crystals upward. At the same time, small water drops move downward. When they collide, ice crystals becomepositively charged and move upward and the water drops become negatively charged and move downward. So the upper part of the cloud is positively charged and the lower part of the cloud is negatively charged. When they come into contact, electrons in the water drops are attracted by the positive charges in the ice crystals. Thus, electricity is generated and lightning is seen.

- Sometimes the lower part of the cloud which is negatively charged comes into contact with the positive charges accumulated near the mountains, trees and even people on the earth. This discharge produces lot of heat and sparks that results in what we see as lightning. Huge quantities of electricity are discharged in lightning flashes and temperatures of over 30,000°C or more can be reached. This extreme heating causes the air to expand explosively fast and then they contract. This expansion and contraction create a shock wave that turns into a booming sound wave, known as thunder.

- Lightning's extreme heat will vaporize the water inside a tree, creating steam that may burn out the tree.

- Sometimes lightning may be seen before the thunder is heard. This is because the distance between the clouds and the surface is very long and the speed of light is much faster than the speed of sound.

- During lightning and thunder, we should avoid standing in ground and open spaces. You should make yourself as small as possible by squating. It is however safe to stay inside a car because the car acts as a shield and protects us from the electric field generated by the storm.

Earthing

- A safety measure devised to prevent people from getting shocked if the insulation inside electrical devices fails is called Earthing. Electrical earthing can be defined as the process of transferring the discharge of electrical energy directly to the Earth with the help of low-resistance wire.

- We get electrical energy from different sources. Battery is one such source. We use it in wall clocks, cell phones etc. For the working of refrigerators, air conditioners, washing machines, televisions, laptops and water heaters we use domestic power supply. Usually an electric appliance such as a heater, an iron box, etc. are fitted with three wires namely live, neutral and earth. The earth wire is connected to the metallic body of the appliance. This is done to avoid accidental shock.

- Suppose due to some defect, the insulation of the live wire inside an electric iron is burnt then the live wire may touch the metallic body of the iron. If the earth wire is properly connected to the metallic body, current will pass into the Earth through earth wire and it will protect us from electric shock. The Earth, being a good conductor of electricity, acts as a convenient path for the flow of electric current that leaksout from the insulation.

Lightning Arresters

- Lightning arrestor is a device used to protect buildings from the effects of lightning. Lightning conductor consists of a metallic lightning rod that remains in air at the top of the building. Major portion of the metal rod and copper cable are installed in the walls during its construction. The other end of the rod is placed deep into the soil. When lightning falls, it is attracted by the metallic rods at the top of the building. The rod provides easy route for the transfer of electric charge to the ground. In the absence of lightning arrestors, lightning will fall on the building and the building will be damaged.

Electric Circuits

- We saw that when two oppositely charged spheres are connected by a metal wire, electrons flow from the sphere which is at lower potential to the sphere at higher potential. Similarly, if two terminals of a battery which are at different potential are connected by a metallic wire, electrons will flow from negative terminal to positive terminal. The path through which electrons flow from one terminal to another terminal of the source, is called electric circuit.

- A simple circuit consists of four elements: a source of electricity (battery), a path or conductor through which electricity flows (wire), a switch to control the circuit and an electrical resistor (lamp) which is any device that requires electricity to operate.

- The above figure shows a simple circuit containing a battery, two wires, key and an electric bulb. The source can be a battery or the electric outlet in your room. The electrical resistor refers to the device that consumes the energy. Control (key) is the mechanism that is used to start, stop and regulate the electriccurrent. When the key is on, electrons from the battery flow through the circuit from the negative terminal through the wire conductor, then through the bulb and finally back to the positive terminal. The light glows when current is flowing through its filament. There are two basic ways in which we can connect these components. They are: series and parallel

- The electric eel is a species of fish which can give electric shocks of upto six hundred fifty watts of electricity. But if the eel repeatedly shocks, its electric organs become completely discharged. Then a person can touch it without being shocked.

Series Circuit

- A series circuit is one that has more than one resistor (bulb) but only one path through which the electrons can travel. From one end of the battery the electrons move along one path with no branches through the resistors (bulbs) to the other end of the cell. All the components in a series circuit are connected end to end. So, current through the circuit remains same throughout the circuit. But, the voltage gets divided across the bulbs in the circuit. In the following series circuit two bulbs are used as resistors.

- In this series circuit, charges (electrons) from the battery have only one path to travel. Here battery, key and two bulbs are connected in series. Charges flow from the battery to each bulb, one at a time, in the order they are wired to the circuit. If one bulb in the circuit is unscrewed, the current flow to another bulb would be interrupted. We put serial lights during festivals. If the lights are in a series circuit, one burnedout bulb will keep all the lights off. If the number of bulbs in a circuit with a battery increases, the light will be dimmer because many resistors are acting on the same power from the battery.

- We saw that in series circuit same current travels through every resistance and the voltagewill be different across each resistance. Let us consider three bulbs connected in series. Let I be the current through the circuit and V1, V2, V3 be the voltage across each bulb. The supply voltage V is the total of the individual voltage drops across the resistances.

$$V = V1 + V2 + V3$$

Parallel Circuit

- In a parallel circuit, there is more than one resistor (bulb) and they are arranged on many paths. This means charges (electrons) can travel from one end of the cell through many branches to the other end of the cell. Here, voltage across the resistors (bulbs) remains the same but the current flowing through the circuit gets divided across each resistor.

- In the above diagram current can flow in two paths: ABEFA and ABCDEFA. Here, it is clear that electricity from the cell can take either path ABEFA or path ABCDEFA to return to the cell. From the diagram you will notice that even when one resistor (bulb) burns out, the other bulbs will work because the electricity is not flowing through only one path. All the light bulbs in our homes are connected in parallel circuit. If one bulb burns out, the other bulbs in the rooms will still work. The bulbs in a parallelcircuit do not dim out as in series circuits. This is because the voltage across one branch is the same as the voltage across all other branches.

- Let us consider three bulbs connected in series. Let V be the voltage across the bulbs and I1, I2, I3 be the current across each bulb. The current I from the battery is the total of the individual current flowing through the resistances.

$$I = I1 + I2 + I3$$

Difference between series and parallel circuits

Series circuits	Parallel circuit
Same amount of current flows through all the components.	The current flowing through each component combines to form the current

	flow
Components are arranged in a line.	Components are arranged Parallel to each other.
Voltage is different across different components.	Sum of the Voltage through each component will be the voltage drawn from the source.
If one compound breaks down, the whole circuit will burn out	Other Components will function even if one component breaks down

Effects of Current

- When current is flowing through a conductor it produces certain effects. These are known as effects of electric current. These effects result in conversion of electrical energy into different forms of energies such as heat energy, mechanical energy, magnetic energy, chemical energy and so on.

Chemical Effect of Current

- We saw that electricity is conducted by metals. This activity shows that liquids also conduct electricity. When electric current is passed through a conducing solution, some chemical reactions take place in the solution. This chemical reactions produce electrons which conduct electricity. This is called chemicaleffect of electric current. The decomposition of molecules of a solution into positive and negative ions on passing an electric current through it, is called electrolysis. Electrolysis has a number of applications. It is used in extraction and purification of metals. The most general use of electrolyte is electroplating.

Electroplating

- Electroplating is one of the most common applications of chemical effects of electric current. The process of depositing a layer of one metal over the surface of another metal by passing electric current in called electroplating.

- Electro plating is applied in many fields. We use iron in bridges and automobiles to provide strength. However, iron tends to corrode and rust. So, a coating of zinc is deposited on iron to protect it from corrosion and formation of rust. Chromium has a shiny appearance. It does not corrode. It resists scratches. But, chromium is expensive and it may not be economical to make the whole object out of chromium. So, the objects such as car parts, bath taps, kitchen gas burners, bicycle handlebars, wheel rims are made from a cheaper metal and only a coating of chromium is deposited over it.

Heating Effect of Current

- When electric current passes through a conductor, there is a considerable 'friction' between the moving electrons and the molecules of the conductor. During this process, electrical energy is transformed to heat energy. This is known as heating effect of electric current. The heat produced depends on the amount ofresistance offered by the wire.

- Copper wire offers very little resistance and does not get heated up quickly. On the other hand, thin wires of tungsten or nichrome which are used in bulbs offer high resistance and gets heated up quickly. This is the reason why tungsten wire is used in the filaments of the bulbs and nichrome wire is used as a heating element in household heating appliances. Heating effect of electric current can be seen in many devices. Some ofthem are given below.

Fuse

- Fuse is a strip of alloy wire which is made up of lead and tin with a very low melting point. This can be connected to the circuit. The fuse is usually designed to take specific amount of current. When current passing through the wire exceeds the maximum limit, it gets heated up. Due to low melting point it melts quickly disconnecting the circuit. This prevents damage to the appliances.

Electric cookers

- Electric cookers turn red hot when electric current is passed through the coil. The heat energy produced is absorbed by the cooking pot through conduction.

Electric kettles

- The heating element is placed at the bottom of the kettle which contains water. The heat is then absorbed by the liquid and distributed throughout the liquid by convection.

Electric irons

- When current flows through the heating element, the heat energy developed is conducted to the heavy metal base, raising its temperature. This energy is then used to press clothes.

9th std

UNIT-4 Electric charge and Electric current

Introduction

- Like mass and length, electric charge also is a fundamental property of all matter. We know that matter is made up of atoms and molecules. Atoms have particles like electrons, protons and neutrons. By nature, electrons and protons have negative and positive charge respectively and neutrons do not have charge. An electric current consists of moving electric charges. Electricity is an important source of energy in the modern times. In this lesson, we will study about electric charges, electric current, electric circuit diagram and the effects of electric current.

Electric charges

- Inside each atom there is a nucleus with positively charged protons and chargeless neutrons and negatively charged electrons orbiting the nucleus. Usually there are as many electrons as there are protons and the atoms themselves are neutral.

- If an electron is removed from the atom, the atom becomes positively charged. Then it is called a positive ion. If an electron is added in excess to an atom then the atom is negatively charged and it is called negative ion.

- When you rub a plastic comb on your dry hair, the comb obtains power to attract small pieces of paper, is it not? When you rub the comb vigorously, electrons from your hair leave and accumulate on the edge of the comb. Your hair is now positively charged as it has lost electrons and the comb is negatively charged as it has gained electrons.

Measuring electric charge

- Electric charge is measured in coulomb and the symbol for the same is C. The charge of an electron is numerically a very tiny value. The charge of an electron (represented as e) is the fundamental unit with a charge equal to 1.6 × 10–19 C. This indicates that any charge (q) has to be an integral multiple (n) of this fundamental unit of electron charge (e). q = ne. Here, n is a whole number.

Practically, we have μC (micro coulomb), nC (nano coulomb)andpC (pico coulomb) as units of electric charge.

1 μC = 10-6 C, 1nC=10-9 and 1pC = 10-12C

- Electric charge is additive in nature. The total electric charge of a system is the algebraic sum of all the charges located in the system. For example, let us say that a system has two charges +5C and –2C. Then the total or net charge on the system is, (+5C) + (–2C) = +3C.

- Electrostatic forces between two point charges obey Newton's third law. The force on one charge is the action and on the other is reaction and vice versa.

Electric force

- Among electric charges, there are two types of electric force (F): one is attractive and the other is repulsive. The like charges repel and unlike charges attract. The force existing between the charges is called as 'electric force'. These forces can be experienced even when the charges are not in contact.

Electric field

- The region in which a charge experiences electric force forms the 'electric field' around the charge. Often electric field (E) is represented by lines and arrowheads indicating the direction of the electric filed (Fig. 4.2). The direction of the electric field is the direction of the force that would act on a small positive charge. Therefore the lines representing the electric field are called 'electric lines of force'. The electric lines of force are straight or curved paths along which a unit positive charge tends to move in the electric field. Electric lines of force are imaginary lines. The strength of an electric field is represented by how close the field lines are to one another.

- For an isolated positive charge the electric lines of force are radially outwards and for an isolated negative charge they are radially inwards.

- Electric field at a point is a measure of force acting on a unit positive charge placed at that point. A positive charge will experience force in the direction of electric field and a negative charge will experience in the opposite direction of electric field.

Electric potential

- Though there is an electric force (either attractive or repulsive) existing among the charges, they are still kept together, is it not?. We now know that in the region of electric charge there is an electric field. Other charges experience force in this field and vice versa. There is a work done on the charges to keep them together. This results in a quantity called 'electric potential'.

- Electric potential is a measure of the work done on unit positive charge to bring it to that point against all electrical forces.

Electric current

- When the charged object is provided with a conducting path, electrons start to flow through the path from higher potential to lower potential region. Normally, the potential difference is produced by a cell or battery. When the electrons move, we say that an electric current is produced. That is, an electric current is formed by moving electrons.

Direction of current

- Before the discovery of the electrons, scientists believed that an electric current consisted of moving positive charges. Although we know this is wrong, the idea is still widely held, as the discovery of the flow of electronsdid not affect the basic understanding of the electric current. The movement of the positive charge is called as 'conventional current'. The flow of electrons is termed as 'electron current'.

- In electrical circuits the positive terminal is represented by a long line and negative terminal as a short line.

Measurement of electric current

- We can measure the value of current and express it numerically. Current is the rate at which charges flow past a point on a circuit. That is, if q is the quantity of charge passing through a cross section of a wire in time t, quantity of current (I) is represented as,

$$I = q/t$$

- The standard SI unit for current is ampere with the symbol A. Current of 1 ampere means that there is one coulomb (1C) of charge passing through a cross section of a wire every one second (1 s).

$$1 \text{ ampere} = 1 \text{ coulomb} / 1 \text{ second (or)}$$
$$1 \text{ A} = 1 \text{ C} / 1 \text{ s} = 1\text{Cs}^{-1}$$

- Ammeter is an instrument used to measure the strength of the electric current in an electric circuit.

- The ammeter is connected in series in a circuit where the current is to be found. . The current flows through the positive (+) red terminal of ammeter and leaves from the negative (–) black terminal.

Electromotive force (e.m.f)

- Imagine that two ends of a water pipe filled with water are connected. Although filled with water, the water will not move or circle around the tube on its own. Suppose, you insert a pump in between and the pump pushes the water, then the water will start moving in the tube. Now the moving water can be used to produce some work. We can insert a water wheel in between the flow and make it to rotate and further use that rotation to operate machinery.

- Likewise if you take a circular copper wire, it is full of free electrons. However, they are not moving in a particular direction. You need some force to push the electrons to move in a direction.
- Devices like electric cells and other electrical energy sources act like pump, 'pushing' the charges to flow through a wire or conductor. The 'pumping' action of the electrical energy source is made possible by the 'electromotive force, (e.m.f). The electromotive force is represented as (ε). The e.m.f of an electrical energy source is the work done (W) by the source in driving a unit charge (q) around the complete circuit.

- ε = W/q where, W is the work done. The SI unit of e.m.f is joules per coulomb (JC-1) or volt (V). In other words the e.m.f of an electrical energy source is one volt if one joule of work is done by the source to drive one coulomb of charge completely around the circuit.

Potential difference (p.d)

- One does not just let the circuit connect one terminal of a cell to another. Often we connect, say a bulb or a small fan or any other electrical device in an electric circuit and use the electric current to drive them. This is how a certain amount of electrical energy provided by the cell or any othersource of electrical energy is converted into other form of energy like light, heat, mechanical and so on. For each coulomb of charge passing through the light bulb (or any appliances) the amount of electrical energy converted to other forms of energy depends on the potential difference across the electrical device or any electrical component in the circuit. The potential difference is represented by the symbol V.

$$V = W/q$$

- where, W is the work done, i.e., the amount of electrical energy converted into other forms of energy measured in joule and q is amount of charge measured in coulomb. The SI unit for both e.m.f and potential difference is the same i.e., volt (V).

- Voltmeter is an instrument used to measure the potential difference. To measure the potential difference across a component in a circuit, the voltmeter must be connected in parallel to it. Say, you want to measure the potential difference across a light bulb, you need to connect the voltmeter.

- Note the positive (+) red terminal of the voltmeter is connected to the positive side of circuit and the negative (–) black terminal is connected to the negative side of the circuit across a component (light bulb in the above illustration).

Resistance

- The Resistance (R) is the measure of opposition offered by the component to the flow of electric current through it. Different electrical components offer different electrical resistance.

- Metals like copper, aluminium etc., have very much negligible resistance. That is why they are called good conductors. On the other hand, materials like nicrome, tin oxide etc., offer high resistance to the electric current. We also have a category of materials called insulators; they do not conduct electric current at all (glass, polymer, rubber and paper). All these materials are needed in electrical circuits to have usefulness and safety in electrical circuits.

- The SI unit of resistance is ohm with the symbol (Ω). One ohm is the resistance of a component when the potential difference of one volt applied across the component drives a current of one ampere through it.

- We can also control the amount of flow of current in a circuit with the help of resistance. Such components used for providing resistance are called as 'resistors'. The resistors can be fixed or variable.

- Fixed resistors have fixed value of resistance, while the variable resistors like rheostats can be used to obtain desired value of resistance.

Electric circuit diagram

- To represent an electrical wiring or solve problem involving electric circuits, the circuit diagrams are made.
-
  The four main components of any circuits namely,

(i) cell,
(ii) connecting wire,
(iii) switch and
(iv) resistor or load are given above.

- In addition to the above many other electrical components are also used in an actualcircuit. A uniform system of symbols has been evolved to describe them. It is like learning a sign language, but useful in understanding circuit diagrams. Some common symbols in the electrical circuit.

Different electrical circuits

- Look at the two circuits, shown in Figure 4.11. In Figure A two bulbs are connected in series and in Figure B they are connected in parallel. Let us look at each of these separately.

Series circuits

- Let us first look at the current in a series circuit. In a series circuit the components are connected one after another in a single loop. In a series circuit there is only one pathway through which the electric charge flow. From the above we can know that the current I all along the series circuit remain same. That is in a series circuit the current in each point of the circuit is same.

Parallel circuits

- In parallel circuits, the components are connected to the e.m.f source in two or more loops. In a parallel circuit there is more than one path for the electric charge to flow. In a parallel circuit the sum of the individual current in each of the parallel branches is equal to the main current flowing into or out of the parallel branches. Also, in a parallel circuit the potential difference across separate parallel branches are same.

Effects of electric current

- When current flows in a circuit it exhibits various effects. The main effects are heating, chemical and magnetic effects.

- When the flow of current is 'resisted' generally heat is produced. This is because the electrons while moving in the wire or resistor suffer resistance. Work has to be done to overcome the resistance which is converted in to heat energy. This conversion of electrical energy into heating energy is called 'Joule heating' as this effect was extensively studied by the scientist Joule. This forms the principle of all electric heating appliances like iron box, water heater, toaster etc. Even connecting wires offer a small resistance to the flow of current. That is why almost all electrical appliances including the connecting wires are warm when used in an electric circuit.

- So far we have come across the cases in which only the electrons can conduct electricity. But, here when current passes through electrolyte like copper sulphate solution, both the electron and the positive copper ion conduct electricity. The process of conduction of electric current through solutions is called 'electrolysis'. The solution through which the electricity passes is called 'electrolyte'. The positive terminal inserted in to the solution is called 'anode' and the negative terminal 'cathode'. In the above experiment, copper wire is anode and carbon rod is cathode.

- Extremely weak electric current is produced in the human body by the movement of charged particles. These are called synaptic signals. These signals are produced by electro-chemical process. They travel between brain and the organs through nervous system.

Magnetic effect of electricity

- A wire or a conductor carrying current develops a magnetic field perpendicular to the direction of the flow of current. This is called magnetic effect of current. The discovery of the scientist Oersted and the ‘right hand thumb rule’ are detailed in the chapter on Magnetism and Electromagnetism in this book.

Direction of current is shown by the right hand thumb and the direction of magnetic field is shown by other fingers of the same right hand.

Types of current

- There are two distinct types of electric currents that we encounter in our everyday life: direct current (dc) and alternating current (ac).

Direct current

- We know current in electrical circuits is due to the motion of positive charge from higher potential to lower potential or electron from lower to higher electrical potential. Electrons move from negative terminal of the battery to positive of the battery. Battery is used to maintain a potential difference between the two ends of the wire. Battery is one of the sources for dc current. The dc is due to the unidirectional flow of electric charges. Some other sources of dc are solar cells, thermocouples etc.

- Many electronic circuits use dc. Some examples of devices which work on dc are cell phones, radio, electric keyboard, electric vehicles etc.

Alternating current

- If the direction of the current in a resistor or in any other element changes its direction alternately, the current is called an alternating current. The alternating current varies sinusoidally with time. This variation is characterised by a term called as frequency. Frequency is the number of complete cycle of variation, gone through by the ac in one second. In ac, the electrons do not flow in one direction because the potential of the terminals vary between high and low alternately. Thus, the electrons move to and fro in the wire carrying alternating current. It is diagrammatically represented.

- Domestic supply is in the form of ac. When we want to use an electrical device in dc, then we have to use a device to convert ac to dc. The device used to convert ac to dc is called rectifier. Colloquially it is called with several names like battery eliminator, dc adaptor and so on. The device used to convert dc into ac is called inverter.

Advantages of ac over dc

- The voltage of ac can be varied easily using a device called transformer. The ac can be carried over long distances using step up transformers. The loss of energy while distributing current in the form of ac is negligible. Direct current cannot be transmitted as such. The ac can be easily converted into dc and generating ac is easier than dc. The ac can produce electromagnetic induction which is useful in several ways.

Advantage of dc

- Electroplating, electro refining and electrotyping can be done only using dc. Electricity can be stored only in the form of dc.

- In India, the voltage and frequency of ac used for domestic purpose is 220 V and 50 Hz respectively where as in United States of America it is 110 V and 60 Hz respectively.

Dangers of electricity and precautions to be taken

- The following are the possible dangers as for as electric current is concerned.

Damaged insulation:

- Do not touch the bare wire. Use safety glows and stand on insulating stool or rubber slippers while handling electricity.

Overload of power sockets:

- Do not connect too many electrical devices to a single electrical socket.

Inappropriate use of electrical appliances:

- Always use the electrical appliances according to the power rating of the device like ac point, TV point, microwave oven point etc.

Environment with moisture and dampness:

- Keep the place, where there is electricity, out of moisture and wetness as it will lead to leakage of electric current.

Beyond the reach of children:

- The electrical sockets are to be kept away from the reach of little children who do not know the dangers of electricity.

- Resistance of a dry human body is about 1,00,000 ohm. Because of the presence of water in our body the resistance is reduced to few hundred ohm. Thus, a normal human body is a good conductor of electricity. Hence, precautions are required while doing electrical work.

Points to Remember

- Electric charge is a fundamental property of all matter.

- Like charges repel and unlike charges attract.
- Electric field (E) is represented by lines and arrowheads indicating the direction of the electric filed.
- Electric current flows from higher electric potential to lower electric potential.
- The movement of the positive charge is called as ‘conventional current’. The flow of electrons is termed as ‘electron current’.
- The opposition to the flow of current is called resistance.
- The SI unit of resistance is ohm with the symbol Ω.
- The four main components of any circuit are: cell, connecting wire, switch and resistor.
- In a parallel circuit there is more than one path for the electric charge to flow.
- The main effects when current flows in a circuit are heating, chemical and magnetic effects.
- There are two distinct types of electric currents that we encounter in our everyday life: direct current (dc) and alternating current (ac).

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Unit-4Electricity

INTRODUCTION

- You have already learnt about electricity in your lower classes, haven't you? Well, electricity deals with the flow of electric charges through a conductor. As a common term it refers to a form of energy. Th e usage of electric current in our day to day life is very important and indispensable. You are already aware of the fact that it is used in houses, educational institutions, hospitals, industries, etc. Therefore, its generation and transmission becomes a very crucial aspect of our life. In this lesson you will learn various terms used in understanding the concept of electricity. Eventually, you will realise the importance of the applications of electricity in day to day situations.

ELECTRIC CURRENT

- The motion of electric charges (electrons) through a conductor (e.g., copper wire) will constitute an electric current. Th is is similar to the flow of water through a channel or flow of air from a region of high pressure to a region of low pressure. In a similar manner, the electric current passes from the positive terminal (higher electric potential) of a battery to the negative terminal (lower electric potential) through a wire as shown in the Figure 4.1.

Definition of electric
Current

- Electric current is oft en termed as 'current' and it is represented by the symbol 'I'. It is defined as the rate of flow of charges in a conductor. Th is means that the electric current represents the amount of charges fl owing in any cross section of a conductor (say a metal wire) in unit time. If a net charge 'Q' passes through any cross section of a conductor in time 't', then the current fl owing through the conductor is

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

SI unit of electric current

- The SI unit of electric current is ampere (A). Th e current fl owing through a conductor is said to be one ampere, when a charge of one coulomb flows across any cross-section of a conductor, in one second.

$$\text{Hence, 1 ampere} = \frac{1\text{coulomb}}{1 second}$$

Solved Problem-1

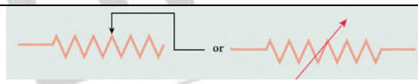
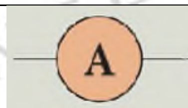
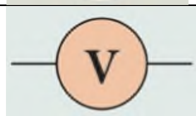
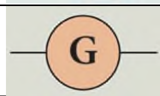
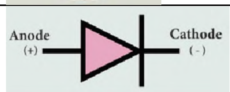
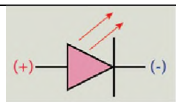
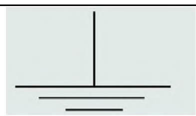
- A charge of 12 coulomb flows through a bulb in 5 second. What is the current through the bulb?

Solution:

Charge Q = 12 C, Time t = 5 s. Therefore,
current I= $\frac{Q}{t}$= $\frac{12}{5}$= 2.4 A

ELECTRIC CIRCUIT

- An electric circuit is a closed conducting loop (or) path, which has a network of electrical components through which electrons are able to flow. Th is path is made using electrical wires so as to connect an electric appliance to a source of electric charges (battery). A schematic diagram of an electric circuit comprising of a battery, an electric bulb, and a switch is given in Figure 4.2.

COMPONENT	USE OF THE COMPONENT	SYMBOL USED
Resistor	Used to fix the magnitude of the current through a circuit	
Variable resistor or Rheostat	Used to select the magnitude of the current through a circuit.	
Ammeter	Used to measure the current	
Voltmeter	Used to measure the potential diff erence.	
Galvanometer	Used to indicate the direction of current.	
A diode	A diode has various uses, which you will study in higher classes.	
Light Emitting Diode (LED)	A LED has various uses which you will study in higher classes.	
Ground connection	Used to provide protection to the electrical components. It also serves as a reference point to measure the electric potential.	

- In this circuit, if the switch is 'on', the bulb glows. If it is switched off, the bulb does not glow. Therefore, the circuit must be closed in order that the current passes through it. The potential difference required for the flow of charges is provided by the battery. The electrons flow from the negative terminal to the positive terminal of the battery.

- v *By convention, the direction of current is taken as the direction of flow of positive charge (or) opposite to the direction of flow of electrons*.

- Thus, electric current passes in the circuit from the positive terminal to the negative terminal.

Electrical components

- The electric circuit given in Figure 4.2 consists of different components, such as a battery, a switch and a bulb. All these components can be represented by using certain symbols. It is easier to represent the components of a circuit using their respective symbols.

The symbols that are used to represent some commonly used components are given in Table 4.1. The uses of these components are also summarized in the table.

ELECTRIC POTENTIAL AND POTENTIAL DIFFERENCE

- You are now familiar with the water current and air current. You also know that there must be a difference in temperature between two points in a solid for the heat to flow in it. Similarly, a difference in electric potential is needed for the flow of electric charges in a conductor. In the conductor, the charges will flow from a point in it, which is at a higher electric potential to a point, which is at a lower electric potential.

Electric Potential

- The electric potential at a point is defined as the amount of work done in moving a unit positive charge from infinity to that point against the electric force.

Electric Potential Difference

- The electric potential difference between two points is defined as the amount of work done in moving a unit positive charge from one point to another point against the electric force.
- Suppose, you have moved a charge Q from a point A to another point B. Let 'W' be the work done to move the charge from A to B. Then, the potential difference between the points A and B is given by the following expression:

Potential Difference (V) $= \frac{\boldsymbol{workdone(w)}}{\boldsymbol{charge\ (Q)}}$

- Potential difference is also equal to the difference in the electric potential of these two points. If VA and VB represent the electric potential at the points A and B respectively, then, the potential difference between the points A and B is given by:

$$V = V_A – V_B \text{ (if } V_A \text{ is more than } V_B)$$
$$V = V_B – V_A \text{ (if } V_B \text{ is more than } V_A)$$

Volt

- The SI unit of electric potential or potential difference is volt (V).
- The potential difference between two points is one volt, if one joule of work is done in moving one coulomb of charge from one point to another against the electric force.

$$1\text{volt} = \frac{\mathbf{1}\boldsymbol{joule}}{\mathbf{1}\text{coulomb}}$$

Solved Problem-2

- The work done in moving a charge of 10 C across two points in a circuit is 100 J. What is the potential difference between the points?

Solution:

Charge, Q = 10 C Work Done, W = 100 J
Potential Difference $V = \frac{W}{Q} = \frac{100}{10}$.
Therefore, V = 10 volt

OHM’S LAW

- A German physicist, Georg Simon Ohm established the relation between the potential difference and current, which is known as Ohm’s Law. This relationship can be understood from the following activity.

- According to Ohm’s law, at a constant temperature, the steady current ‘I’ flowing through a conductor is directly proportional to the potential difference ‘V’ between the two ends of the conductor.

$$I \propto V. \text{ Hence, } \frac{I}{V} = \text{constant.}$$

The value of this proportionality constant is found to be ,$\frac{1}{R}$
Therefore, $I = \frac{1}{R} V$

$$V = I R$$

- Here, R is a constant for a given material (say Nichrome) at a given temperature and is known as the resistance of the material. Since, the potential difference V is proportional to the current I, the graph between V and I is a straight line for a conductor, as shown in the Figure 4.5.

RESISTANCE OF A MATERIAL

- In Figure 4.4, a Nichrome wire was connected between X and Y. If you replace the Nichrome wire with a copper wire and conduct the same experiment, you will notice a different current for the same value of the potential difference across the wire. If you again replace the copper wire with an aluminium wire, you will get another value for the current passing through it. From equation (4.3), you have learnt that V/I must be equal to the resistance of the conductor used. The variations in the current for the same values of potential difference indicate that the resistance of different materials is different. Now, the primary question is, "what is resistance?"

- Resistance of a material is its property to oppose the flow of charges and hence the passage of current through it. *It is different for different materials*.

From Ohm's Law, $\frac{V}{I}$=R

- The resistance of a conductor can be defined as the ratio between the potential difference across the ends of the conductor and the current flowing through it.

Unit of Resistance

- The SI unit of resistance is ohm and it is represented by the symbol Ω.
- Resistance of a conductor is said to be one ohm if a current of one ampere flows through it when a potential difference of one volt is maintained across its ends.

$$1 \text{ ohm} =, \frac{1volt}{1ampre}$$

Solved Problem-3

- Calculate the resistance of a conductor through which a current of 2 A passes, when the potential difference between its ends is 30 V.

Solution:

Current through the conductor I = 2 A, Potential Difference V = 30 V
From Ohm's Law: R = $\frac{V}{I}$. Therefore, R = $\frac{30}{2}$= 15 Ω

ELECTRICAL RESISTIVITY & ELECTRICAL CONDUCTIVITY

Electrical Resistivity

- You can verify by doing an experiment that the resistance of any conductor 'R' is directly proportional to the length of the conductor 'L' and is inversely proportional to its area of cross section 'A'.

$$R \propto L, R \propto \frac{1}{A},$$
$$\text{Hence}, R \propto \frac{L}{A}$$

Therefore, $R = \rho \frac{L}{A}$

- Where, ρ (rho) is a constant, called as electrical resistivity or specific resistance of the material of the conductor.

From equation $\rho = \frac{Ra}{L}$

If L = 1 m, A = 1 m2 then, from the above equation ρ = R

- Hence, the electrical resistivity of a material is defined as the resistance of a conductor of unit length and unit area of cross section. Its unit is ohm metre.

- Electrical resistivity of a conductor is a measure of the resisting power of a specified material to the passage of an electric current. It is a constant for a given material.

Nichrome is a conductor with highest resistivity equal to 1.5 × 10–6 **Ω** m. Hence, it is used in making heating elements.

Conductance and Conductivity

- Conductance of a material is the property of a material to aid the flow of charges and hence, the passage of current in it. The conductance of a material is mathematically defined as the reciprocal of its resistance (R). Hence, the conductance 'G' of a conductor is given by

$$G = \frac{1}{R} \quad (4.5)$$

Its unit is ohm–1. It is also represented as 'mho'.

- The reciprocal of electrical resistivity of a material is called its electrical conductivity.

$$\sigma = \frac{1}{\rho} \quad (4.6)$$

- Its unit is ohm–1 metre–1. It is also represented as mho metre–1. The conductivity is a constant for a given material. Electrical conductivity of a conductor is a measure of its ability to pass the current through it. Some materials are good conductors of electric current. Example: copper, aluminium, etc. While some other materials are non-conductors of electric current (insulators). Example: glass, wood, rubber, etc.
- Conductivity is more for conductors than for insulators. But, the resistivity is less for conductors than for insulators. The resistivity of some commonly used materials is given in Table 4.2.

NATURE OF THE MATERIAL	MATERIAL	RESISTIVITY (Ω m)
Conductor	Copper	1.62×10^{-8}
	Nickel	6.84×10^{-8}
	Chromium	12.9×10^{-8}
Insulator	Glass	10^{10} to 10^{14}
	Rubber	10^{13} to 10^{16}

Solved Problem-4

- The resistance of a wire of length 10 m is 2 ohm. If the area of cross section of the wire is 2 × 10–7 m2, determine its (i) resistivity (ii) conductance and (iii) conductivity

Solution:

Given: Length, L = 10 m, Resistance, R = 2 ohm and Area, A = 2 × 10–7 m2

Resistivity, $\rho = \frac{RA}{L} = \frac{2\times 2 \times 10{-}7}{10}$ =

= $4 \times 10^{-8}\ \Omega$ m

Conductance, G = $\frac{1}{R} = \frac{1}{2}$ = 0.5 mho

Conductivity, $\sigma = \frac{1}{\rho} = \frac{1}{4 \times 10{-}8}$ = 0.25 × 10–8 mho m–1

SYSTEM OF RESISTORS

- So far, you have learnt how the resistance of a conductor affects the current through a circuit. You have also studied the case of the simple electric circuit containing a single resistor. Now in practice, you may encounter a complicated circuit, which uses a combination of many resistors. This combination of resistors is known as 'system of resistors' or 'grouping of resistors'. Resistors can be connected in various combinations. The two basic methods of joining resistors together are:

a) Resistors connected in series, and b) Resistors connected in parallel.

- In the following sections, you shall compute the effective resistance when many resistors having different resistance values are connected in series and in parallel.

Resistors in series

- A series circuit connects the components one after the other to form a 'single loop'. A series circuit has only one loop through which current can pass. If the circuit is interrupted at any point in the loop, no current can pass through the circuit and hence no electric appliances connected in the circuit will work. Series circuits are commonly used in devices such as flashlights. Thus, if resistors are connected end to end, so that the same current passes through each of them, then they are said to be connected in series.

- Let, three resistances R1, R2 and R3 be connected in series (Figure 4.6). Let the current flowing through them be I. According to Ohm's Law, the potential differences V1, V2 and V3 across R1, R2 and R3 respectively, are given by:

$V_1 = I R_1$
$V_2 = I R_2$
$V_3 = I R_3$

- The sum of the potential differences across the ends of each resistor is given by:

$$V = V_1 + V_2 + V_3$$

Using equations (4.7), (4.8) and (4.9), we get

$$V = I R_1 + I R_2 + I R_3 \quad (4.10)$$

- The effective resistor is a single resistor, which can replace the resistors effectively, so as to allow the same current through the electric circuit. Let, the effective resistance of the series-combination of the resistors, be R_S. Then,

$V = I R_S$ (4.11)

Combining equations (4.10) and (4.11), you get,

$$I R_S = I R_1 + I R_2 + I R_3$$
$$R_S = R_1 + R_2 + R_3 \quad (4.12)$$

- Thus, you can understand that when a number of resistors are connected in series, their equivalent resistance or effective resistance is equal to the sum of the individual resistances. When 'n' resistors of equal resistance R are connected in series, the equivalent resistance is 'n R'.

i.e., $R_S = n R$

- *The equivalent resistance in a series combination is greater than the highest of the individual resistances.*

Solved Problem-5

- Three resistors of resistances 5 ohm, 3 ohm and 2 ohm are connected in series with 10 V battery. Calculate their effective resistance and the current flowing through the circuit.

Solution:

$R_1 = 5\ \Omega$, $R_2 = 3\ \Omega$, $R_3 = 2\ \Omega$, $V = 10$ V
$Rs = R_1 + R_2 + R_3$, $Rs = 5 + 3 + 2 = 10$, hence $Rs = 10\ \Omega$
The current, $I = \frac{V}{Rs} = \frac{10}{10} = 1$ A

Resistances in Parallel

- A parallel circuit has two or more loops through which current can pass. If the circuit is disconnected in one of the loops, the current can still pass through the other loop(s). The wiring in a house consists of parallel circuits.

- Consider that three resistors R1, R2 and R3 are connected across two common points A and B. The potential difference across each resistance is the same and equal to the potential difference between A and B. This is measured using the voltmeter. The current I arriving at A divides into three branches I1, I2 and I3 passing through R1, R2 and R3 respectively.

According to the Ohm's law, you have,

$I1 = \frac{V}{R1}$ R_1R_2 R_3

$I2 = \frac{V}{R2}$

$I3 = \frac{V}{R3}$

The total current through the circuit is given by

$I = I_1 + I_2 + I_3$

Using equations (4.13), (4.14) and (4.15), you get

$I = \frac{V}{R1} + \frac{V}{R2} + \frac{V}{R3}$

Let the effective resistance of the parallel combination of resistors be RP. Then,

$I = \frac{V}{Rp}$

Combining equations (4.16) and (4.17), you have

$\frac{V}{Rp} = \frac{V}{R1} + \frac{V}{R2} + \frac{V}{R3}$

$\frac{1}{Rp} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$

- Thus, when a number of resistors are connected in parallel, the sum of the reciprocals of the individual resistances is equal to the reciprocal of the effective or equivalent resistance. When 'n' resistors of equal resistances R are connected in parallel, the equivalent resistance is $\frac{R}{n}$.

$$\frac{1}{Rp}=\frac{1}{R}+\frac{1}{R}+\frac{1}{R}...+\frac{1}{R}=\frac{n}{R}.$$

Hence, $R_p = \frac{R}{n}$

- The *equivalent resistance in a parallel combination is less than the lowest of the individual resistances*.

Series Connection of Parallel Resistors

- If you consider the connection of a set of parallel resistors that are connected in series, you get a series – parallel circuit. Let R1 and R2 be connected in parallel to give an effective resistance of RP1. Similarly, let R3 and R4 be connected in parallel to give an effective resistance of RP2. Then, both of these parallel segments are connected in series (Figure 4.8).

Using equation (4.18), you get

$$\frac{1}{Rp1}=\frac{1}{R1}+\frac{1}{R2}$$

$$\frac{1}{Rp}=\frac{1}{R3}+\frac{1}{R4}$$

Finally, using equation (4.12), the net effective resistance is given by Rtotal= RP1 + RP2

Parallel Connection of Series Resistors

- If you consider a connection of a set of series resistors connected in a parallel circuit, you get a parallel-series circuit. Let R1 and R2 be connected in series to give an effective resistance of RS1. Similarly, let R3 and R4 be connected in series to give an effective resistance of RS2. Then, both of these serial segments are connected in parallel (Figure 4.9).

S.no	CRITERIA	SERIES	PARALLEL
1	Equivalent resistance	More than the highest resistance.	Less than the lowest resistance.
2	Amount of current	Current is less as effective resistance is more.	Current is more as effective resistance is less.
3	Switching ON / OFF	If one appliance is disconnected, others also do not work.	If one appliance is disconnected, others will work

			independently.

Using equation (4.12), you get

RS1 = R1 + R2, RS2 = R3 + R4

Finally, using equation (4.18), the net effective resistance is given by

$\frac{1}{Rtotal} = \frac{1}{Rs1} + \frac{1}{Rs2}$

Comparison between series and parallel connections

- The difference between series and parallel circuits may be summed as follows in Table 4.3

HEATING EFFECT OF CURRENT

- Have you ever touched the motor casing of a fan, which has been used for a few hours continuously? What do you observe? The motor casing is warm. This is due to the heating effect of current. The same can be observed by touching a bulb, which was used for a long duration. Generally, a source of electrical energy can develop a potential difference across a resistor, which is connected to that source. This potential difference constitutes a current through the resistor. For continuous drawing of current, the source has to continuously spend its energy. A part of the energy from the source can be converted into useful work and the rest will be converted into heat energy. Thus, the passage of electric current through a wire, results in the production of heat. This phenomenon is called heating effect of current. This heating effect of current is used in devices like electric heater, electric iron, etc.

Joule's Law of Heating

- Let 'I' be the current flowing through a resistor of resistance 'R', and 'V' be the potential difference across the resistor. The charge flowing through the circuit for a time interval 't' is 'Q'.

- The work done in moving the charge Q across the ends of the resistor with a potential difference of V is VQ. This energy spent by the source gets dissipated in the resistor as heat. Thus, the heat produced in the resistor is:

$$H = W = VQ$$

- You know that the relation between the charge and current is Q = I t. Using this, you get

$$H = V\,I\,t \quad (4.19)$$

- From Ohm's Law, V = I R. Hence, you have

$$H = I^2 R t \quad (4.20)$$

- This is known as Joule's law of heating.

Joule's law of heating states that the heat produced in any resistor is:

- ü directly proportional to the square of the current passing through the resistor.
- ü directly proportional to the resistance of the resistor.
- ü directly proportional to the time for which the current is passing through the resistor.

Applications of Heating Effect

1. Electric Heating Device:

- The heating effect of electric current is used in many home appliances such as electric iron, electric toaster, electric oven, electric heater, geyser, etc. In these appliances Nichrome, which is an alloy of Nickel and Chromium is used as the heating element. Why? Because:

(i) it has high resistivity, (ii) it has a high melting point, (iii) it is not easily oxidized.

2. Fuse Wire:

- The fuse wire is connected in series, in an electric circuit. When a large current passes through the circuit, the fuse wire melts due to Joule's heating effect and hence the circuit gets disconnected. Therefore, the circuit and the electric appliances are saved from any damage. The fuse wire is made up of a material whose melting point is relatively low.

3. Filament in bulbs:

- In electric bulbs, a small wire is used, known as filament. The filament is made up of a material whose melting point is very high. When current passes through this wire, heat is produced in the filament. When the filament is heated, it glows and gives out light. Tungsten is the commonly used material to make the filament in bulbs.

Solved Problem-6

- An electric heater of resistance 5 Ω is connected to an electric source. If a current of 6 A flows through the heater, then find the amount of heat produced in 5 minutes.

Solution:

- Given resistance R = 5 Ω, Current I = 6 A, Time t = 5 minutes = 5 × 60 s = 300 s

Amount of heat produced, H = I2Rt, H = 62 × 5 × 300. Hence, H = 54000 J

ELECTRIC POWER

- In general, power is defined as the rate of doing work or rate of spending energy. Similarly, the electric power is defined as the rate of consumption of electrical energy. It represents the rate at which the electrical energy is converted into some other form of energy.

- Suppose a current 'I' flows through a conductor of resistance 'R' for a time 't', then the potential difference across the two ends of the conductor is 'V'. The work done 'W' to move the charge across the ends of the conductor is given by the equation (4.19) as follows:

$$W = V\,I\,t, \text{ Power } P = \frac{work}{\text{Time}} = \frac{VIt}{t}$$

$$P = V\,I \quad (4.21)$$

- Thus, the electric power is the product of the electric current and the potential difference due to which the current passes in a circuit.

Unit of Electric Power

- The SI unit of electric power is watt. When a current of 1 ampere passes across the ends of a conductor, which is at a potential difference of 1 volt, then the electric power is

P = 1 volt × 1 ampere = 1 watt

- Thus, one watt is the power consumed when an electric device is operated at a potential difference of one volt and it carries a current of one ampere. A larger unit of power, which is more commonly used is kilowatt.

HORSE POWER:
The horse power (hp) is a unit in the foot-pound-second (fps) or English system, sometimes used to express the electric power. It is equal to 746 watt.

Consumption of electrical energy

- Electricity is consumed both in houses and industries. Consumption of electricity is based on two factors: (i) Amount of electric power and (ii) Duration of usage. Electrical energy consumed is taken as the product of electric power and time of usage. For example, if 100 watt of electric power is consumed for two hours, then the power consumed is 100 × 2 = 200 watt hour. Consumption of electrical energy is measured and expressed in watt hour, though its SI unit is watt second. In practice, a larger unit of electrical energy is needed. This larger unit is kilowatt hour (kWh). One kilowatt hour is otherwise known as one unit of electrical energy. One kilowatt hour means that an electric power of 1000 watt has been utilized for an hour. Hence,

1 kWh = 1000 watt hour = 1000 × (60 × 60) watt second = 3.6 × 106 J

DOMESTIC ELECTRIC CIRCUITS

- The electricity produced in power stations is distributed to all the domestic and industrial consumers through overhead and underground cables. The diagram, which shows the general scheme of a domestic electric circuit, is given in Figure 4.10.

- In our homes, electricity is distributed through the domestic electric circuits wired by the electricians. The first stage of the domestic circuit is to bring the power supply to the main-box from a distribution panel, such as a transformer. The important components of the main-box are: (i) a fuse box and (ii) a meter. The meter is used to record the consumption of electrical energy. The fuse box contains either a fuse wire or a miniature circuit breaker (MCB). The function of the fuse wire or a MCB is to protect the house hold electrical appliances from overloading due to excess current.

- You have learnt about a fuse wire in section 4.8.2. An MCB is a switching device, which can be activated automatically as well as manually. It has a spring attached to the switch, which is attracted by an electromagnet when an excess current passes through the circuit. Hence, the circuit is broken and the protection of the appliance is ensured. represents a fuse and an MCB.

- The electricity is brought to houses by two insulated wires. Out of these two wires,one wire has a red insulation and is called the 'live wire'. The other wire has a black insulation and is called the 'neutral wire'. The electricity supplied to your house is actually an alternating current having an electric potential of 220 V. Both, the live wire and the neutral wire enter into a box where the main fuse is connected with the live wire. After the electricity meter, these wires enter into the main switch, which is used to discontinue the electricity supply whenever required. After the main switch, these wires are connected to live wires of two separate circuits. Out of these two circuits, one circuit is of a 5 A rating, which is used to run the electric appliances with a lower power rating, such as tube lights, bulbs and fans. The other circuit is of a 15 A rating, which is used to run electric appliances with a high power rating, such as air-conditioners, refrigerators, electric iron and heaters.

- It should be noted that all the circuits in a house are connected in parallel, so that the disconnection of one circuit does not affect the other circuit. One more advantage of the parallel connection of circuits is that each electric appliance gets an equal voltage.

In India, domestic circuits are supplied with an alternating current of potential 220/230V and frequency 50 Hz. In countries like USA and UK, domestic circuits are supplied with an alternating current of potential 110/120 V and frequency 60 Hz.

Overloading and Shortcircuiting

- The fuse wire or MCB will disconnect the circuit in the event of an overloading and short circuiting. Over loading happens when a large number of appliances are connected in series to the same source of electric power. This leads to a flow of excess current in the electric circuit.

- When the amount of current passing through a wire exceeds the maximum permissible limit, the wires get heated to such an extent that a fire may be caused. This is known as overloading. When a live wire comes in contact with a neutral wire, it causes a 'short circuit'. This happens when the insulation of the wires get damaged due to temperature changes or some external force. Due to a short circuit, the effective resistance in the circuit becomes very small, which leads to the flow of a large current through the wires. This results in heating of wires to such an extent that a fire may be caused in the building.

Earthing

- In domestic circuits, a third wire called the earth wire having a green insulation is usually connected to the body of the metallic electric appliance. The other end of the earth wire is connected to a metal tube or a metal electrode, which is buried into the Earth. This wire provides a low resistance path to the electric current. The earth wire sends the current from the body of the appliance to the Earth, whenever a live wire accidentally touches the body of the metallic electric appliance. Thus, the earth wire serves as a protective conductor, which saves us from electric shocks.

LED BULB

- An LED bulb is a semiconductor device that emits visible light when an electric current passes through it. The colour of the emitted light will depend on the type of materials used. With the help of the chemical compounds like Gallium Arsenide and Gallium Phosphide, the manufacturer can produce LED bulbs that radiates red, green, yellow and orange colours. Displays in digital watches and calculators, traffic signals, street lights, decorative lights, etc., are some examples for the use of LEDs.

Seven Segment Display

- A ‘Seven Segment Display’ is the display device used to give an output in the form of numbers or text. It is used in digital meters, digital clocks, micro wave ovens, etc. It consists of 7 segments of LEDs in the form of the digit 8.These seven LEDs are named as a, b, c, d, e, f and g (Figure 4.12). An extra 8th LED is used to display a dot.

Merits of a LED bulb

1. As there is no filament, there is no loss of energy in the form of heat. It is cooler than the incandescent bulb.

2. In comparison with the fluorescent light, the LED bulbs have significantly low power requirement.

3. It is not harmful to the environment.

4. A wide range of colours is possible here.

5. It is cost-efficient and energy efficient.

6. Mercury and other toxic materials are not required.

One way of overcoming the energy crisis is to use more LED bulbs.

LED TELEVISION

- LED Television is one of the most important applications of Light Emitting Diodes. An LED TV is actually an LCD TV (Liquid Crystal Display) with LED display. An LED display uses LEDs for backlight andan array of LEDs act as pixels. LEDs emitting white light are used in monochrome (black and white) TV; Red, Green and Blue (RGB) LEDs are used in colour television. The first LED television screen was developed by James P. Mitchell in 1977. It was a monochromatic display. But, after about three decades, in 2009, SONY introduced the first commercial LED Television.

Advantages of LED television

v It has brighter picture quality.

v It is thinner in size.

v It uses less power and consumes very less energy.

v Its life span is more.

v It is more reliable.

Points to Remember

- The magnitude of current is defined as the rate of flow of charges in a conductor.
- The SI unit of electric current is ampere (A).
- The SI unit of electric potential and potential difference is volt (V).
- An electric circuit is a network of electrical components, which forms a continuous and closed path for an electric current to pass through it.
- The parameters of conductors like its length, area of cross-section and material, affect the resistance of the conductor.
- SI unit of electrical resistivity is ohm metre. The resistivity is a constant for a given material.
- The reciprocal of electrical resistivity of a material is called its electrical conductivity.
  $\sigma = \frac{1}{\rho}$
- The passage of electric current through a wire results in the production of heat.
- This phenomenon is called heating effect of current.
- One horse power is equal to 746 watts.
- The function of a fuse wire or a MCB is to protect the house hold electrical appliances from excess current due to overloading or a short circuit.

11th std (Term-I)
Unit - 4
WORK, ENERGY AND POWER

INTRODUCTION

- The term work is used in diverse contexts in daily life. It refers to both physical as well as mental work. In fact, any activity can generally be called as work. But in Physics, the term work is treated as a physical quantity with a precise definition. Work is said to be done by the force when the force applied on a body displaces it. To do work, energy is required. In simple words, energy is defined as the ability to do work. Hence, work and energy are equivalents and have same dimension. Energy, in Physics exists in different forms such as mechanical, electrical, thermal, nuclear and so on. Many machines consume one form of energy and deliver energy in a different form. In this chapter we deal mainly with mechanical energy and its two types namely kinetic energy and potential energy. The next quantity in this sequence of discussion is the rate of work done or the rate of energy delivered. The rate of work done is called power. A powerful strike in cricket refers to a hit on the ball at a fast rate. This chapter aims at developing a good understanding of these three physical quantities namely work, energy and power and their physical significance.

WORK

- Let us consider a force ($\vec{F}$), acting on a body which moves it by a displacement in some direction ($d\vec{r}$)
- The expression for work done (w) by the force on the body is mathematically written as,

$$W = \vec{F} \cdot d\vec{r}$$

- Here, the product $\vec{F} \cdot d\vec{r}$ is a scalar product(or dot product). The scalar product of two vectors is a scalar. Thus, work done is a scalar quantity. It has only magnitude and no direction. In SI system, unit of work done is N m (or) joule (J). Its dimensional formula is $[ML^2T^{-2}]$.

The equation (4.1) is,

$$W = Fdr\cos\theta$$

- which can be realised using (as $\vec{a} \cdot \vec{b} = ab\cos\theta$) where, θ is the angle between applied force and the displacementof the body.

- The work done by the force depends on the force (F), displacement (dr) and the angle (θ) between themWork done is zero in the following cases.

- When the force is zero (F = 0). For example, a body moving on a horizontal smooth frictionless surface will continue to do so as no force (not even friction) is acting along the plane. (This is an ideal situation.)

- When the displacement is zero (dr= 0). For example, when force is applied ona rigid wall it does not produce anydisplacement. Hence, the work done iszero

- When the force and displacement are perpendicular (**θ** = 90o) to each other. when a body moves on a horizontaldirection, the gravitational force (mg)does no work on the body, since it acts atright angles to the displacement as shownin Figure 4.3(b). In circular motion thecentripetal force does not do work on theobject moving on a circle as it is alwaysperpendicular to the displacement.

- For a given force (F) and displacement (dr), the angle (θ) between them decides the value of work done as consolidated.

- There are many examples for the negative work done by a force. In a football game, the goalkeeper catches the ball coming towards him by applying a force such that the force is applied in a direction opposite to that of the motion of the ball till it comes to rest in his hands. During the time of applying the force, he does a negative work on the ball. We will discuss many more situations of negative work further in this unit.

- A box is pulled with a force of 25 N to produce a displacement of 15 m. If the angle between the force and displacement is 30o, find the work done by the force.

  - Force, F = 25 N
  - Displacement, dr = 15 m
  - Angle between F and dr, θ = 30^o

Angle (θ)	cosθ	Work
θ = 0°	1	Positive, Maximum
0° < θ < 90° (acute)	0 < cosθ < 1	Positive
θ = 90° (right angle)	0	Zero
90° < θ < 180°	-1 < cosθ < 0	Negative
θ = 180°	-1	Negative, Maximum

Work done, $W = Fdr \cos q$

$$W = 25 \times 15 \times \cos 30 = 25 \times 15 \times \frac{\sqrt{3}}{2}$$

$$W = 324.76 \text{ J}$$

Work done by a constant force

- When a constant force F acts on a body, the small work done (dW) by the force in producing a small displacement dr is given by the relation,

$$dW = (F\cos\theta)\,dr$$

- The total work done in producing a displacement from initial position r_i to final position r_f is,

$$W = \int_{r_1}^{r_f} dW$$

$$W = \int_{r_f}^{r_f} (F\cos\theta)\,dr = (F\cos\theta)\int_{r_f}^{r_f} dr$$

$$= (F\cos\theta)(r_f - r_i)$$

- The graphical representation of the work done by a constant force . The area under the graph shows the work done by the constant force.

- An object of mass 2 kg falls from a height of 5 m to the ground. What is the work done by the gravitational force on the object? (Neglect air resistance; Take g = 10 m s^{-2})

- In this case the force acting on the object is downward gravitational force $m\vec{g}$. This is a constant force. Work done by gravitational force is

$$W = \int_{r_1}^{r_f} \vec{F}.d\vec{r}$$

$$W = (\cos\theta)\int_{r_1}^{r_f} d\vec{r} = (mg.\cos\theta)(r_f - r_1)$$

The object also moves downward which is in the direction of gravitational force $\vec{F} = m\vec{g}$ as shown in figure. Hence, the angle between them is θ = 0°; cos θ =1 and the displacement, $(r_f - r_1)$ =5m.

$$W = mg\,(r_f - r_1)$$

$$W = 2 \times f \times 5 = f$$

The work done by the gravitational force on the object is positive.

- An object of mass *m*=1 kg is sliding from top to bottom in the frictionless inclined plane of inclination angle θ=30°and the length of inclined plane is 10 m as shown in the figure. Calculate the work done by gravitational force and normal force on the object. Assume acceleration due to gravity, g = 10 m s-2

- We calculated in the previous chapter that the acceleration experienced by the object in the inclined plane as gsinθ.According to Newton's second law, the force acting on the mass along the inclined plane F = mgsinθ. Note that this force is constant throughout the motion of the mass. The work done by the parallel component of gravitational force (mg sinθ) is given by

$$W = \vec{F}.d\vec{r} = Fdr\cos\phi$$

- where ϕ is the angle between the force (mg sin θ) and the direction of motion (dr). In this case, force (mg sin θ) and the displacement $(d\vec{r})$ are in the same direction. Hence $\phi = and \cos\phi = 1$

W = F dr = (mgsinθ) (dr)

(dr = length of the inclined place)

$$W = 1 \times 10 \times \sin(30°) \times 10 = 100 \times \frac{1}{2} = 50J$$

- The component mg cosθand the normal force *N* are perpendicular to the direction of motion of the object, so they do notperform any work.
- If an object of mass 2 kg is thrown up from the ground reaches a height of 5 m and falls back to the Earth (neglect the air resistance). Calculate

1. The work done by gravity when the object reaches 5 m height
2. The work done by gravity when the object comes back to Earth
3. Total work done by gravity both in upward and downward motion and mention the physical significance of the result.

- When the object goes up, the displacement points in the upward direction whereas the gravitational force acting on the object points in downward direction. Therefore, the angle between gravitational force and displacement of the object is 180°.

The work done by gravitational force in the upward motion.

Given that Δr =5m and F =mg

$$W_{up} = F\Delta r\cos\theta = mg\Delta r\cos 180^o$$

$$W_{up} = 2 \times 10 \times 5 \times (-1) = -100\ joule.$$
$$[\cos 180^o = -1]$$

- When the object falls back, both the gravitational force and displacement of the object are in the same direction. This implies that the angle between gravitational force and displacement of the object is 0°.

$$W_{down} = F\Delta r \cos 0^o$$
$$W_{down} = 2 \times 10 \times 5 \times (1) = 100\ joule$$
$$[\cos 0^o = 1]$$

The total work done by gravity in the entire trip (upward and downward motion).

$$W_{total} = W_{up} + W_{down}$$
$$= -100\ joule + 100\ joule = 0$$

- It implies that the gravity does not transfer any energy to the object. When the object is thrown upwards, the energy is transferred to the object by the external agency, which means that the object gains some energy. As soon as it comes back and hits the Earth, the energygained by the object is transferred to the surfaceof the Earth (i.e., dissipated to the Earth).

A weight lifter lifts a mass of 250 kg with a force 5000 N to the height of 5 m.

1. What is the workdone by the weight lifter?
2. What is the workdone by the gravity?
3. What is the net workdone on the object?

- When the weight lifter lifts the mass, force and displacement are in the same direction, which means that the angle between them $\theta = 0^o$. Therefore, the work done by the weight lifter,

$$W_{weight\ lifter} = F_w h \cos\theta = F_w h(\cos 0^0)$$
$$= 5000 \times 5 \times (1) = 25,000\ joule = 25kJ$$

- When the weight lifter lifts the mass, the gravity acts downwards which means that the force and displacement are in opposite direction. Therefore, the angle between them $\theta = 180^o$

$$W_{gravity} = F_g h \cos\theta = mgh(\cos 180^o)$$

$$= 250 \times 10 \times 5 \times (-1)$$
$$= -12,500\, joule = -12.5kJ$$

- The net work done (or total work done) on the object

$$\mathrm{W_{net}} = \mathrm{W_{weight\ lifter}} + \mathrm{W_{gravity}}$$
$$= 25kJ - 12.5kJ = +12.5kJ$$

Work done by a variable force

- When the component of a variable force F acts on a body, the small work done (dW) by the force in producing a small displacement dr is given by the relation

dW=F cos θ dr
[F cos θ is the component of the variable force F]

- where, F and θ are variables. The total work done for a displacement from initial positionr_i to final position r_f is given by the relation,

$$W = \int_{r_i}^{r_f} dW = \int_{r_i}^{r_f} F \cos\theta\, dr$$

- A graphical representation of the work done by a variable force.The area under the graph is the work done by the variable force.

- A variable force F = k x^2acts on a particle which is initially at rest. Calculate the work done by the force during the displacement of the particle from x = 0 m to x =4 m. (Assume the constant k =1 N m^{-2})

Work done,

$$W = \int_{x_i}^{x_f} F(x)dx = k\int_{0}^{4} x^2 dx = \frac{64}{3} Nm$$

- Energy is defined as the capacity to do work. In other words, work done is the manifestation of energy. That is why work and energy have the same dimension (ML^2T^{-2})

- The important aspect of energy is that for an isolated system, the sum of all forms of energy i.e., the total energy remains the same in any process irrespective of whatever internal changes may take place. This means that the energy disappearing in one form reappears in another form. This is known as the law of conservation of energy. In this chapter we shall take up only the mechanical energy for discussion.

In a broader sense, mechanical energy is classified into two types

1. Kinetic energy
2. Potential energy

- The energy possessed by a body due to its motion is called kinetic energy. The energy possessed by the body by virtue of its position is called potential energy.
-
- The SI unit of energy is the same as that of work done i.e., N m (or) joule (J). The dimension of energy is also the same as that of work done. It is given by $[ML^2T^{-2}]$. The other units of energy and their SI equivalent values.

SI equivalent of other units of energy

Unit	Equivalent in joule
1 erg (CGS unit)	10^{-7} J
1 electron volt (eV)	1.6×10^{-19} J
1 calorie (cal)	4.186 J
1 kilowatt hour (kWh)	3.6×10^{6} J

Kinetic energy

- Kinetic energy is the energy possessed by a body by virtue of its motion. All moving objects have kinetic energy. A body that is in motion has the ability to do work. For example a hammer kept at rest on a nail does not push the nail into the wood. Whereas the same hammer when it strikes the nail, draws the nail into the wood. Kinetic energy is measured by the amount of work that the body can perform before it comes to rest. The amount of work done by a moving body depends both on the mass of the body and the magnitude of its velocity. A body which is not in motion does not have kinetic energy.

Work–Kinetic Energy Theorem

- Work and energy are equivalents. This is true in the case of kinetic energy also. To prove this, let us consider a body of mass m at rest on a frictionless horizontal surface.

- The work (W) done by the constant force (F) for a displacement (s) in the same\ direction is,

$$W=Fs$$

The constant force is given by the equation,

$$F=ma$$

$$V^2=u^2+2as$$

$$a=\frac{V^2-u^2}{2s}$$

Substituting for a in equation

$$F=m\left(\frac{V^2-u^2}{2s}\right)$$

$$W=m\left(\frac{V^2}{2s}S\right)-m\left(\frac{u^2}{2s}S\right)$$

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

The term $\left(\frac{1}{2}mv^2\right)$ in the above equation is the kinetic energy of the body of mass (m) moving with velocity (v).

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

Kinetic energy of the body is always positive. From equations

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

Thus, $W=\Delta KE$

- The expression on the right hand side (RHS) of equation (4.12) is the change in kinetic energy (ΔKE) of the body.

- This implies that the work done by the force on the body changes the kinetic energy of the body. This is called work-kinetic energy theorem.

The work-kinetic energy theorem implies the following.

1. If the work done by the force on thebody is positive then its kinetic energy increases.
2. If the work done by the force on the body is negative then its kinetic energy decreases.

3. If there is no work done by the force on the body then there is no change in its kinetic energy, which means that the body has moved at constant speed provided its mass remains constant.

Relation between Momentum and Kinetic Energy

· Consider an object of mass m moving with a velocity $\vec{v}$. Then its linear momentum is $\vec{p}=m\vec{v}$ and its kinetic energy, $KE=\frac{1}{2}mv^2$.

$$KE=\frac{1}{2}mv^2=\frac{1}{2}m\left(\vec{v}.\vec{v}\right)$$

Multiplying both the numerator and denominator of equation

$$KE=\frac{1}{2}\frac{m^2\left(\vec{v}.\vec{v}\right)}{m}$$

$$=\frac{1}{2}\frac{\left(m\vec{v}\right).\left(m\vec{v}\right)}{m}\left[\vec{p}=m\vec{v}\right]$$

$$=\frac{1}{2}\frac{\vec{p}.\vec{p}}{m}$$

$$=\frac{p^2}{2m}$$

$$KE=\frac{p^2}{2m}$$

· where $|\vec{p}|$ is the magnitude of the momentum. The magnitude of the linear momentum can be obtained by

$$|\vec{p}|=p=\sqrt{2m(KE)}$$

· Note that if kinetic energy and mass are given, only the magnitude of the momentum can be calculated but not the direction of momentum. It is because the kinetic energy and mass are scalars.

Two objects of masses 2 kg and 4 kg are moving with the same momentum of 20 kg m s^{-1}.

1. Will they have same kinetic energy?
2. Will they have same speed?

The kinetic energy of the mass is given by $KE = \frac{p^2}{2m}$

For the object of mass 2 kg, kineticenergy is

$$KE_1 = \frac{(20)^2}{2 \times 2} = \frac{400}{4} = 100J$$

For the object of mass 4 kg, kinetic energy is

$$KE_2 = \frac{(20)^2}{2 \times 4} = \frac{400}{8} = 50J$$

- Note that $KE_1 \neq KE_2$ i.e., even though both are having the same momentum, the kinetic energy of both masses is not the same. The kinetic energy of the heavier object has lesser kinetic energy than smaller mass. It is because the kinetic energy is inversely proportional to the mass $\left(KE \propto \frac{1}{m}\right)$ for a given momentum.

As the momentum, *p* = *mv*, the two objects will not have same speed.

Potential Energy

- The potential energy of a body is associated with its position and configuration with respect to its surroundings. This is because the various forces acting on the body also depends on position and configuration.

- "Potential energy of an object at a point Pis defined as the amount of work done by an external force in moving the object at constant velocity from the point O (initial location) to the point P (final location). At initial point O potential energy can be taken as zero.

Mathematically, potential energy is defined as $U = \int \vec{F}_a . d\vec{r}$

- where the limit of integration ranges from initial location point O to final location point P.

We have various types of potential energies. Each type is associated with a particular force.

1. The energy possessed by the body due to gravitational force gives rise to gravitational potential energy

2. The energy due to spring force and other similar forces give rise to elastic potential energy.
3. The energy due to electrostatic force on charges gives rise to electrostatic potential energy.

We will learn more about conservativeforces in the section. Now, we continueto discuss more about gravitational potential energy and elastic potential energy.

Potential energy near the surface of theEarth

- The gravitational potential energy (U) at some height *h* is equal to the amount of work required to take the object from ground to that height *h* with constant velocity.

- Let us consider a body of mass *m* being moved from ground to the height h against the gravitational force.

- The gravitational force $\vec{F}_g$ acting on the body is, $\vec{F}_g = -mg\hat{j}$ (as the force is in y direction, unit vector $\hat{j}$ is used). Here, negative sign implies that the force is acting vertically downwards. In order to move the body without acceleration (or with constant velocity), an external applied force $\vec{F}_a$ equal in magnitude but opposite to that of gravitational force $\vec{F}_g$ has to be applied on the body i.e., $\vec{F}_a = \vec{F}_g$. This implies that = $\vec{F}_a = +mg\hat{j}$. The positive sign implies that the applied force is in vertically upward direction. Hence, when the body is lifted up its velocity remains unchanged and thus its kinetic energy also remains constant.

The gravitational potential energy (U) at some height *h* is equal to the amount of work required to take the object from the ground to that height *h*.

$$U = \int \vec{F}_a . d\vec{r} = \int_0^h |\vec{F}_a||d\vec{r}|\cos\theta$$

Since the displacement and the applied force are in the same upward direction, the angle between them, $\theta = 0^o$. Hence, cos0º=1 and $|\vec{F}_a| = mg$ and $|d\vec{r}| = dr$.

$$U = mg\int_0^h dr$$

$$U = mg\left[r\right]_0^h = mgh$$

- Note that the potential energy stored in the object is defined through work done by the external force which is positive.Physically this implies that the agencywhich is applying the external force is transferring the energy to the object which is then stored as potential energy. If the object is allowed to fall from a height *h* then the stored potential energy is converted into kinetic energy.

An object of mass 2 kg is taken to a height 5 m from the ground $(g = 10\,ms^{-2})$.

1. Calculate the potential energy stored in the object.
2. Where does this potential energy come from?
3. What external force must act to bring the mass to that height?
4. What is the net force that acts on the object while the object is taken to the height 'h'?

- The potential energy $U = mgh = 2 \times 10 \times 5 = 100$ J Here the positive sign implies that the energy is stored on the mass

- This potential energy is transferred from external agency which applies the force on the mass.

The external applied force $\vec{F}_a$ which takes the object to the height 5 m is $\vec{F}_a = -\vec{F}_g$.

$$\vec{F}_a = -\left(-mg\hat{j}\right) = mg\hat{j}$$

where, $\hat{j}$ represents unit vector along vertical upward direction.

From the definition of potential energy, the object must be moved at constant velocity. So the net force acting on the object is zero.

$$\vec{F}_g + \vec{F}_a = 0$$

Elastic Potential Energy

- When a spring is elongated, it develops a restoring force. The potential energy possessed by a spring due to a deforming force which stretches or compresses the spring is termed as elastic potential energy. The work done by the applied force against the restoring force of the spring is stored as the elastic potential energy in the spring.

- Consider a spring-mass system. Let us assume a mass, *m* lying on a smooth horizontal. Here, $x = 0$ is the equilibrium position. One end of the spring is attached to a rigid wall and the other end to the mass.

- As long as the spring remains in equilibrium position, its potential energy is zero. Now an external force $\vec{F}_a$ is applied so that it is stretched by a distance (x) in the direction of the force.

- There is a restoring force called spring force $\vec{F}_s$ developed in the spring which tries to bring the mass back to its original position. This applied force and the spring force are equal in magnitude but opposite in direction i.e., $\vec{F}_a = -\vec{F}_s$ According Hooke's law, the restoring force developed in the spring is

$$\vec{F}_s = -k\vec{x}$$

- The negative sign in the above expression implies that the spring force is always opposite to that of displacement $\vec{x}$ and k is the force constant. Therefore applied force is $\vec{F}_a = +k\vec{x}$. The positive sign implies that the applied force is in the direction of displacement $\vec{x}$. The spring force is an example of variable force as it depends on the displacement $\vec{x}$. Let the spring be stretched to a small distance

$d\vec{x}$.The work done by the applied force on the spring to stretch it by a displacement $\vec{x}$ is stored as elastic potential energy.

$$U = \int \vec{F}_a . d\vec{r} = \int_0^x |\vec{F}_a| |d\vec{r}| \cos\theta$$

$$= \int_0^x F_a dx \cos\theta$$

- The applied force $\vec{F}_a$ and the displacement $d\vec{r}$ (i.e., here dx) are in the same direction. As, the initial position is taken as the equilibrium position or mean position, x=0 is the lower limit of integration.

$$U = \int_0^x kx dx$$

$$U = k\left[\frac{x^2}{2}\right]_0^x$$

$$U = \frac{1}{2}kx^2$$

- If the initial position is not zero, and if the mass is changed from position x_i to x_f ,then the elastic potential energy is

$$U = \frac{1}{2}k\left(x_f^2 - x_i^2\right)$$

Force-displacement graph for a spring

- Since the restoring spring force and displacement are linearly related as $F = -kx$,and are opposite in direction, the graph between F and x is a straight line with dwelling only in the second and fourth quadrant as shown in Figure 4.10. Th e elastic potential energy can be easily calculatedby drawing a F - x graph. Th e shaded area (triangle) is the work done by the spring force.

$$\text{Area} = \frac{1}{2}(\text{base})(\text{height}) = \frac{1}{2} \times (x) \times (kx)$$

$$= \frac{1}{2}kx^2$$

Potential energy-displacement graph for a spring

- A compressed or extended spring will transfer its stored potential energy into kinetic energy of the mass attached to the spring.

In a frictionless environment, the energy gets transferred from kinetic to potential and potential to kinetic repeatedly such that the total energy of the system remains constant. At the mean position,

$$\Delta KE = \Delta U$$

- Let the two springs A and B be such that $k_A > k_B$. On which spring will more work has to be done if they are stretched by the same force?

$$F = K_A x_A = K_B x_B$$

$$x_A = \frac{F}{k_A}, x_B = \frac{F}{k_B}$$

- The work done on the springs are stored as potential energy in the springs.

$$U_A = \frac{1}{2}k_A x_A^2 \quad ; \quad U_B = \frac{1}{2}k_B x_B^2$$

$$\frac{U_A}{U_B} = \frac{k_A x_A^2}{k_B x_B^2} = \frac{k_A\left(\frac{F}{k_A}\right)^2}{k_B\left(\frac{F}{k_B}\right)^2} = \frac{\frac{1}{k_A}}{\frac{1}{k_B}}$$

$$\frac{U_A}{U_B} = \frac{k_B}{k_A}$$

$k_A > k_B$ implies that $U_B > U_A$. Thus, more work is done on B than A.

- A body of mass m is attached to the spring which is elongated to 25 cm by an applied force from its equilibrium position.

1. Calculate the potential energy stored in the spring-mass system?
2. What is the work done by the spring force in this elongation?
3. Suppose the spring is compressed to the same 25 cm, calculate the potential energy stored and also the work done by the spring force during compression. (The spring constant, k = 0.1 N m^{-1}).

The spring constant, k = 0.1 N m^{-1}
The displacement, x = 25 cm = 0.25 m

The potential energy stored in the spring is given by

$$U = \frac{1}{2}kx^2 = \frac{1}{2} \times 0.1 \times (0.25)^2 = 0.0031 J$$

The work done W_s by the spring force $\vec{F_s}$ is given by,

$$W_s = \int_0^x \vec{F}_s \cdot d\vec{r} = \int_0^x \left(-k x \hat{i}\right) \cdot (dx\, \hat{i})$$

The spring force $\vec{F_s}$ acts in the negative x direction while elongation acts in thpositive x direction.

$$W_s = \int_0^x (-kx)\,dx = -\frac{1}{2}kx^2$$

$$W_s = -\frac{1}{2} \times 0.1 \times (0.25)^2 = -0.0031 J$$

- Note that the potential energy is defined through the work done by the external agency. The positive sign in the potential energy implies that the energy is transferred from the agency to the object. But the work done by the restoring force in this case is negative since restoring force is in the opposite direction to the displacement direction.

- During compression also the potential energy stored in the object is the same.

$$U = \frac{1}{2}kx^2 = 0.0031J$$

Work done by the restoring spring force during compression is given by

$$W_s = \int_0^x \vec{F}_s . d\vec{r} = \int_0^x \left(k\, x\, \hat{i}\right).\left(-dx\, \hat{i}\right)$$

In the case of compression, the restoring spring force acts towards positive *x*-axis and displacement is along negative *x* direction.

$$W_s = \int_0^x (-kx)\, dx = -\frac{1}{2}kx^2 = -0.0031J$$

Conservative and nonconservativeforces

Conservative force

- A force is said to be a conservative force if the work done by or against the force in moving the body depends only on the initial and final positions of the body and not on the nature of the path followed between the initial and final positions. Let us consider an object at point A on the Earth. It can be taken to another point B at a height *h* above the surface of the Earth by three paths.

- Whatever may be the path, the work done against the gravitational force is the same as long as the initial and final positions are the same. This is the reason why gravitational force is a conservative force. Conservative force is equal to the negative gradient of the potential energy. In one dimensional case,Examples for conservative forces are elastic spring force, electrostatic force, magnetic force, gravitational force, etc.

S.No	Conservative forces	Non-conservative forces
1.	Work done is independent of the path	Work done depends upon the path
2.	Work done in a round trip is zero	Work done in a round trip is not zero
3	Total energy remains constant	Energy is dissipated as heat energy
4	Work done is completely recoverable	Work done is not completely recoverable.
5	Force is the negative gradient of potential energy	No such relation exists.

Non-conservative force

· A force is said to be non-conservative if the work done by or against the force in moving a body depends upon the path between the initial and final positions. This means that the value of work done is different in different paths.

1. Frictional forces are non-conservative forces as the work done against friction depends on the length of the path moved by the body.
2. The force due to air resistance, viscous force are also non-conservative forces as the work done by or against these forces depends upon the velocity of motion.

Compute the work done by the gravitational force for the following cases

$$\text{Force } \vec{F} = mg\left(-\hat{j}\right) = -mg\hat{j}$$

Displacement vector $d\vec{r} = dx\hat{i} + dy\hat{j}$

(As the displacement is in two dimension; unit vectors $\hat{i}$ and $\hat{j}$ are used)

· Since the motion is only vertical, horizontal displacement component dx is zero. Hence, work done by the force along path 1 (of distance h).

$$W_{path\ 1} = \int_A^B \vec{F}.d\vec{r} = \int_A^B \left(-mg\hat{j}\right).\left(dy\,\hat{j}\right)$$

$$= -mg\int_0^h dy = -mgh$$

Total work done for path 2 is

$$W_{path\ 2} = \int_A^B \vec{F}.d\vec{r} = \int_A^C \vec{F}.d\vec{r} + \int_C^D \vec{F}.d\vec{r} + \int_D^B \vec{F}.d\vec{r}$$

But

$$\int_A^C \vec{F}.d\vec{r} = \int_A^C \left(-mg\hat{j}\right).\left(dx\,\hat{i}\right) = 0$$

$$\int_C^D \vec{F}.d\vec{r} = \int_C^D \left(-mg\hat{j}\right).\left(dy\,\hat{j}\right)$$

$$= -mg\int_0^h dy = -mgh$$

$$\int_D^B \vec{F}.d\vec{r} = \int_D^B \left(-mg\hat{j}\right).\left(-dx\,\hat{i}\right) = 0$$

Therefore, the total work done by the force along the path 2 is

$$W_{\text{path 2}} = \int_A^B \vec{F}.d\vec{r} = -mgh$$

- Note that the work done by the conservative force is independent of the path.

- Consider an object of mass 2 kg moved by an external force 20 N in a surface having coefficient of kinetic friction 0.9 to a distance 10 m. What is the work done by the external force and kinetic friction ? Comment on the result. (Assume g = 10 ms^{-2})

m = 2 kg, *d* = 10 m, F_{ext}= 20 N, μ_k= 0.9. When an object is in motion on the horizontal surface, it experiences two forces.

1. External force, F_{ext}=20 N
2. Kinetic friction

$$f_k = \mu_k mg = 0.9 \times (2) \times 10 = 18\,\text{N}.$$

The work done by the external force W_{ext}=*F d* ´ 20´ 10 ´ 200J

- The work done by the force of kinetic friction W_k=f_k= (−18)×10 = −180 J. Here the negative sign implies that the force of kinetic friction is opposite to the direction of displacement.

The total work done on the object W_{total}=W_{ext}+W_k= 200 J −180 J = 20 J.

- Since the friction is a non-conservative force, out of 200 J given by the external force, the 180 J is lost and it can not be recovered.

Law of conservation of energy

- When an object is thrown upwards its kinetic energy goes on decreasing and consequently its potential energy keeps increasing (neglecting air resistance). When it reaches the highest point its energy is completely potential. Similarly, when the object falls back from a height its kinetic energy increases whereas its potential energy decreases. When it touches the ground its energy is completely kinetic. At the intermediate points the energy is both kinetic and potential When the body reaches the ground the kinetic energy is completely dissipated into some other form of energy like sound, heat, light and deformation of the body etc.

- In this example the energy transformation takes place at every point. The sum of kinetic energy and potential energy i.e., the total mechanical energy always remains constant, implying that the total energy is conserved. This is stated as the law of conservation of energy.

- The law of conservation of energystates that energy can neither be created nor destroyed. It may be transformed from one form to another but the total energy of an isolated system remains constant.

- illustrates that, if an object starts from rest at height h, the total energy is purely potential energy (U=mgh) and the kinetic energy (KE) is zero at h. When the object falls at some distance y, the potential energy and the kinetic energy are not zero whereas, the total energy remains same as measured at height h. When the object is about to touch the ground, the potential energy is zero and total energy is purely kinetic.

An object of mass 1 kg is falling from the height h = 10 m. Calculate

1. The total energy of an object at h =10 m
2. Potential energy of the object when it is at h = 4 m
3. Kinetic energy of the object when it is at h = 4 m
4. What will be the speed of the object when it hits the ground? (Assume g =10 ms^{-2})

- The gravitational force is a conservative force. So the total energy remains constant throughout the motion. At h =10 m, the total energy E is entirely potential energy.

$$E = U = mgh = 1 \times 10 \times 10 = 100 \text{ J}$$

The potential energy of the object at h =4 m is

$$U = mgh = 1 \times 10 \times 4 = 40 \text{ J}$$

- Since the total energy is constant throughout the motion, the kinetic energy at h=4m must be $KE = E - U = 100 - 40 = 60$J

- Alternatively, the kinetic energy could also be found from velocity of the object at 4 m. At the height 4 m, the object has fallen through a height of 6 m.

The velocity after falling 6 m is calculated from the equation of motion,

$$v = \sqrt{2gh} = \sqrt{2 \times 10 \times 6} = \sqrt{120} \text{ m s}^{-1}; \quad v^2 = 120$$

The kinetic energy is $KE = \frac{1}{2}mv^2 = \frac{1}{2} \times 1 \times 120 = 60 \text{J}$

- When the object is just about to hit the ground, the total energy is completely kinetic and the potential energy, U=0.

$$E = KE = \frac{1}{2}mv^2 = 100\ J$$

$$v = \sqrt{\frac{2}{m}KE} = \sqrt{\frac{2}{1} \times 100} = \sqrt{200} \approx 14.12\ m\ s^{-1}$$

- A body of mass 100 kg is lifted to a height 10 m from the ground in two different ways as shown in the figure. What is the work done by the gravity in both the cases? Why is it easier to take the object through a ramp?

m = 100 kg, h = 10 m
Along path (1):

- The minimum force $F1$ required to move the object to the height of 10 m shouldbe equal to the gravitational force, F_1=mg =100´ 10 =1000 N

The distance moved along path (1) is, h=10 m

$$W = F\ h = 1000 \times 10 = 10{,}000\ J$$

Along path (2):

- In the case of the ramp, the minimum force F_2 that we apply on the object to take it up is not equal to mg, it is rather equal to mg sin$q$. (mg sin$q$ <mg) .

Here, angle $\theta = 30^o$

Therefore, F_2 = mg sinθ = 100 × 10 × sin30o = 100 × 10 × 0.5 =500N

Hence, (mg sin$q$ <mg).

$$l = \frac{h}{\sin 30} = \frac{10}{0.5} = 20\,m$$

The work done on the object along path (2) is, W = F_2 l = 500 × 20 = 10,000 J

- Since the gravitational force is a conservative force, the work done by gravity on the object is independent of the path taken.

In both the paths the work done by the gravitational force is 10,000 J

Along path (1): more force needs to be applied against gravity to cover lesser distance .

Along path (2): lesser force needs to be applied against the gravity to cover more distance.

- As the force needs to be applied along the ramp is less, it is easier to move the object along the ramp.

- An object of mass m is projected from the ground with initial speed v_0. Find the speed at height h.

- Since the gravitational force is conservative; the total energy is conserved throughout the motion.

	Initial	Final
Kinetic energy	$\frac{1}{2}mv_o^2$	$\frac{1}{2}mv^2$
Potential energy	0	mgh
Total energy	$\frac{1}{2}mv_o^2 + 0 = \frac{1}{2}mv_o^2$	$\frac{1}{2}mv^2 + mgh$

- Final values of potential energy, kinetic energy and total energy are measured a the height h.

- By law of conservation of energy, the initial and final total energies are the same.

$$\frac{1}{2}mv_o^2 = \frac{1}{2}mv^2 + mgh$$
$$v_o^2 = v^2 + 2gh$$
$$v = \sqrt{v_o^2 - 2gh}$$

- Note that in section similar result is obtained using kinematic equation based on calculus method. However, calculation through energy conservation method is much easier than calculus method.

- An object of mass 2 kg attached to a spring is moved to a distance x=10 m from its equilibrium position. The spring constant k=1 N m^{-1} and assume that the surface is frictionless.

1. When the mass crosses the equilibrium position, what is the speed of the mass?
2. What is the force that acts on the object when the mass crosses the equilibrium position and extremum position x = ±10 m.

- Since the spring force is a conservative force, the total energy is constant. At x=10 m, the total energy is purely potential.

$$E = U = \frac{1}{2}kx^2 = \frac{1}{2} \times (1) \times (10)^2 = 50 \text{ J}$$

When the mass crosses the equilibrium position (x=0) , the potential energy

$$U = \frac{1}{2} \times 1 \times (0) = 0 \text{ J}$$

The entire energy is purely kinetic energy at this position.

$$E = KE = \frac{1}{2} mv^2 = 50 \text{J}$$

The speed

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2 \times 50}{2}} = \sqrt{50}\, m s^{-1} \approx 7.07\, m s^{-1}$$

- Since the restoring spring force is F = - kx, when the object crosses the equilibrium position, it experiences no force. Note that at equilibrium position, the object moves very fast. When the object is at x = +10 m (elongation), the force F = − k x

- F = − (1) (10) = − 10 N. Here the negative sign implies that the force is towards equilibrium i.e., towards negative x-axis and when the object is at x = − 10m (compression), it experiences a forces F = − (1) (− 10) = +10 N. Here the positive sign implies that the force points towards positive x-axis.

- The object comes to momentary rest at x = ±10m even though it experiences a maximum force at both these points.

Motion in a vertical circle

- Imagine that a body of mass (m) attached to one end of a massless and inextensible string executes circular motion in a vertical plane with the other end of the string fixed. The length of the string becomes the radius ($\vec{r}$) of the circular path

- Let us discuss the motion of the body by taking the free body diagram (FBD) at a position where the position vector ($\vec{r}$) makes an angle θ with the vertically downward direction and the instantaneous velocity.

There are two forces acting on the mass.

1. Gravitational force which acts downward
2. Tension along the string.

- Applying Newton's second law on the mass, In the tangential direction,

$$mg\sin\theta = ma_t$$
$$mg\sin\theta = -m\left(\frac{dv}{dt}\right)$$
where, $a_t = -\frac{dv}{dt}$ is tangential retardation

In the radial direction,

$$T - mg\cos\theta = m\,a_r$$
$$T - mg\cos\theta = \frac{mv^2}{r}$$
where, $a_r = \frac{v^2}{r}$ is the centripetal acceleration.

- The circle can be divided into four sections A, B, C, D for better understanding of the motion. The four important facts to be understood from the two equations are as follows:

1. The mass is having tangential acceleration (g sin θ) for all values of θ (except θ = 0o), it is clear that this vertical cirular motion is not a uniform circular motion.
2. From the equations (4.28) and (4.29) it is understood that as the magnitude of velocity is not a constant in the course of motion, the tension in the string is also not constant

   The equation (4.29), $T = mg\cos\theta + \frac{mv^2}{r}$ highlights that in sections A and D of the circle, $\left(\text{for } -\frac{\pi}{2} < \theta < \frac{\pi}{2};\ \cos\theta \text{ is positive}\right)$, the term mg cosθ is always

   greater than zero. Hence the tension cannot vanish even when the velocity vanishes.

   The equation (4.29), $\frac{mv^2}{r} = T - mg\cos\theta$; further highlights that in sections B and C of the circle, $\left(\text{for } \frac{\pi}{2} < \theta < \frac{3\pi}{2};\ \cos\theta \text{ is negative}\right)$, the second term is always greater than zero. Hence velocity cannot vanish, even when the tension vanishes.

- These points are to be kept in mind while solving problems related to motion in vertical circle.

- To start with let us consider only two positions, say the lowest point 1 and the highest point 2 as shown in Figure 4.15 for further analysis. Let the velocity of the body at the lowest point 1 be $\vec{v}_1$, at the highest point 2 be $\vec{v}_2$ and $\vec{v}$ at any other point. The direction of velocity is tangential to the circular path at all points. Let $\vec{T}_1$ be the tension in the string at the lowest point and $\vec{T}_2$ be the tension at the highest point and $\vec{T}$ be the tension at any other point. Tension at each point acts towards the center. The tensions and velocities at these two points can be found by applying the law of conservation of energy.

$$T_1 - mg = \frac{mv_1^2}{r}$$

$$T_1 = \frac{mv_1^2}{r} + mg$$

- At the highest point 2, both the gravitational force mg on the body and the tension $\vec{T}_2$ act downwards, i.e. towards the center again.

$$T_2 + mg = \frac{mv_2^2}{r}$$

$$T_2 = \frac{mv_2^2}{r} - mg$$

$$T_1 - T_2 = \frac{mv_1^2}{r} + mg - \left(\frac{mv_2^2}{r} - mg\right)$$

$$= \frac{mv_1^2}{r} + mg - \frac{mv_2^2}{r} + mg$$

$$T_1 - T_2 = \frac{m}{r}\left[v_1^2 - v_2^2\right] + 2mg \qquad (3$$

- The term $[v_1^2 - v_2^2]$ can be found easily by applying law of conservation of energy.

- Total Energy at point 1(E_1) is same as the total energy at a point 2 (E_2)

$$E_1 = E_2$$

Potential Energy at point 1, U_1=0 (by taking reference as point 1)

Kinetic Energy at point 1,

$$KE_1 = \frac{1}{2}mv_1^2$$

Total Energy at point 1,

$$E_1 = U_1 + KE_1 = 0 + \frac{1}{2}mv_1^2 = \frac{1}{2}mv_1^2$$

Similarly, Potential Energy at point 2, U_2=mg (2r)

Kinetic Energy at point 2,

$$KE_2 = \frac{1}{2}mv_2^2$$

Total Energy at point 2,

$$E_2 = U_2 + KE_2 = 2\text{ mg r} + \frac{1}{2}mv_2^2$$

From the law of conservation of energy given in equation

$$\frac{1}{2}mv_1^2 = 2mgr + \frac{1}{2}mv_2^2$$

After rearranging,

$$\frac{1}{2}m\left(v_1^2 - v_2^2\right) = 2mgr$$

$$v_1^2 - v_2^2 = 4gr$$

Substituting equation

$$T_1 - T_2 = \frac{m}{r}[4gr] + 2mg$$

Therefore, the difference in tension is

$$T_1 - T_2 = 6\text{ mg}$$

- The body must have a minimum speed at point 2 otherwise, the string will slack before reaching point 2 and the body will not loop the circle. To find this minimum speed let us take the tension T_2 = 0 in equation

$$0 = \frac{mv_2^2}{r} - mg$$

$$\frac{mv_2^2}{r} = mg$$

$$v_2^2 = rg$$

$$v_2 = \sqrt{gr}$$

- The body must have a speed at point 2, $v_2 \geq \sqrt{gr}$ to stay in the circular path.

- To have this minimum speed $\left(v_2 = \sqrt{gr}\right)$ at point 2, the body must have minimum speed also at point 1.

- By making use of equation (4.36) we can find the minimum speed at point 1.

$$v_1^2 - v_2^2 = 4gr$$

Substituting equation

$$v_1^2 - gr = 4gr$$

$$v_1^2 = 5gr$$

$$v_1 = \sqrt{5gr}$$

The body must have a speed at point 1, $v_1 \geq \sqrt{5gr}$ to stay in the circular path.

It is clear that the minimum speed at the lowest point 1 should be $\sqrt{5}$ times more than the minimum speed at the highest point 2, so that the body loops without leaving the circle.

- Water in a bucket tied with rope is whirled around in a vertical circle of radius 0.5 m. Calculate the minimum velocity at the lowest point so that the water does not spill from it in the course of motion. (g = 10 ms^{-2})

Radius of circle r = 0.5 m

The required speed at the highest point

$v_2 = \sqrt{gr} = \sqrt{10 \times 0.5} = \sqrt{5}\ ms^{-1}$. The speed at lowest point $v_1 = \sqrt{5gr} = \sqrt{5} \times \sqrt{gr} = \sqrt{5} \times \sqrt{5} = 5\ ms^{-1}$

POWER

Definition of Power

- Power is a measure of how fast or slow a work is done. Power is defined as the rate of work done or energy delivered.

$$\text{Power } (P) = \frac{\text{work done}(W)}{\text{time taken}(t)}$$

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

Average power

The average power (P_{av}) is defined as the ratio of the total work done to the total time taken.

$$P_{av} = \frac{\text{total work done}}{\text{total time taken}}$$

Instantaneous power

- The instantaneous power (P_{inst}) is defined as the power delivered at an instant (as time interval approaches zero),

$$P_{inst} = \frac{dW}{dt}$$

Unit of Power

- Power is a scalar quantity. Its dimension is $[ML^2T^{-3}]$. The SI unit of power is watt (W),named after the inventor of the steam engineJames Watt. One watt is defined as the powerwhen one joule of work is done in one second,($1 \text{ W} = 1 \text{ J s}^{-1}$).

  The higher units are kilowatt(kW), megawatt(MW), and Gigawatt(GW).

$$1\text{kW} = 1000 \text{ W} = 10^3 \text{ watt}$$
$$1\text{MW} = 10^6 \text{ watt}$$
$$1\text{GW} = 10^9 \text{ watt}$$

- For motors, engines and some automobiles an old unit of power still commercially in use which is called as the horse-power (hp). We have a conversion for horse-power (hp) into watt (W) which is,

$$1 \text{ hp} = 746 \text{ W}$$

- All electrical goods come with a definite power rating in watt printed on them. A 100 watt bulb consumes 100 joule of electrical energy in one second. The energy measured in joule in terms of power in watt and time in second is written as, 1 J =1 W s. When electrical appliances are put in use for long hours, they consume a large amount of energy. Measuring the electrical energy in a small unit watt.second (W s) leads to handling large numerical values. Hence, electrical energy is measured in the unit called kilowatt hour (kWh).

$$1 \text{ electrical unit} = 1 \text{ kWh} = 1 \times (10^3 \text{ W}) \times (3600 \text{ s})$$
$$1 \text{ electrical unit} = 3600 \times 10^3 \text{ W s}$$
$$1 \text{ electrical unit} = 3.6 \times 10^6 \text{ J}$$
$$1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$$

- Electricity bills are generated in units of kWh for electrical energy consumption. 1 unit of electrical energy is 1 kWh. (Note: kWh is unit of energy and not of power.)

- Calculate the energy consumed in electrical units when a 75 W fan is used for 8 hours daily for one month (30 days).

Power, P = 75 W

- Time of usage, t = 8 hour × 30 days = 240 hours
- Electrical energy consumed is the product of power and time of usage.

Electrical energy = power × time of usage = P × t

$$= 75 \text{ watt} \times 240 \text{ hour}$$
$$= 18000 \text{ watt hour}$$
$$= 18 \text{ kilowatt hour} = 18 \text{ kWh}$$
$$1 \text{ electrical unit} = 1 \text{ kWh}$$
$$\text{Electrical energy} = 18 \text{ unit}$$

Incandescent lamps glow for 1000 hours. CFL lamps glow for 6000 hours. But LED lamps glow for 50000 hrs (almost 25 years at 5.5 hour per day).

Relation between power and velocity

The work done by a force $\vec{F}$ for a displacement $d\vec{r}$ is

$$W = \int \vec{F} \cdot d\vec{r}$$

Left hand side of the equation (4.40) can be written as

$$W = \int dW = \int \frac{dW}{dt} dt$$

Since, velocity is $\vec{v} = \frac{d\vec{r}}{dt}; d\vec{r} = \vec{v}dt.$ Right hand side of the equation (4.40) can be written as

$$\int \vec{F} \cdot d\vec{r} = \int \left(\vec{F} \cdot \frac{d\vec{r}}{dt} \right) dt = \int \left(\vec{F} \cdot \vec{v} \right) dt \quad \left[\vec{v} = \frac{d\vec{r}}{dt} \right]$$

$$\int \frac{dW}{dt} dt = \int \left(\vec{F} \cdot \vec{v} \right) dt$$

$$\int \left(\frac{dW}{dt} - \vec{F} \cdot \vec{v} \right) dt = 0$$

- This relation is true for any arbitrary value of dt. This implies that the term within the bracket must be equal to zero, i.e.,

$$\frac{dW}{dt} - \vec{F} \cdot \vec{v} = 0$$

Or

$$\frac{dW}{dt} = \vec{F} \cdot \vec{v}$$

- A vehicle of mass 1250 kg is driven with an acceleration 0.2 ms^{-2} along a straight level road against an external resistive force 500 N. Calculate the power delivered by the vehicle's engine if the velocity of the vehicle is 30 ms^{-1}.

- The vehicle's engine has to do work against resistive force and make vechile to move with an acceleration. Therefore, power delivered by the vehicle engine is

$$P = (\text{resistive force} + \text{mass} \times \text{acceleration})\ (\text{velocity})$$

$$P = \vec{F}_{tot} \vec{v} = (F_{resistive} + F)\vec{v}$$

$$P = \vec{F}_{tot} \cdot \vec{v} = (F_{resistive} + ma)\vec{v}$$

$$= (500\ N + (1250\ kg) \times (0.2\ ms^{-2}))$$

$$(30\ ms^{-1}) = 22.5\ kW$$

COLLISIONS

- Collision is a common phenomenon that happens around us every now and then. For example, carom, billiards, marbles, etc.,. Collisions can happen between two bodies with or without physical contacts.

- Linear momentum is conserved in all collision processes. When two bodies collide, the mutual impulsive forces acting between them during the collision time (Δt) produces a change in their respective momenta. That is, the first body exerts a force

$\vec{F}_{12}$ on the second body. From Newton's third law, the second body exerts a force $\vec{F}_{21}$ on the first body. This causes a change in momentum $\Delta \vec{p}_1$ and $\Delta \vec{p}_2$ of the first body and second body respectively. Now, the relations could be written as,

$$\Delta\vec{p}_1 = \vec{F}_{12}\Delta t$$
$$\Delta\vec{p}_2 = \vec{F}_{21}\Delta t$$

Adding equation

$$\Delta\vec{p}_1 + \Delta\vec{p}_2 = \vec{F}_{12}\Delta t + \vec{F}_{21}\Delta t = \left(\vec{F}_{12} + \vec{F}_{21}\right)\Delta t$$

According to Newton's third law, $\vec{F}_{12} = -\vec{F}_{21}$

$$\Delta\vec{p}_1 + \Delta\vec{p}_2 = 0$$
$$\Delta\left(\vec{p}_1 + \vec{p}_2\right) = 0$$

Dividing both sides by Δt and taking limit Δ t→0 , we get

$$\lim_{\Delta t \to 0} \frac{\Delta\left(\vec{p}_1 + \vec{p}_2\right)}{\Delta t} = \frac{d\left(\vec{p}_1 + \vec{p}_2\right)}{dt} = 0$$

- The above expression implies that the total linear momentum is a conserved quantity. Note: The momentum is a vector quantity. Hence, vector addition has to be followed to find the total momentum of the individual bodies in collision.

Types of collections

- In any collision process, the total linearmomentum and total energy are alwaysconserved whereas the total kinetic energyneed not be conserved always. Some partof the initial kinetic energy is transformedto other forms of energy. This is because,the impact of collisions and deformationoccurring due to collisions may in general,produce heat, sound, light etc. By takingthese effects into account, we classify thetypes of collisions as follows:

1. Elastic collision
2. Inelastic collision

Elastic collision

- In a collision, the total initial kinetic energy of the bodies (before collision) is equal to the total final kinetic energy of the bodies (after collision) then, it is called as elastic collision. i.e.,

- Total kinetic energy before collision = Total kinetic energy after collision

Inelastic collision

- In a collision, the total initial kinetic energy of the bodies (before collision) is not equal to the total final kinetic energy of the bodies (after collision) then, it is called as inelastic collision. i.e.,

- Total kinetic energy before collision ≠ Total kinetic energy after collision

$$\begin{pmatrix}\text{Total kinetic energy}\\ \text{after collision}\end{pmatrix} - \begin{pmatrix}\text{Total kinetic energy}\\ \text{before collision}\end{pmatrix} = \begin{pmatrix}\text{loss in energy}\\ \text{during collision}\end{pmatrix} = \Delta Q$$

- Even though kinetic energy is not conserved but the total energy is conserved. This is because the total energy contains the kinetic energy term and also a term ΔQ, which includes all the losses that take place during collision. Note that loss in kinetic energy during collision is transformed to another form of energy like sound, thermal, etc. Further, if the two colliding bodies stick together after collision such collisions are known as completely inelastic collision or perfectly inelastic collision. Such a collision is found very often. For example when a clay putty is thrown on a moving vehicle, the clay putty (or Bubblegum) sticks to the moving vehicle and they move together with the same velocity.

Elastic collisions in one dimension

- Consider two elastic bodies of masses m_1 and m_2 moving in a straight line (along positive x direction) on a frictionless horizontal surface.

Mass	Initial velocity	Final velocity
Mass m_1	u_1	v_1
Mass m_2	u_2	v_2

- In order to have collision, we assume that the mass m_1 moves faster than mass m_2 i.e., $u_1 > u_2$. For elastic collision, the total linear momentum and kinetic energies of the two bodies before and after collision must remain the same.

S.No.	Elastic Collision	Inelastic Collision
1.	Total momentum is conserved	Total momentum is conserved
2.	Total kinetic energy is conserved	Total kinetic energy is not conserved
3.	Forces involved are conservative forces	Forces involved are non-conservative forces
4.	Mechanical energy is not dissipated.	Mechanical energy is dissipated into heat, light, sound etc.

	Momentum of mass m_1	Momentum of mass m_2	Total linear momentum
Before collision	$p_{i1} = m_1u_1$	$p_{i2} = m_2u_2$	$p_i = p_{i1} + p_{i2}$ $p_i = m_1u_1 + m_2u_2$
After collision	$p_{f1} = m_1v_1$	$p_{f2} = m_2v_2$	$p_f = p_{f1} + p_{f2}$ $p_f = m_1v_1 + m_2v_2$

From the law of conservation of linear momentum,

· Total momentum before collision (p_i) = Total momentum after collision (p_f)

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

$$\text{Or } m_1(u_1 - v_1) = m_2(v_2 - u_2)$$

	Kinetic energy of mass m_1	Kinetic energy of mass m_2	Total kinetic energy
Before collision	$KE_{i1} = \frac{1}{2}m_1u_1^2$	$KE_{i2} = \frac{1}{2}m_2u_2^2$	$KE_i = KE_{i1} + KE_{i2}$ $KE_i = \frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2$
After collision	$KE_{f1} = \frac{1}{2}m_1v_1^2$	$KE_{f2} = \frac{1}{2}m_2v_2^2$	$KE_i = KE_{i1} + KE_{i2}$ $KE_f = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$

Total kinetic energy before collision KE_i = Total kinetic energy after collision KE_f

$$\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$$

After simplifying and rearranging the terms,

$$m_1\left(u_1^2 - v_1^2\right) = m_2\left(v_2^2 - u_2^2\right)$$

Using the formula $a^2 – b^2 = (a+b)(a-b)$ we can rewrite the above equation as

$$m_1(u_1 + v_1)(u_1 - v_1) = m_2(v_2 + u_2)(v_2 - u_2)$$

$$\frac{m_1(u_1 + v_1)(u_1 - v_1)}{m_1(u_1 - v_1)} = \frac{m_2(v_2 + u_2)(v_2 - u_2)}{m_2(v_2 - u_2)}$$

$$u_1 + v_1 = v_2 + u_2$$

Rearranging, (4.50)

$$u_1 - u_2 = v_2 - v_1$$

Equation (4.50) can be rewritten as

$$u_1 - u_2 = -(v_1 - v_2)$$

- This means that for any elastic head on collision, the relative speed of the two elastic bodies after the collision has the same magnitude as before collision but in opposite direction. Further note that this result is independent of mass.

Rewriting the above equation for v_1 and v_2,

$$v_1 = v_2 + u_2 - u_1$$

Or

$$v_2 = u_1 + v_1 - u_2$$

To find the final velocities v_1 and v_2:

- Substituting equation (4.52) in equation (4.47) gives the velocity of m_1 as

$$m_1(u_1 - v_1) = m_2(u_1 + v_1 - u_2 - u_2)$$

$$m_1(u_1 - v_1) = m_2(u_1 + v_1 - 2u_2)$$

$$m_1u_1 - m_1v_1 = m_2u_1 + m_2v_1 - 2m_2u_2$$

$$m_1u_1 - m_2u_1 + 2m_2u_2 = m_1v_1 + m_2v_1$$

$$(m_1 - m_2)u_1 + 2m_2u_2 = (m_1 + m_2)v_1$$

$$\text{or } v_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)u_1 + \left(\frac{2m_2}{m_1 + m_2}\right)u_2$$

- Similarly, by substituting (4.51) in equation (4.47) or substituting equation (4.53) in equation (4.52), we get the final velocity of m_2 as

$$v_2 = \left(\frac{2m_1}{m_1 + m_2}\right)u_1 + \left(\frac{m_2 - m_1}{m_1 + m_2}\right)u_2$$

When bodies has the same mass i.e., $m_1 = m_2$,

$$\Rightarrow v_1 = (0)\ u_1 + \left(\frac{2m_2}{2m_2}\right)u_2$$

$$v_1 = u_2$$

$$\Rightarrow v_2 = \left(\frac{2m_1}{2m_1}\right)u_1 + (0)u_2$$

$$v_2 = u_1$$

- The equations (4.55) and (4.56) show that in one dimensional elastic collision, when two bodies of equal mass collide after the collision their velocities are exchanged.

- When bodies have the same mass i.e., $m_1 = m_2$ and second body (usually called target) is at rest ($u_2 = 0$),

- By substituting $m_1 = m_2$ and $u_2 = 0$ in equations (4.53) and equations (4.54) we get,body moves with the initial velocity of the first body.

$$\Rightarrow v_1 = 0$$

$$\Rightarrow v_2 = u_1$$

The first body is very much lighter than the second body

$$\left(m_1 \ll m_2, \frac{m_1}{m_2} \ll 1\right) \text{ then the ratio } \frac{m_1}{m_2} \approx 0$$

Dividing numerator and denominator of equation (4.53) by m2, we get

$$v_1 = \left(\frac{\frac{m_1}{m_2} - 1}{\frac{m_1}{m_2} + 1} \right) u_1 + \left(\frac{2}{\frac{m_1}{m_2} + 1} \right) (0)$$

$$v_1 = \left(\frac{0 - 1}{0 + 1} \right) u_1$$

$$v_1 = - u_1$$

- Dividing numerator and denominator of equation (4.54) by m2, we get

$$v_2 = \left(\frac{2\frac{m_1}{m_2}}{\frac{m_1}{m_2} + 1} \right) u_1 + \left(\frac{1 - \frac{m_1}{m_2}}{\frac{m_1}{m_2} + 1} \right) (0)$$

$$v_2 = (0) u_1 + \left(\frac{1 - \frac{m_1}{m_2}}{\frac{m_1}{m_2} + 1} \right) (0)$$

$$v_2 = 0$$

- The equation (4.59) implies that the first body which is lighter returns back (rebounds) in the opposite direction with the same initial velocity as it has a negative sign. The equation (4.60) implies that the second body which is heavier in mass continues to remain at rest even after collision. For example, if a ball is thrown at a fixed wall, the ball will bounce back from the wall with the same velocity with which it was thrown but in opposite direction.

- The second body is very much lighter than the first body

$$\left(m_2 \ll m_1, \frac{m_2}{m_1} \ll 1 \right) \text{ then the ratio } \frac{m_2}{m_1} \approx 0$$

$$v_1 = \left(\frac{1 - \frac{m_2}{m_1}}{1 + \frac{m_2}{m_1}} \right) u_1 + \left(\frac{2\frac{m_2}{m_1}}{1 + \frac{m_2}{m_1}} \right) (0)$$

$$v_1 = \left(\frac{1-0}{1+0} \right) u_1 + \left(\frac{0}{1+0} \right) (0)$$

$$v_1 = u_1$$

- Dividing numerator and denominator of equation (4.58) by m1, we get

$$v_2 = \left(\frac{2}{1 + \frac{m_2}{m_1}} \right) u_1 + \left(\frac{\frac{m_2}{m_1} - 1}{1 + \frac{m_2}{m_1}} \right) (0)$$

$$v_2 = \left(\frac{2}{1+0} \right) u_1$$

$$v_2 = 2u_1$$

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The equation (4.61) implies that the first body which is heavier continues to move with the same initial velocity. The equation (4.62) suggests that the second body which is lighter will move with twice the initial velocity of the first body. It means that the lighter body is thrown away from the point of collision.

- A lighter particle moving with a speed of 10 m s^{-1} collides with an object of double its mass moving in the same direction with half its speed. Assume that the collision is a one dimensional elastic collision. What will be the speed of both particles after the collision?

- Let the mass of the first body be m which moves with an initial velocity, u1 = 10 m s-1. Therefore, the mass of second body is 2m and its initial velocity is

$$u_2 = \frac{1}{2} u_1 = \frac{1}{2}\left(10 \text{ m s}^{-1}\right),$$

- Then, the final velocities of the bodies can be calculated from the equation (4.53) and equation (4.54)

$$v_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)u_1 + \left(\frac{2m_2}{m_1 + m_2}\right)u_2$$

$$v_1 = \left(\frac{m - 2m}{m + 2m}\right)10 + \left(\frac{2 \times 2m}{m + 2m}\right)5$$

$$v_1 = -\left(\frac{1}{3}\right)10 + \left(\frac{4}{3}\right)5 = \frac{-10 + 20}{3} = \frac{10}{3}$$

$$v_1 = 3.33 \ ms^{-1}$$

$$v_2 = \left(\frac{2m_1}{m_1 + m_2}\right)u_1 + \left(\frac{m_2 - m_1}{m_1 + m_2}\right)u_2$$

$$v_2 = \left(\frac{2m}{m + 2m}\right)10 + \left(\frac{2m - m}{m + 2m}\right)5$$

$$v_2 = \left(\frac{2}{3}\right)10 + \left(\frac{1}{3}\right)5 = \frac{20 + 5}{3} = \frac{25}{3}$$

$$v_2 = 8.33 ms^{-1}$$

As the two speeds v_1 and v_2 are positive, they move in the same direction with the velocities, 3.33 m s^{-1} and 8.33 m s^{-1} respectively.

Perfect inelastic collision

- In a perfectly inelastic or completely inelastic collision, the objects stick together permanently after collision such that they move with common velocity. Let the two bodies with masses m_1 and m_2 move with initial velocities u_1 and u_2 respectively before collision. After perfect inelastic collision both the objects move together with a common velocity v

Since, the linear momentum is conserved during collisions,

$$m_1 u_1 + m_2 u_2 = (m_1 + m_2) \, v$$

	Velocity		Linear momentum	
	Initial	Final	Initial	Final
Mass m_1	u_1	v	$m_1 u_1$	$m_1 v$
Mass m_2	u_2	v	$m_2 u_2$	$m_2 v$
Total			$m_1 u_1 + m_2 u_2$	$(m_1 + m_2)$ v

The common velocity can be computed by

$$v = \frac{m_1u_1 + m_2u_2}{(m_1 + m_2)}$$

- A bullet of mass 50 g is fired from below into a suspended object of mass 450 g. The object rises through a height of 1.8 m with bullet remaining inside the object. Find the speed of the bullet. Take g = 10 ms^{-2}.

$$m_1 = 50\ g = 0.05\ kg; \quad m_2 = 450\ g = 0.45\ kg$$

- The speed of the bullet is u1. The second body is at rest u_2= 0 . Let the common velocity of the bullet and the object after the bullet is embedded into the object is v.

$$v = \frac{m_1u_1 + m_2u_2}{(m_1 + m_2)}$$

$$v = \frac{0.05u_1 + (0.45 \times 0)}{(0.05 + 0.45)} = \frac{0.05}{0.50}u_1$$

- The combined velocity is the initial velocity for the vertical upward motion of the combined bullet and the object. From second equation of motion,

$$v = \sqrt{2gh}$$

$$v = \sqrt{2 \times 10 \times 1.8} = \sqrt{36}$$

$$v = 6\,ms^{-1}$$

Substituting this in the above equation, the value of u_1 is

$$6 = \frac{0.05}{0.50}u_1 \quad \text{or} \quad u_1 = \frac{0.50}{0.05} \times 6 = 10 \times 6$$

$$u_1 = 60\,ms^{-1}$$

Loss of kinetic energy in perfect inelastic collision

- In perfectly inelastic collision, the loss in kinetic energy during collision is transformed to another form of energy like sound, thermal, heat, light etc. Let KE_i be the total kinetic energy before collision and KE_fbe the total kinetic energy after collision.

Total kinetic energy before collision,

$$KE_i = \frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2$$

$$KE_f = \frac{1}{2}(m_1 + m_2)v^2$$

Then the loss of kinetic energy is Loss of KE, DQ = KE_i-KE_f

$$= \frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 - \frac{1}{2}(m_1 + m_2)v^2$$

Substituting equation (4.63) in equation (4.66), and on simplifying (expand v by using the algebra

$$(a+b)^2 = a^2 + b^2 + 2ab,$$

$$\text{Loss of KE, } \Delta Q = \frac{1}{2}\left(\frac{m_1m_2}{m_1 + m_2}\right)(u_1 - u_2)^2$$

Coefficient of restitution (e)

- Suppose we drop a rubber ball and a plasticball on the same floor. The rubber ballwill bounce back higher than the plasticball. This is because the loss of kineticenergy for an elastic ball is much lesserthan the loss of kinetic energy for a plasticball. The amount of kinetic energy afterthe collision of two bodies, in general,can be measured through a dimensionlessnumber called the coefficient of restitution(COR).

- It is defined as the ratio of velocity ofseparation (relative velocity) after collisionto the velocity of approach (relative velocity)before collision, i.e.,

$$e = \frac{\text{velocity of separation (after collision)}}{\text{velocity of approach (before collision)}}$$

$$= \frac{(v_2 - v_1)}{(u_1 - u_2)}$$

- In an elastic collision, we have obtained the velocity of separation is equal to the velocity of approach i.e.,

$$(u_1 - u_2) = (v_2 - v_1) \rightarrow \frac{(v_2 - v_1)}{(u_1 - u_2)} = 1 = e$$

- This implies that, coefficient of restitution for an elastic collision, e=1. Physically, it means that there is no loss of kinetic energy after the collision. So, the body bounces back with the same kinetic energy which is usually called as perfect elastic.

- In any real collision problems, there will be some losses in kinetic energy due to collision, which means e is not always equal to unity. If the ball is perfectly plastic, it will never bounce back and therefore their separation of velocity is zero after the collision. Hence, the value of coefficient of restitution, e=0.

- In general, the coefficient of restitution for a material lies between

$$0 < e < 1.$$

- Show that the ratio of velocities of equal masses in an inelastic collision when one of the masses is stationary is

$$\frac{v_1}{v_2} = \frac{1-e}{1+e}.$$

$$e = \frac{\text{velocity of separation (after collision)}}{\text{velocity of approach (before collision)}}$$

$$= \frac{(v_2 - v_1)}{(u_1 - u_2)} = \frac{(v_2 - v_1)}{(u_1 - 0)} = \frac{(v_2 - v_1)}{u_1}$$

$$\Rightarrow v_2 - v_1 = e u_1$$

From the law of conservation of linear momentum,

$$m u_1 = m v_1 + m v_2 \Rightarrow u_1 = v_1 + v_2 \quad (2)$$

Using the equation (2) for u1 in (1), we get

$$v_2 - v_1 = e(v_1 + v_2)$$

On simplification, we get

$$\frac{v_1}{v_2} = \frac{1-e}{1+e}$$