Physics – Part -2		
Heat		
6th term - 2	Unit -1	Heat
7th term - 2	Unit -1	Heat & Temperature
8th term - 2	Unit -1	Heat
9 th Std	Unit - 1	Heat
10th Std	Unit - 3	Thermal Physics
11thPhysics vol - 2	Unit - 8	Heat & Thermodynamics
Light		
7th term 3	Unit -1	Light
8th term 1	Unit - 3	Light
9 th Std	Unit - 6	Light
10th Std	Unit - 2	Optics
12thPhysics vol - 2	Unit - 6	Optics
Sound		
8th Std term - 3	Unit - 1	Sound
9 th Std	Unit - 8	Sound
10th Std	Unit - 5	Acoustics

Heat

6th Standard - Term-II
Unit 1: Heat

Sources Of Heat
♦ **Sun**

- We all know that the sun gives us light. Does it give us heat? After standing under the sun light for some time, touch your head. Does it feel hot? Yes, it feels hot because the sun gives out heat besides light. Now, You can understand why it is diff cult to walk bare-footed on sunny days in the afternoon.

♦**Combustion (Burning)**

- Heat energy can be generated by the burning of fuels like wood, kerosene, coal, charcoal, gasoline/petrol, oil, etc., In your home, how do you get heat energy to cook food?♦ **Friction**
- Rub your palms for some time and then hold them todo you feel? We can generate heat by rubbing two surfaces of some substances. In the past people used to rub two stones together to light f re.

♦ **Electricity**

- Whenelectric current fows through a conductor, heat energy is produced. The waterheater, iron box, electric kettle etc., work on this principle.

Heat

Molecules in objects are constantly vibrating or moving inside objects. We cannot see that movement with our naked eye. When we heat the object this vibration and movement of molecules increases and temperature of the object also increases.

Thus, Heat is an energy that raises the temperature of a thing by causing the molecules in that thing to move faster.

Heat is not a matter. It doesn't occupy space. It has no weight. Like light, sound and electricity, heat is a form of energy.

In short, Heat is the total kinetic energy of constituent particles of objects. **SI Unit of Heat is joule**. The unit calorie is also used.

Hot and cold objects

- In our day-to-day life, we come across a number of objects. Some of them are hot and some of them are cold. How do we decide which object is hotter than the other?

- use the tip of our finger to find out whether the tea in a cup has enough heat to drink or whether milk has been cooled enough to set for making curds. We often determine heat by touching the objects. But is our sense of touch reliable?

Temperature
Definition of Temperature

- The measurement of warmness or coldness of a substance is known as its Temperature.

- SI unit of temperature is kelvin. Celsius and Fahrenheit are the other units used. Celsius is called as Centigrade as well.

- It determines the direction of flow of heat when two bodies are placed in contact

Is Neela correct?

- Beaker A and B has water at 80o C.

- Then pour the water of A and B to an empty beaker C. Now, What is the temperature of the water in the beaker C? Neelasays it will be 160°C.

- What is your opinion? Does Neela say correctly? Make a guess and verify it experimentally

- One day in 1922, the air temperature was measured at 59°C in the shade in Libya, Africa. The coldest temperature in the world was measured in the Antarctic continent. It was approximately – 89oC. The minus sign (–) is used when the temperature falls below the freezing point of water, which is 0°C. If water becomes ice at 0°C, you can imagine how cold – 89°C would be. Our normal body temperature is 37°C. Our body feels cool if the air temperature is around 15 to 20 degree Celsius. Can you estimate the night temperature in your village or city during winter

Heat and Temperature

- Heat and temperature are not the same thing, they in fact mean two different things;

- Temperature is related to how fast the atoms or molecules move or vibrate within the substance.

- 2. Heat not only depends on the temperature of the substance but also depends on how many molecules are there in the object.

- 3. Temperature measures the average kinetic energy of molecules. Heat measures the total Kinetic Energy of the molecules in the substance.

- Total heat is measured by calorie, the amount of heat needed to raise one gram of water by one degree centigrade.

Flow of Heat

An analogy between temperature and water level:

- Water**'flows'** when there is a difference in the 'levels' of water in different places. It does not matter if there is more water in one place or another. Water from a puddle can flow into a reservoir or the other way around. The **'temperature'** of an object is like the water level – itdetermines the direction in which 'heat' will flow. Heat energy flows from higher temperature to lower temperature.

Thermal contact and Thermal equilibrium

- Consider two bodies A and B. Let the temperature of A be higher than that of B. On bringing bodies A and B in contact , heat will flow from hot body A to the cold body B. Heat will continue to flow till both the bodies attain the same temperature.

Expansion in solids

- Sam is trying to open a tight jar, but he cannot open it. He asks his uncle to help. His uncle says that pour some hot water on the lid of the jar. Sam does so and tries to open it now. Wow! The jar is opened easily! Do you have such experience? How do you open a tightly closed cap of thepen which could not be opened by you normally?

- Most substances expand when heated andcontract when cooled. The change in length / area or volume (due to contraction / expansion) is directly related to temperature change.

- The expansion of a substance on heating is called, the thermal expansion of that substance.

Linear and Cubical Expansion

❖ A solid has a definite shape, so when a solid is heated, it expands in all directions i.e., in length, area and volume, all increase on heating.

❖ The expansion in length is called linear expansion and the expansion in volume is called cubical expansion.

❖ Why is the iron rim of a bullock cart wheel heated before it is fitted onto the wheel? Why is a small gap left between two lengths of railway lines?

❖ We can perform an interesting experiment to find out an answer to these questions. All we need to do is to heat a cycle spoke.

Uses of Thermal Expansion

Fitting the iron rim on the wooden wheel

- The diameter of the iron ring is slightly less than that of the wooden wheel. Therefore, it cannot be easily slipped on from the rim of wooden wheel. The iron ring is, therefore, fi rst heated to a higher temperature so that it expands in size and the hot ring is then easily slipped over to the rim of the wooden wheel. Cold water is now poured on the iron ring so that it contracts in size and holds the wooden wheel tightly.

Rivetting

- Rivets are used to join two steel plates together. Hot rivet is driven through the hole in the plates. One end of the rivet is hammered to form a new rivet head. When cooled, the rivet will contract and hold the two plates tightly together.

Thermal Expansion Examples

Give Reasons for the following

❖ Gaps are left in between rails while laying a railway track.
❖ Gaps are left in between two joints of a concrete bridge.

Cracking of a thick glass tumbler

- Glass is a poor conductor of heat. When hot liquid is poured into the tumbler, the inner surface of the tumbler becomes hot and expands while the outer surface remains at the room temperature and does not expand. Due to this unequal expansion, the tumbler cracks. Electric wires Electric wires between electric posts contract on cold days and sag in summers. To solve this problem, we leave wires slackso that they are free to change length.

- Glassware used in kitchen and laboratory are generally made up of Borosilicate glass (pyrex glass). The reason is that the Borosilicate glass do not expand much on being heated and therefore they do not crack.

7th Standard - Term(II)
Unit 1. Heat and Temperature

Temperature Units:

- There are three units which are used tomeasure the temperature: DegreeCelsius,Fahrenheit and Kelvin.

  - **Degree Celsius:** Celsius is written as°C andreadas degree. For example 20°C; it is read as twentydegree Celsius. Celsiusis called as Centigrade aswell.

  - **Fahrenheit:** Fahrenheit is written as °F forexample 25°F; it is read as twentyfive degreeFahrenheit.

  - **Kelvin:** Kelvin is written as K. For example100K; it is read as hundred Kelvin.

  - The SI unit of temperature is kelvin (K).

Measuring Temperature

- The temperature of theobject is well approximatedwith the kinetic energy ofthe substances. The hightemperature means that themolecules within the objectare moving at a faster rate.But the question arises, how to measureit? Molecules inany substance are very smallto analyze and calculate its movement (Kineticenergy)in order to measure its temperature.You must use an indirect method to measure thekinetic energy of the molecules of a substance.We studied that solids expandswhen heat issupplied to it. Like solid substances, liquids arealso affected by heat.

- In a thermometer, when liquid gets heat,it expands and when it is cooleddown, itcontracts. It is used to measure temperature.Like solid and liquid objects,the effect ofheat is also observed on gaseous objects.

Thermometer:

- Thermometer is the most common instrumentto measure temperature.Thereare various kinds of thermometers.Some of them are like glass tubes which lookthin and are filled with some kind of liquid.Why Mercury or Alcohol is used inThermometer?Mostly Alcohol and Mercury are used inthermometers as theyremain in liquid formeven with a change of temperature in them.A small change inthe temperature causeschange in volume of a liquid. We measure thistemperatureby measuring expansion of a liquidin thermometer.

Properties of Mercury:-

- Its expansion is uniform. (For equal amountsof heat it expands by equal lengths.)
- It is opaque and shining.
- It does not stick to the sides of the glass tube.
- It is a good conductor of heat.
- It has a high boiling point (357°C) and a lowfreezing point (−39°C). Hence a wide rangeof temperatures can be measured using amercury thermometer

Properties of Alcohol

- The freezing point of alcohol is less than−100°C. So it can be used to measure verylow temperatures.
- Its expansion per degree Celsius rise intemperature is very large.
- It can be coloured brightly and hence iseasily visible.

Types of Thermometers

- There are differenttypes of thermometers formeasuring the temperaturesofdifferent things like air,our bodies, food and manyother things. Among these,thecommonly used thermometers are clinicalthermometers and laboratorythermometers.

Clinical Thermometer

- These thermometers are used to measurethe temperature of a human body, athome,clinics and hospitals. All clinical thermometershave a kink that prevents themercury fromflowing back into the bulb when thethermometer is taken out of thepatient'smouth, so that the temperature can benoted conveniently. There aretemperaturescales on either side of the mercurythread, one in Celsius scale and theotherin Fahrenheit scale. Since the Fahrenheitscale is more sensitive than theCelsiusscale, body temperature is measured inF only. A clinical thermometerindicatestemperatures from a minimum of 35°C or94°F to a maximum of 42°C or108°F.

Precautions to be Followed While Using aClinical Thermometer

- ❖ The thermometer should be washed beforeand after use, preferably with anantisepticsolution.
- ❖ Jerk the thermometer a few times to bringthe level of the mercury down.
- ❖ Before use, the mercury level should bebelow 35°C or 94°F.
- ❖ Do not hold the thermometer by its bulb.

- ❖ Keep the mercury level along your line ofsight and then take the reading.
- ❖ Handle the thermometer with care. If it hitsagainst some hard object, it may break.
- ❖ Do not place the thermometer in a hot flameor in the hot sun.

Laboratory Thermometers

- Laboratory thermometers are used tomeasure the temperature in school andotherlaboratories for scientific research. They arealso used in the industry as theycan measuretemperatures higher than what clinicalthermometers can record. Thestem and thebulb of a lab thermometer are longer whencompared to that of aclinical thermometer andthere is no kink in the lab thermometer.A laboratorythermometer has only theCelsius scale ranging from −10°C to110°C.

Precautions to be Followed While Using a Laboratory Thermometer

- ❖ Do not tilt the thermometer whilemeasuring the temperature. Place itupright.
- ❖ Note the reading only when thebulb has been surrounded by thesubstance from all sides.

Do you know?

- In humans, the averageinternal temperature is37°C (98.6°F), though itvariesamong individuals.However, no person always has exactlythe same temperature atevery moment ofthe day. Temperatures cycle regularly upand down through theday according toactivities and external factors.

Clinical Thermometer	**Laboratory Thermometer**
Clinical Thermometer is scaled from 35°C to 42°C or from 94°C to 108°F.	Laboratory thermometer is generally from -10°C-110°C.
Mercury level does not fall on its own, as there is a link near the bulb to prevent the fall of mercury level.	Mercury level falls on its own as no kink is present
Temperature can be read after removing the thermometer from armpit or mouth.	Temperature is read while keeping the thermometer in the source of temperature, e.g. a liquid or any other thing.
To lower the mercury level jerks are given.	No need to give jerk to lower the mercury level

It is used for taking the body temperature	It is used to take temperature in laboratory

Digital Thermometer

- Here is a lot of concernover the use of mercury inthermometers. Mercuryis atoxic substance andis very difficultto dispose of if athermometer breaks. These days, digitalthermometers are available which donot use mercury. Instead, it has asensorwhich can measure the heat coming outfrom the body directly and from thatcan measure the temperature of thebody.Digital thermometers are mainlyused totake the body temperature.

Caution

- Alex wanted to measure the temperatureof hot milk using a clinicalthermometer. Histeacher stopped him from doing so.We are advised not to use aclinicalthermometer for measuring the temperature ofany object other than humanbody. Also we areadvised to avoid keeping it in the sun or near aflame. Why?A clinical thermometer has smalltemperature range. The glass will crack/ burstdue toexcessive pressure created by expansionof mercury.

Do you know?

Maximum - Minimum thermometer

- The maximum andminimum temperatures ofthe previous day reported inweatherreports are measured by a thermometercalled the maximum – minimumthermometer.

Scales of thermometers

Celsius scale

- Celsius is the common unit of measuringtemperature, termed after Swedishastronomer,Anders Celsius in 1742, before that it wasknown as Centigrade asthermometers usingthis scale are calibrated from (Freezing pointof water) 0°C to 100°C (boiling point of water).

- In Greek, 'Centium' means 100 and 'Gradus'means steps, both words make itcentigrade andlater Celsius.

Fahrenheit Scale

- Fahrenheit is a Common unit to measurehuman body temperature. It istermed after thename of a German Physicist Daniel GabrielFahrenheit. Freezingpoint of water is taken as32°F and boiling point 212°F. Thermometers withFahrenheit scale are calibrated from 32°F to 212°F.

Kelvin scale

- Kelvin scale is termed after Lord Kelvin.It is the SI unit of measuringtemperature andwritten as K also known as absolute scale as itstarts from absolutezero temperature.

- Temperature in Celsius scale can be easily converted to Fahrenheit and Kelvin scale as discussed

  - Relation between Fahrenheit scale and Celsius scales is as under.

$$\frac{(F-32)}{9}=\frac{C}{5}, K = 273.15 + C$$

- The equivalence between principal temperatures scales are given in Table for some temperatures.

Temperature	**Celsius scale (°C)**	**Fahrenheit scale (°F)**	**Kelvin scale (K)**
Boiling temperature	100	212	373.15
Freezing point of water	0	32	273.15
Mean temperature of human body	37	98.6	310.15
Room temperature	72	23	296.15

8^{th} Standard
Term II
Unit 1. Heat

Effect of heat

- When heat energy is supplied to any substance, it brings about many changes. There are three important changes that we can see in our daily life. They are:

  - Expansion
  - Increase in temperature
  - Change in state

Expansion in solids

- Why didn't the ball go through the ring initially but went through it after some time? When the ball is heated the atoms in the ball gain heat energy. They start vibrating and force each other apart. As a result an expansion takes place. That's why the ball did not go through the ring. After some time, as the ball lost the heat energy to the surrounding it came back to its original size and it went through the ring. This shows that heat energy causes expansion in solids. This expansion takes place in liquids and gases also. It is maximum in gases.

- You would have noticed some space being left in railway tracks. Why? It is because railway tracks which are made up of iron metal expand during summer. When there is a gap, there will not be any damage in the track due to expansion of the metal rod

Rise in Temperature

- When the water is heated, water molecules receive heat energy. This heat energy supplied increases the kinetic energy of the molecules. temperature of the water increases. This shows that heat energy causes increase in temperature.

- Heat energy change in temperature

Change of State

- In ice cubes the force of attraction between the water molecules is more. So they are close together. When we heat them the force of attraction between the molecules decreases and the ice cubes become water. When we heat the water, the force of attraction decreases further. Hence they move away from one another and become vapour. Since water vapour escape to the surrounding, water level decreases further. From this we understand that heat energy causes change in the state of the substances. When heat energy is removed, changes take place in reverse direction.

- If heat energy is supplied to or taken out from a substance, it will undergo a change from one state of matter to another. One of the following transformations may take place due to heat energy.

    - **Solid to Liquid (Melting)**
    - **Liquid to Gas (Vapourisation)**
    - **Solid to Gas (Sublimation)**
    - **Gas to Liquid (Condensation)**
    - **Liquid to Solid (Freezing)**
    - **Gas to Solid (Deposition)**

- Water is the only matter on the Earth that can be found naturally in all three states - Solid, Liquid and Gas.

Transfer of heat

- If heat energy is supplied to any substance, it will be transferred from one part of the substance to another part. It takes place in different ways depending on the state of the substance. Three ways of heat transfer are:

    - **Conduction**
    - **Convection**
    - **Radiation**

Conduction

- How did the other end of the spoon become hot? It is because heat in the hot water is transferred from one end to other end of the spoon. In solid substances such as silver spoon, atoms are arranged very closely. Hot water molecules which are vibrating transfer the heat energy to the atoms in the spoon and make them vibrate. Those atoms make other atoms to vibrate and thus heat is transferred to the other end of the spoon.

- In conduction heat transfer takes place between two ends of the same solid or through two solid substances that are at different temperatures but in contact with one another. Thus, we can define conduction as the process of heat transfer in solids from the region of higher temperature to the region of lower temperature without the actual movement ofatoms or molecules.

- All metals are good conductors of heat. The substances which does not conduct heat easily are called bad conductors or insulators. Wood, cork, cotton, wool, glass, rubber,etc are insulators.

Conduction in daily life

❖ We cook food in vessels made up of metals. When the vessel is heated, heat is transferred from the metal to the food.

- When we iron dresses heat is transferred from the iron to the cloth.

- Handles of cooking utensils are made up of plastic or wood because they are poor conductors of heat.

- The temperature inside igloo (snow house) is warm because snow is a poor conductor of heat.

Convection

- When water in the vessel is heated, water molecules at the bottom receive heat energy and move upward. Then the molecules at the top comes down and get heated. This kind of heat transfer is known as convection. This is how air in the atmosphere is also heated. Thusthe form of heat transfer from places of high temperature to places of low temperature by the actual movement of molecules is called convection. Convection takes place in liquids and gases.

Convection in daily life

- **Formation of land breeze and sea breeze is due to convection of air.**
- **Wind flows from one region to another region by convection.**
- **In hot air balloons heat is transferred by convection and so the balloon raises.**
- **In refrigirators, cool air moves downward and replaces the hot air because of convection.**

Radiation

- Radiation is the third form of heat transfer. By conduction, heat is transferred through solids, by convection heat is transferred through liquids and gases, but by radiation heat can be transferred throughempty space even through vacuum. Heat energy from the Sun reaches the Earth by this

- Heat transfer by radiation is visible to our eyes. When a substance is heated to 500°C the radiation begins to become visible to the eye as a dull red glow, and it is sensed as warmth by the skin. Further heating

- rapidly increases the amount of radiation, and its perceived colour becomes orange, yellow and finally white

- form of heat transfer. Radiation is defined as the way of heat transfer from one place to another in the form of electromagnetic waves.

Radiation in daily life

- · Heat energy from the Sun reaches the Earth by radiation.

- While standing near fire we feel the heat which is transferred as radiation.

- Black surfaces absorb heat radiation. So that the bottom of the cooking vessels are painted black.

- White colour reflects heat radiation. That's why we are advised to wear white cloth during summer.

Calorimetry

- We studied about the effects of heat energy. When heat energy is supplied to substances, physical changes take place in them. Solid form of water (ice) is changed to liquid form, and liquid form of water is changed to gaseous form. These are all the physical changes due to heat energy. Similarly, heat energy produces chemical changes also. To know more about the physical and chemical changes that take place in substances, we need to measure the amount of heat involved. The technique used to measure the amount of heat involved in a physical or a chemical process is known as calorimetry.

Temperature

- Temperature is a physical quantity which expresses whether an object is hot or cold. It is measured with the help of thermometer. There are three scales to measure the temperature.

  They are:
  - **Celcius scale**
  - **Fahrenheit scale**
  - **Kelvin scale**

- Among these three scales, Kelvin scale is the most commonly used one. You will study about this in detail in Standard IX.

Unit of Heat

- We know that heat is a form of energy. The unit of energy in SI system is joule. So, heat is also measured in joule. It is expressed by the symbol J. The most commonly used unit of heat is calorie. One calorie is the amount of heat energy required to raise the temperature of 1 gram of water through 1°C. The relation between calorie and joule is given as, 1 calorie = 4.186 J.

- The amount of energy in food items is measured by the unit kilo calorie. 1 kilo calorie = 4200 J (Approximately).

Heat capacity

- In general, the amount of heat energy gained or lost by a substance is determined by three factors. They are:

  - **Mass of the substance**
  - **Change in temperature of the substance**
  - **Nature of the material of the substance**

- Different substances require different amount of heat energy to reach a particular temperature. This nature is known as heat capacity of a substance. Heat capacity is defined as the amount of heat energy required by a substance to raise its temperature by 1°C or 1 K. It is denoted by the symbol C'. Heat capacity

$$\frac{Amount\ of\ heat\ energy\ reqiured(Q)}{Raise\ in\ temperature\ (\Delta T)}$$

Therefore, C' = Q / ΔT

- The unit of heat capacity is cal / °C. In SI system, it is measured in JK-1.

Specific heat capacity

- When the heat capacity of a substance is expressed for unit mass, it is called specific heat capacity. Specific heat capacity of a substance is defined as the amount of heat energy required to raise the temperature of 1 kilogram of a substance by 1°C or 1 K. It is denoted by the symbol C.

Specific heat of capacity

$$= \frac{Amount\ of\ heat\ energy\ reqiured(Q)}{Mass \times Raise\ in\ temperature\ (\Delta T)}$$

Therefore, C = Q /m . ΔT

The SI unit of specific heat capacity is J Kg-1 K -1.

Calorimeter

- A calorimeter is a device used to measure the amount of heat gained or lost by a substance. It consists of a vessel made up of metals like copper or aluminium which are good conductors of heat and electricity.

- The metallic vessel is kept in an insulating jacket to prevent heat loss to the environment. There are two holes in it. Through one hole a thermometer is inserted to measure thetemperature of the contents. A stirrer is inserted through another hole for stirring the content in the vessel. The vessel is filled with liquid whichis heated by passing current through the heating element. Using this device we can measure the heat capacity of the liquid in the container.

- The world's first ice-calorimeter was used in the year 1782 by Antoine Lavoisier and Pierre- Simon Laplace, to determine the heat generated by various chemical changes.

Thermostat

- A thermostat is a device which maintains the temperature of a place or an object constant. The word thermostat is derived from two Greek words, 'thermo' meaning heat and 'static' meaning staying the same. Thermostats are used in any device or system that gets heated or cools down to a pre-set temperature. It turns an appliance or a circuit on or off when a particular temperature is reached. Devices which use thermostat include building heater, central heater in a room, air conditioner, water heater, as well as kitchen equipments including oven and refrigerators. Sometimes, a thermostat functions both as the sensor and the controller of a thermal system.

Thermos Flask

(Vacuum flask)

- The thermos flask (Vacuum flask) is an insulating storage vessel that keeps its content hotter or cooler than the surroundings for a longer time. It is primarily meant to enhance the storage period of a liquid by maintaining a uniform temperature and avoiding possibilities of getting a bad taste.

- The vacuum flask was invented by Scottish scientist Sir James Dewar in 1892. In his honour it is called Dewar flask. It's also known as Dewar bottle.

Working of Thermos flask

- A thermos flask has double walls, which are evacuated. It is silvered on the inside. The vacuum between the two walls prevents heat being transferred from the inside to the outside by conduction and convection.

- With very little air between the walls, there is almost no transfer of heat from the inner wall to the outer wall or vice versa. Conduction can only occur at the points where the two walls meet, at the top of the bottle and through an insulated support at the bottom. The silvered walls reflect radiated heat back to the liquid in the bottle.

9th Standard
Unit – 7 – Heat

Heat transfer takes place in three ways:

i. **Conduction,**
ii. Convection,
iii. Radiation

Conduction

- In solids, molecules are closely arranged so that they cannot move freely. When one end of the solid is heated, molecules at that end absorb heat energy and vibrate fast at their own positions. These molecules in turn collide with the neighboring molecules and make them vibrate faster and so energy is transferred. This process continues till all the molecules receive the heat energy.

- The process of transfer of heat in solids from a region of higher temperature to a region of lower temperature without the actual movement of molecules is called conduction.

Conduction in daily life

i. Metals are good conductors of heat. So, aluminium is used for making utensils to cook food quickly.

ii. Mercury is used in thermometers because, it is a good conductor of heat.

iii. We wear woolen clothes is winter to keep ourselves warm. Air, which is a bad conductor, does not allow our body heat to escape.

Convection

- In this activity, water molecules at the bottom of the beaker receive heat energy and move upward and replace the molecules at the top. Same thing happens in air also. When air is heated, the air molecules gain heat energy allowing them to move further apart. Warm air being less dense than cold air will rise. Cooler air moves down to replace the air that has risen. It heats up, rises and is again replaced by cooler air, creating a circular flow.

- Convection is the flow of heat through a fluid from places of higher temperature to places of lower temperature by movement of the fluid itself.

Convection in daily life

Hot air balloons:

- Air molecules at the bottom of the balloon get heated by a heat source and rise. As the warm air rises, cold air is pushed downward and it is also heated. When the hot air is trapped inside the balloon, it rises.

Breezes:

- During day time, the air in contact with the land becomes hot and rises. Now the cool air over the surface of the sea replaces it. It is called sea breeze. During night time, air above the sea is warmer. As the warmer air over the surface of the sea rises, cooler air above the land moves towards the sea. It is called land breeze.

Winds:

- Air flows from area of high pressure to area of low pressure. The warm air molecules over hot surface rise and create low pressure. So, cooler air with high pressure flows towards low pressure area. This causes wind flow.

Chimneys:

- Tall chimneys are kept in kitchen and industrial furnaces. As the hot gases and smoke are lighter, they rise up in the atmosphere.

Radiation

- Radiation is a method of heat transfer that does not require particles to carry the heat energy. In this method, heat is transferred in the form of waves from hot objects in all direction. Radiation can occur even in vacuum whereas conduction and convection need matter to be present. Radiation consists of electromagnetic waves travelling at the speed of light. Thus, radiation is the flow of heat from one place to another by means of electromagnetic waves.

- Transfer of heat energy from the sun reaches us in the form of radiation. Radiation is emitted by all bodies above 0 K. Some objects absorb radiation and some other objects reflect them.

- While firing wood, we can observe all the three ways of heat transfer. Heat in one end of the wood will be transfered to other end due to conduction. The air near the wood will become warm and replace the air above. This is convection. Our hands will be warm because heat reaches us in the form of radiation.

Radiation in daily life

i. White or light colored cloths are good reflectors of heat. They keep us cool during summer.

ii. Base of cooking utensils is blackened because black surface absorbs more heat from the surrounding.

iii. Surface of airplane is highly polished because it helps to reflect most of the heat radiation from the sun.

Concept of temperature

- Temperature is the degree of hotness or coolness of a body. Hotter the body, higher is its temperature.

Unit of Temperature

- The SI unit of temperature is kelvin (K). For day to day applications, Celsius (°C) is used. Temperature is measured with a thermometer.

Temperature scales

There are three scales of temperature.

i. Fahrenheit scale

ii. Celsius or Centigrade scale

iii. Kelvin or Absolute scale

Fahrenheit scale

- In Fahrenheit scale, 32 °F and 212 °F are the freezing point and boiling point respectively. Interval has been divided into 180 parts.

- Celsius temperature scale

- In Celsius scale, also called centigrade scale, 0°C and 100 °C are the freezing point and boiling point respectively. Interval has been divided into 100 parts. The formula to convert a Celsius scale to Fahrenheit scale is:

$$F=\frac{9}{5}C+32$$

The formula for converting a Fahrenheit scale to Celsius scale is:

$$C=\frac{5}{9}(F-32)$$

Kelvin scale (Absolute scale)

- Kelvin scale is known as the absolute scale. On the Kelvin scale 0 K represents absolute zero, the temperature at which the molecules of a substance have their lowest possible energy. The solid, liquid, gaseous

- The temperature at which the pressure and volume of a gas theoretically reaches zero is called absolute zero. This is shown in Figure 7.7.

- For all gases, the pressure extrapolates to zero at the temperature –273.15 °C. It is known as absolute zero or 0 K. Some base linetemperatures in the three temperature scales are shown in Table.

Temperature	Kelvins (K)	DegreCelcius (°C)	Degrees Fahrenheit (°F)
Boiling point of water	373.15	100	212
Melting point of ice	273.15	0	32
Absolute zero	0	-273	-460

Change of state

- The process of changing of a substance from one physical state to another at a definite temperature is known as change of state. For example, water molecules are in liquid state at normal temperature. When water is heated to 100°C, it becomes steam which is a gaseous state of matter. On reducing the temperature of the steam it becomes water again. If we reduce the temperature further to 0 °C, it becomes ice which is a solid state of water. Ice on heating, becomes water again. Thus, water changes its state when there is a change in temperature. There are different such processes in the change of state in matter. Figure 7.8 shows various processes of change of state.

Melting – Freezing

- The process in which a solid is converted to liquid by absorbing heat is called melting or fusion. The temperature at which a solid changes its state to liquid is called melting point. The reverse of melting is freezing. The process in which a liquid is converted to solid by releasing heat is called freezing. The temperature at which a liquid changes its state to solid is called freezing point. In the case of water, melting and boiling occur at 0°C.

Boiling-Condensation

- The process in which a liquid is converted to vapor by absorbing heat is called boiling or vaporization. The temperature at which a liquid changes its state to gas is called boiling point. The process in which a vapor is converted to liquid by releasing heat is called condensation. The temperature at which vapour changes its state to liquid is called condensation point. Boiling point as well as condensation point of water is 100°C.

Sublimation

- Some solids like dry ice, iodine, frozen carbon dioxide and naphthalene balls change directly from solid state to gaseous state without becoming liquid. The process in which a solid is converted to gaseous state is called sublimation. Various stages of conversion of state of matter by heat with the corresponding change in temperature.

Latent heat

- The word, 'latent' means hidden. So, latent heat means hidden heat or hidden energy. In order to understand latent heat, let us do the activity given belowIn the above activity, temperature is constant at 0°C until entire ice is converted into liquid and again constant at 100°C until all the ice is converted into vapor. Why? It is because, when a substance changes from one state to another, a considerable amount of heat energy is absorbed or liberated. This energy is called latent heat. Thus, latent heat is the amount of heat energy absorbed or released by a substance during a change in its physical states without any change in its temperature.

- Heat energy is absorbed by the solid during melting and an equal amount of heat energy is liberated by the liquid during freezing, without any temperature change. It is called latent heat of fusion. In the same manner, heat energy is absorbed by a liquid during vaporization and an equal amount of heat energy is liberated by the vapor during condensation, without anytemperature changes. This is called latent heat of vaporization.

Specific latent heat

- Latent heat, when expressed per unit mass of a substance, is called specific latent heat. It is denoted by the symbol L. If Q is the amount of heat energy absorbed or liberated by 'm' mass of a substance during its change of phase at a constant temperature, then specific latent heat is given as $L = Q/m$.

- Thus, specific latent heat is the amount of heat energy absorbed or liberated by unit mass of a substance during change of state without causing any change in temperature. The SI unit of specific latent heat is J/kg.

10th Standard

Unit 3. Thermal Physics

EFFECT OF HEAT ENERGY

- When a certain amount of heat energy is given to a substance, it will undergo one or more of the following changes:
    - **Temperature of the substance rises.**
    - **The substance may change its state from solid to liquid or from liquid to gas.**
    - **The substance will expand when heated.**

- The rise in temperature is in proportion to the amount of heat energy supplied. It also depends on the nature and mass of the substance. About the rise in temperature and the change of state, you have studied in previous classes. In the following section, we shall discuss about the expansion of substances due to heat.

Expansion of Substances

- When heat energy is supplied to a body, there can be an increase in the dimension of the object. This change in the dimension due to rise in temperature is called thermal expansion of the object. The expansion of liquids (e.g. mercury) can be seen when a thermometer is placed in warm water. All forms of matter (solid, liquid and gas) undergo expansion on heating.

a) Expansion in solids

- When a solid is heated, the atoms gain energy and vibrate more vigorously. This results in the expansion of the solid. For a given change in temperature, the extent of expansion is smaller in solids than in liquids and gases. This is due to the rigid nature of solids.

- The different types of expansion of solid are listed and explained below:
    - **Linear expansion**
    - **Superficial expansion**
    - **Cubical expansion**

1. Linear expansion:

- When a body is heated or cooled, the length of the body changes due to change in its temperature. Then the expansion is said to be **linear or longitudinal expansion.**

- The ratio of increase in length of the body per degree rise in temperature to its unit length is called as the coefficient of linear expansion. The SI unit of Coefficient of Linear expansion is K-1. The value of coefficient of linear expansion is different for different materials.

- The equation relating the change in length and the change in temperature of a body is given below:

$$\Delta L / L_o = \alpha_L \Delta T$$

ΔL - Change in length (Final length- Original length)

L_o - Original length

ΔT - Change in temperature (Final temperature - Initial temperature)

α_L - Coefficient of linear expansion.

2. Superficial expansion:

- If there is an increase in the area of a solid object due to heating, then the expansion is called superficial or areal expansion.

- Superficial expansion is determined in terms of coefficient of superficial expansion. The ratio of increase in area of the body per degree rise in temperature to its unit area is called as coefficient of superficial expansion. Coefficient of superficial expansion is different for different materials. The SI unit of Coefficient of superficial expansion is K-1

- The equation relating to the changein area and the change in temperature.

$$\Delta A / A_o = \alpha_A \Delta T$$

ΔA - Change in area (Final area - Initial area)

A_o- Original area

ΔT - Change in temperature (Final temperature - Initial temperature)

α_A - Coefficient of superficial expansion.

3. Cubical expansion:

- If there is an increase in the volume of a solid body due to heating, then the expansion is called cubical or volumetric expansion.

- As in the cases of linear and areal expansion, cubical expansion is also expressed in terms of coefficient of cubical expansion. The ratio of increase in volume of the body per degree rise in temperature to its unit volume is called as coefficient of cubical expansion. This is also measured in K^{-1}.

- The equation relating to the change in volume and the change in temperature is given below:

$$\Delta V / V_o = \alpha_V \Delta T$$

ΔV - Change in volume(Final volume - Intial volume)

Vo - Original volume

ΔT - Change in temperature (Final temperature - Initial temperature)

αV - Coefficient of cubical expansion.

- Different materials possess different coefficient of cubical expansion.The following table gives the coefficient of cubical expansion for some common materials.

Coefficient of cubical expansion of some materials

S.No.	Name of the material	Coefficient of cubic expansion (K–1)
1	Aluminium	7×10^{-5}
2	Brass	6×10^{-5}
3	Glass	2.5×10^{-5}
4	Water	20.7×10^{-5}
5	Mercury	18.2×10^{-5}

b) Expansion in liquids and gases

- When heated, the atoms in a liquid or gas gain energy and are forced further apart. The extent of expansion varies from substance to substance. For a given rise in temperature, a liquid will have more expansion than a solid and a gaseous substance has the highest expansion when compared with the other two. The coefficient of cubical expansion of liquid is independent of temperature whereas its value for gases depends on the temperature of gases.

- When a liquid is heated, it is done by keeping the liquid in some container and supplying heat energy to the liquid through the container. The thermal energy supplied will be partly used in expanding the container and partly used in expanding the liquid. Thus, what we observe may not be the actual or real expansion of the liquid. Hence, for liquids, we can define real expansion and apparent expansion.

1) Real expansion

- If a liquid is heated directly without using any container, then the expansion that you observe is termed as **real expansion** of the liquid.

- **Coefficient of real expansion** is defined as the ratio of the true rise in the volume of the liquid per degree rise in temperature to its unit volume. The SI unit of coefficient of real expansion is K–1.

2) Apparent expansion

- Heating a liquid without using a container is not possible. Thus, in practice, you can heat any liquid by pouring it in a container. A part of thermal energy is used in expanding the container and a part is used in expanding the liquid. Thus, what you observe is not the actual or real expansion of the liquid. The expansion of a liquid apparently observed without considering the expansion of the container is called the **apparent expansion** of the liquid.

- **Coefficient of apparent expansion** is defined as the ratio of the apparent rise in the volume of the liquid per degree rise in temperature to its unit volume. The SI unit of coefficient of apparent expansion is K–1.

Experiment to measure real and apparent expansion of liquid

- To start with, the liquid whose real and apparent expansion is to be determined is poured in a container up to a level. Mark this level as L1. Now, heat the container and the liquid using a burner.

- Initially, the container receives the thermal energy and it expands. As a result, the volume of the liquid appears to have reduced. Mark this reduced level of liquid as L2.

- On further heating, the thermal energy supplied to the liquid through the container results in the expansion of the liquid. Hence, the level of liquid rises to L3. Now, the difference between the levels L1 and L3 is called as **apparent expansion,** and the difference between the levels L2 and L3 is called **real expansion**. The real expansion is always more than that of apparent expansion.

Real expansion = L3 – L2
Apparent expansion = L3 – L1

FUNDAMENTAL LAWS OF GASES

- The three fundamental laws which connect the relation between pressure, volume and temperature are as follows:
    - Boyle's Law
    - Charles's law
    - Avogadro's law

Boyle's law:

- When the temperature of a gas is kept constant, the volume of a fixed mass of gas is inversely proportional to its pressure.

$$P \propto 1/V$$

- In other words, for an invariable mass of a perfect gas, at constant temperature, the product of its pressure and volume is a constant.

(i.e) PV = constant

Charles's law (The law of volume)

- Charles's law was formulated by a French scientist Jacques Charles. According to this law, When the pressure of gas is kept constant, the volume of a gas is directly proportional to the temperature of the gas.

V α T
or
V /T= constant

Avogadro's law

- Avogadro's law states that at constant pressure and temperature, the volume of a gas is directly proportional to number of atoms or molecules present in it.

i.e. V α n
(or) V/N= constant

- Avogadro's number (NA) is the total number of atoms per mole of the substance. It is equal to 6.023 × 1023 /mol.

GASES

- Gases are classified as real gases and ideal gases.

Real Gases

- If the molecules or atoms of a gases interact with each other with a definite amount of intermolecular or inter atomic force of attraction, then the gases are said to be real gases. At very high temperature or low pressure, a real gases behaves as an ideal gases because in this condition there is no interatomic or intermolecular force of attraction.

Ideal Gases

- If the atoms or molecules of a gas do not interact with each other, then the gas is said to be an ideal gas or a perfect gas.

- Actually, in practice, no gas is ideal. The molecules of any gas will have a certain amount of interaction among them. But, these interactions are weaker when the pressure is low or the temperature is high because the interatomic or intermolecular forces of attraction are weak in ideal gas. Hence, a real gas at low pressure or high temperature can be termed as a perfect gas.

- Ideal gases obey Boyle's law, Charles's law and Avogadro's law. All these laws state the relationship between various properties of a gas such as pressure (P), volume (V), temperature (T) and number of atoms (n). In a given state of the gas, all these parameters will have a definite set of values. When there is a change in the state of the gas, any one or more of these parameters change its value. The above said laws relate these changes.

Ideal Gas Equation

- The ideal gas equation is an equation, which relates all the properties of an ideal gas. An ideal gas obeys Boyle's law and Charles' **law and Avogadro's law. According to Boyle's law,**

$$PV = constant \quad (3.1)$$

According to Charles's law,

$$V/T = constant \quad (3.2)$$

According to Avogadro's law,

$$V/n = constant \quad (3.3)$$

- After combining equations (3.1), (3.2) and (3.3), you can get the following equation.

$$PV/nT = constant \quad (3.4)$$

- The above relation is called the combined law of gases. If you consider a gas, which contains μ moles of the gas, the number of atoms contained will be equal to μ times the Avogadro number, NA.

  i.e. $n = \mu N_A$. (3.5)

  Using equation (3.5), equation (3.4) can be written as

  $$PV/\mu N_A T = \text{constant}$$

- The value of the constant in the above equation is taken to be kB, which is called as **Boltzmann constant (1.38 × 10–23 JK–1).** Hence, we have the following equation:

  $$PV/\mu N_A T = k_B$$

  $$PV = \mu N_A k_B\, T$$

  Here, $\mu N_A k_B = R$, which is termed as universal gas constant whose value is

  $8.31\ J\ mol^{-1}\ K^{-1}$.

  $$PV = RT \quad (3.6)$$

- Ideal gas equation is also called as equation of statebecause it gives the relation between the state variables and it is used to describe the state of any gas.

Solved Problems

Example 1

- A container whose capacity is 70 ml is filled with a liquid up to 50 ml. Then, the liquid in the container is heated. Initially, the level of the liquid falls from 50 ml to 48.5 ml. Then we heat more, the level of the liquid rises to 51.2 ml. Find the apparent and real expansion.

Data:

Level of the liquid L1 = 50 ml
Level of the liquid L2 = 48.5 ml
Level of the liquid L3 = 51.2 ml

Apparent expansion = L3 − L1
= 51.2 ml – 50 ml = 1.2ml
Real expansion = L3 − L1
= 51.2 ml – 48.5ml = 2.7ml

So, Real expansion > apparent expansion

Example 2

- Keeping the temperature as constant, a gas is compressed four times of its initial pressure. The volume of gas in the container changing from 20cc (V_1 cc) to V_2 cc. Find the final volume V_2.

Data:

Initial pressure (P_1)= P
Final Pressure (P_2) = 4P
Initial volume (V_1) = 20cc = 20cm3
Final volume (V_2) = ?

Using Boyle's Law, PV = constant

$$P_1V_1 = P_2V_2$$

$$P_1 / P_2 \times V_2 = V_1$$

$$= P/4P \times 20cm^3$$

$$\mathbf{V_2 = 5\ cm^3}$$

11th Standard - Volume (II)

UNIT 8: HEAT AND THERMODYNAMICS

Anomalous expansion of water:

- The volume of given amount of water decreases as it is cooled but up to 4℃. Below 4℃ volume increases so density decreases. Water has maximum density at 4℃. this behaviour is called anomalous expansion of water.

- Since ice have lower density than water at 4℃ the ice will float at top of water. As water freezes only at top, species in bottom of the lake will be safe.

Change of state:

- Latent heat capacity of substance is defined as the amount of heat energy required to change the state of unit mass of the material.
- When heat is added or removed during a change of state, the temperature remains constant.

- The triple point of substance is the temperature and pressure at which the three phases (gas, liquid and solid) of that substance coexist in thermodynamic equilibrium. The triple point of water is at 273.1 K at a partial vapour pressure of 611.657 Pascal.

Calorimetry:

- A sample is heated at high temperature (T_1) and immersed into water at room temperature (T_2) in the calorimeter. After some time both reach a final equilibrium temperature T_f.

$$\mathbf{T_f = \frac{m_1 s_1 T_1 + m_2 s_2 T_2}{m_1 s_1 + m_2 s_2}}$$

Here $s1$ and $s2$ specific heat capacity of hot sample and water respectively.

Newton's law of cooling:

- Newton's law of cooling states that the rate of loss of heat of a body is directly proportional to the difference in the temperature between that body and its surroundings.

$$\mathbf{\frac{dQ}{dt} \propto -(T - T_s)}$$

- The negative sign indicates that quantity of heat lost by liquid goes on decreasing with time. Where T= temperature of object T_s= temperature of surrounding

Laws of Heat transfer:

Prevost theory of heat exchange:

- Only at absolute zero temperature a body will stop emitting. Therefore Prevost theory states that all bodies emit thermal radiation at all temperatures above absolute zero irrespective of the nature of the surroundings. A body at high temperature radiates more heat to the surroundings than it receives from it.

Stefan Boltzmann Law:

- Stefan Boltzmann law states that, the total amount of heat radiated per second per unit area of a black body is directly proportional to the fourth power of its absolute temperature.

$$E = \sigma T^4$$

Stefan constant, $\sigma = 5.67 \times 10^{-8}\ Wm^{-2}k^{-4}$

If a body is not a perfect black body, then

$$E = e\sigma T^4$$

- 'e' is emissivity of surface. Emissivity is defined as ratio of energy radiated from a material's surface to that radiated from a perfect black body at same temperature and wavelength.

Wien's displacement law:

- Wien's law states that, the wavelength of maximum intensity of emission of a black body radiation is inversely proportional to the absolute temperature of the black body.

$$\lambda_m = \frac{b}{T}$$

Where Wien's constant, $b = 2.898 \times 10^{-3}\ m\ K$

- It implies that if temperature of the body increases, maximal intensity wavelength (λ_m) shift s towards lower wavelength (higher frequency) of electromagnetic spectrum.

- The Sun is approximately taken as a black body. Since any object above 0 K will emit radiation, Sun also emits radiation. Its surface temperature is about 5700K.

$$\boldsymbol{\lambda_m = \frac{b}{T} = \frac{2.898 \times 10^{-3}}{5700} \approx 508\ nm}$$

- The humans evolved under the Sun by receiving its radiations. The human eye is sensitive only in the visible spectrum. Suppose if humans had evolved in a planet near the star Sirius (9940K), then they would have had the ability to see the Ultraviolet rays!

THERMODYNAMICS:

- A branch of physics which describes the laws governing the process of conversion of work into heat and conversion of heat into work is thermodynamics.

- A thermodynamic system is a finite part of the universe. It is a collection of large number of particles (atoms and molecules) specified by certain parameters called pressure (P), Volume (V) and Temperature (T). The remaining part of the universe is called surrounding.

Thermal equilibrium:

- Two systems are said to be in thermal equilibrium with each other if they are at the same temperature, which will not change with time.

- A system is said to be in mechanical equilibrium if no unbalanced force acts on the thermodynamic system or on the surrounding by thermodynamic system.

- There is no net chemical reaction between two thermodynamic systems in contact with each other then it is said to be in chemical equilibrium.

If two systems are set to be in thermodynamic equilibrium, then the systems are at thermal, mechanical and chemical equilibrium with each other. In a state of thermodynamic equilibrium the macroscopic variables such as pressure, volume and temperature will have fixed values and do not change with time.

Thermodynamic state variables:

- Heat and work are not state variables rather they are process variables.

- There are two types of thermodynamic variables: Extensive and Intensive

Extensive variable depends on the size or mass of the system.

Example: Volume, total mass, entropy, internal energy, heat capacity etc. Intensive variables do not depend on the size or mass of the system.

Example: Temperature, pressure, specific heat capacity, density etc.

- The equation which connects the state variables in a specific manner is called equation of state. A thermodynamic equilibrium is completely specified by these state variables by the equation of state.

ZEROTH LAW OF THERMODYNAMICS:

- The zeroth law of thermodynamics states that if two systems, A and B, are in thermal equilibrium with a third system, C, then A and B are in thermal equilibrium with each other.

Example: Temperature of the thermometer will be same as the human body. This principle is used in finding the body temperature.

INTERNAL ENERGY (U):

- The internal energy of a thermodynamic system is the sum of kinetic and potential energies of all the molecules of the system with respect to the centre of mass of the system. The energy due to molecular motion including translational, rotational and vibrational motion is called internal kinetic energy (E_K) The energy due to molecular interaction is called internal potential energy (E_P). Example: Bond energy.

$$U = E_K + E_P$$

- Since ideal gas molecules are assumed to have no interaction with each other the internal energy consists of only kinetic energy part (E_K) which depends on the temperature, number of particles and is independent of volume. However this is not true for real gases like Van der Waals gases.

- Internal energy is a state variable. It depends only on the initial and final states of the thermodynamic system and not the way it is arrived at.

- Internal energy of a thermodynamic system is associated with only the kinetic energy of the individual molecule due to its random motion and the potential energy of molecules which depends on their chemical nature.The bulk kinetic energy of the entire system or gravitational potential energy of the system should not be mistaken as a part of internal energy.

Heat does not always increase the internal energy.

Joule's Mechanical Equivalent of Heat:

- In the eighteenth century, Joule showed that mechanical energy can be on converted into internal energy and vice versa. In fact, Joule was able to show that the mechanical work has the same effect as giving heat. He found that to raise 1 g of an object by 1°C, 4.186 J of energy is required.

$$1\ cal = 4.186\ J$$

First Law of Thermodynamics:

- This law states that 'Change in internal energy (ΔU) of the system is equal to heat supplied to the system (Q) minus the work done by the system (W) on the surroundings'.

$$\Delta U = Q - W$$

System gains heat	Q is positive	Internal energy increase
System loses heat	Q is negative	Internal energy decreases
Work done on the system	W is negative	Internal energy increase
Work done by the system	W is positive	Internal energy decreases

- This law is applicable to solid, liquid and gases.

Quasi static process:

- A quasi-static process is an infinitely slow process in which the system changes its variables (P,V,T) so slowly such that it remains in thermal, mechanical and chemical equilibrium with its surroundings throughout.

Work Done in Volume changes:

$$W = \int_{V_i}^{V_f} PdV$$

- If work is done on the system $V_i > V_f$ and W is negative. The area under the PV diagram will give the work done during expansion or compression.

SPECIFIC HEAT CAPACITY OF A GAS:
Specific heat capacity at constant pressure (s_p):

- ❖ The amount of heat energy required to raise the temperature of one kg of a substance by 1 K or 1°C by keeping the pressure constant is called specific heat capacity of at constant pressure.

- In this process a part of the heat energy is used for doing work (expansion) and the remaining part is used to increase the internal energy of the gas.

Specific heat capacity at constant volume (s_v):

- The amount of heat energy required to raise the temperature of one kg of a substance by 1 K or 1°C by keeping the volume constant. If the volume is kept constant, then the supplied heat is used to increase only the internal energy. No work is done by the gas.

s_p is always greater than s_v.

- The amount of heat required to raise the temperature of one mole of a substance by 1K or 1°C at constant volume is called molar specific heat capacity at constant volume (Cv). If pressure is kept constant, it is called molar specific heat capacity at constant pressure (Cp).

$$C_v = \frac{1}{\mu}\frac{dU}{dT}$$

Meyer's Relation:

$$C_p - C_v = R$$

THERMODYNAMIC PROCESS

Isothermal process (constant temperature):

$$\Delta U = 0$$
$$Q = W$$

So, the heat supplied to a gas is used to do only external work.

Examples:

(i) When water is heated, at the boiling point, the temperature will not increase unless the water completely evaporates. Similarly, at the freezing point, when the ice melts to water, the temperature of ice will not increase even when heat is supplied to ice.

(ii) All biological processes occur at constant body temperature (37°C).

Adiabatic process:

- This is a process in which no heat flows into or out of the system (Q=0). But the gas can expand by spending its internal energy or gas can be compressed through some external work.

$$\Delta U = W$$

The adiabatic process can be achieved by the following methods

❖ Thermally insulating the system from surroundings.

❖ If the process occurs so quickly that there is no time to exchange heat with surroundings even though there is no thermal insulation.

Example: When the warm air rises from the surface of the Earth, it adiabatically expands. As a result the water vapour cools and condenses into water droplets forming a cloud.

$$PV^{\gamma} = constant$$

Here γ is adiabatic exponent and $\gamma = {C_p}/{C_v}$ which depends on nature of gas.

- The PV diagram for an adiabatic process is also called *adiabat.* The PV diagram for isothermal and adiabatic processes look similar. But the adiabatic curve is steeper than isothermal curve.

$$TV^{\gamma-1} = constant$$
$$T^{\gamma}P^{1-\gamma} = constant$$

Work done in adiabatic process,

$$W_{adia} = \frac{\mu R}{\gamma - 1}\left[T_i - T_f\right]$$

❖ In adiabatic expansion, work done is positive and $T_i > T_f$ and gas cools.

❖ In adiabatic compression, work done is negative and $T_i < T_f$ and temperature of gas increases.

Isobaric Process (constant pressure):

Examples for Isobaric process:

❖ When the gas is heated and pushes the piston so that it exerts a force equivalent to atmospheric pressure plus the force due to gravity.

- ❖ When the food is cooked in an open vessel, the pressure above the food is always at atmospheric pressure.

Work done in an isobaric process,

$$W = P\Delta V = \mu R T_f \left(1 - \frac{T_i}{T_f}\right)$$
$$\Delta U = Q - P\Delta V$$

Isochoric Process (constant volume):

$$\Delta V = 0 \; and \; W = 0. \; So, \qquad \Delta U = Q$$

Examples:

- When food is being cooked in closed position, after a certain time you can observe the lid is being pushed upwards by the water steam. This is because when the lid is closed, the volume is kept constant. As the heat continuously supplied, the pressure increases and water steam tries to push the lid upwards

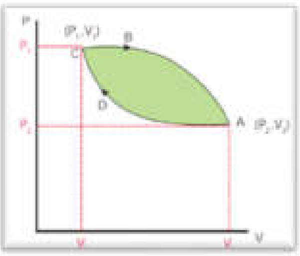
- In automobiles the petrol engine undergoes four processes. First the piston is adiabatically compressed to some volume as shown in the Figure (a). In the second process (Figure (b)), the volume of the air-fuel mixture is kept constant and heat is being added. As a result the temperature and pressure are increased. This is an isochoric process. For a third stroke (Figure (c)) there will be an adiabatic expansion, and fourth stroke again isochoric process by keeping the piston immoveable (Figure (d)).

Cyclic process:

- The thermodynamic system returns to its initial state after undergoing a series of changes. The change in the internal energy is zero. From the first law of thermodynamics, the net heat transferred to the system is equal to work done by the gas.

$$Q_{net} = Q_{in} - Q_{out} = W$$

PV diagram for cyclic process:



- The total work done is green shaded area in the figure. If the net work done is positive, then work done by the system is greater than the work done on the system. If the net work done is negative then the work done by the system is less than the work done on the system.

- Further, in a cyclic process the net work done is positive if the process goes clockwise and network done is negative if the process goes anti-clockwise.

Limitations of First Law of Thermodynamics:

- The first law of thermodynamics explains well the inter convertibility of heat and work. But it does not indicate the direction of change.

For example,

- ❖ According to first law, it is possible for the energy to flow from hot object to cold object or from cold object to hot object. But in nature the direction of heat flow is always from higher temperature to lower temperature
- ❖ Heat produced against friction is not reconverted to the kinetic energy of the car.

Reversible Process:

- A thermodynamic process can be considered reversible only if it possible to retrace the path in the opposite direction in such a way that the system and surroundings pass through the same states as in the initial, direct process.

Example: A quasi–static isothermal expansion of gas, slow compression and expansion of a spring. Conditions for reversible process:

1. The process should proceed at an extremely slow rate.

2. The system should remain in mechanical, thermal and chemical equilibrium state at all the times with the surroundings, during the process.

3. No dissipative forces such as friction, viscosity, electrical resistance should be present.

Irreversible process:

- All natural processes are irreversible. Irreversible process cannot be plotted in PV diagram.
- According to second law of thermodynamics "Heat always flows from hotter object to colder object spontaneously". This is known as the Clausius form of second law of thermodynamics.

Process		Heat Q	Temperature & internal	Pressure	Volume	Equation of state	Work done (ideal gas)
Isotherm al	Expansion	$Q > 0$	Constant	Decrea	Increas	$PV = constant$	$W = \mu RT\ ln\left(\frac{V_f}{V_i}\right) > 0$
	Compressi	• $Q < 0$	Constant	Increas	Decrea		$W = \mu RT\ ln\left(\frac{V_f}{V_i}\right) < 0$
Isobaric	Expansion	$Q > 0$	Increases	Consta	Increas	$\frac{V}{T} = constant$	$W = P[V_f - V_i] = P\Delta V$
	Compressi	$Q < 0$	Decrease	Consta	Decrea		$W = P[V_f - V_i] = P\Delta V$
Isochoric	Expansion	$Q > 0$	Increase	Increas	Consta	$\frac{P}{T} = constant$	Zero
	Compressi	$Q < 0$	Decrease	Decrea	Consta		
Adiabatic	Expansion	$Q = 0$	Decrease	Decrea	Increas	$PV^{\gamma} = constant$	$W_{adia} = \frac{\mu R}{\gamma - 1}[T_i - T_f] > 0$
	Compressi	$Q = 0$	Increase	Increas	Decrea		$W_{adia} = \frac{\mu R}{\gamma - 1}[T_i - T_f] < 0$

HEAT ENGINE:

- ❖ Heat engine is a device which takes heat as input and converts this heat in to work by undergoing a cyclic process.

❖ A heat engine has three parts:

(a) Hot reservoir (or) Source: It is maintained at a high temperature T_H

(b) Working substance

❖ It is a substance like gas or water, which converts the heat supplied into work.
❖ The working substance in steam engine is water which absorbs heat from the burning of coal. The heat converts the water into steam.
❖ This steam is does work by rotating the wheels.(c) Cold reservoir (or) Sink: It is maintained at lower temperature T_L

Reservoir:

❖ It is defined as a thermodynamic system which has very large heat capacity. By taking in heat from reservoir or giving heat to reservoir, the reservoir's temperature does not change.

❖ The heat engine works in a cyclic process. After a cyclic process it returns to the same state. Since the heat engine returns to the same state after it ejects heat, the change in the internal energy of the heat engine is zero.

$$efficiency, \eta = \frac{output}{input} = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

- Since $Q_L < Q_H$, the efficiency (η) always less than 1. This implies that heat absorbed is not completely converted into work.

Kelvin-Planck statement:

It is impossible to construct a heat engine that operates in a cycle, whose sole effect is to convert the heat completely into work. This implies that no heat engine in the universe can have 100% efficiency.

Carnot's ideal Heat Engine:

❖ A reversible heat engine operating in a cycle between two temperatures in a particular way is called a Carnot Engine.

❖ The carnot engine has four parts.

i Source: It is at T_H. Any amount of heat can be extracted, without changing temperature.

ii Sink: It is maintained at T_L. It can absorb any amount of heat.

iii Insulating stand: It is made of perfectly non-conducting material.

iv Working substance: It is an ideal gas enclosed in a cylinder with perfectly non-conducting walls and perfectly conducting bottom. A non-conducting and frictionless piston is fitted in it.

The working substance is subjected to four successive reversible processes forming what is called Carnot's cycle.

a) Quasi-static Isothermal Expansion
b) Quasi- static Adiabatic Expansion
c) Quasi-static Isothermal compression
d) Quasi-static Adiabatic Compression

- After one cycle the working substance returns to the initial temperature TH. This implies that the change in internal energy of the working substance after one cycle is zero.

Efficiency of Carnot Engine:

$$\text{efficiency}, \eta = 1 - \frac{T_L}{T_H}$$

a) It can be 100% only when $T_L = 0\ K$ which is impossible.

b) Efficiency is independent of working substance.

c) When $T_L = T_H, \eta = 0.$ No carnot engine can have source and sink at same temperature.

d) Carnot theorem is stated as 'Between two constant temperatures reservoirs, only Carnot engine can have maximum efficiency. All real heat engines will have efficiency less than the Carnot engine'

e) The efficiency depends on the ratio of the two temperature and not on the difference in the temperature. The engine which operates in lower temperature has highest efficiency.

Entropy and second law of thermodynamics:

$$\mathbf{entropy} = \frac{\mathbf{Q}}{\mathbf{T}}$$

- Change in entropy of Carnot Engine in one cycle is zero. "For all the processes that occur in nature (irreversible process), the entropy always increases. For reversible process entropy will not change".
- Entropy determines the direction in which natural process should occur.
- Entropy is also called 'measure of disorder'. All natural process occur such that the disorder should always increases.
- **Example:**a drop of ink diffusing in water.

Refrigerator:

- A refrigerator is a Carnot's engine working in the reverse order.

- The working substance (gas) absorbs quantity of heat $Q_L$from cold body (sink) at lower temperature T_L. A certain amount of work W is done on the working substance by the compressor and a quantity of heat $Q_H$is ejected to the hot body (source) i.e., atmosphere at T_H.

$$\boldsymbol{Q_L + W = Q_H}$$

As a result, cold reservoir gets further cooled down and surroundings are heated more.

$$\text{coefficient of performance, COP} = \beta = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L} = \frac{T_L}{T_H - T_L}$$

1. The greater the COP, the better is the condition. A refrigerator has COP around 5 to 6.

2. Lesser the difference in the temperatures of the cooling chamber and the atmosphere, higher is the COP of a refrigerator.

3. In the refrigerator the heat is taken from cold object to hot object by doing external work. It is not a violation of second law of thermodynamics, because the heat is ejected to surrounding air and total entropy of (refrigerator + surrounding) is always increased.

Greenhouse effect:

- Top of the atmosphere is at -19°C and bottom of the atmosphere is at +14°C. The increase in 33°C from top to bottom is due to Greenhouse gases and this effect is called Greenhouse effect.

- The greenhouse gases are mainly CO_2, water vapour, Ne, He, NO_2,

- CH_4, Xe, Kr, ozone and NH_3. Except CO_2 and water vapour, all others are present only in very small amount in the atmosphere. The radiation from the Sun is mainly in the visible region of the spectrum. The earth absorbs these radiations and reradiate in the infrared region. Carbon dioxide and water Vapour are good absorbers of infrared radiation since they have more vibrational degree of freedom compared to nitrogen and oxygen which keeps earth warmer.

- The amount of CO_2 present in the atmosphere is increased from 20% to 40% due to human activities since 1900s. The major emission of CO_2 comes from burning of fossil fuels in automobiles. Due to this increase in the CO_2 content in the atmosphere, the average temperature of the earth increases by 1°C. This effect is called global warming. It has serious influence and alarming effect on ice glaciers. In addition, the CO_2 content is also increasing in ocean which is very dangerous to species in the oceans.

- Another very important greenhouse gas is Chloroflouro carbon(CFC) which is used as coolant in refrigerators. In the human made greenhouse gases CO_2 is 55%, CFCs are 24%. Nitrogen oxide is 6% and methane is 15%. CFCs also has made huge damage to ozone layer.

Light

Unit - 1. Light

Do You Know?

Light is the only source of energy for plants. So, they entirely depend on light. People and animals derive energy from carbohydrates, protein and fat through their food. Plants produce food using the energy from Sun light, carbon-di-oxide and water by the process called as Photosynthesis. Sun light acts a vital role in the process of photosynthesis.

Sources of Light.

Objects which are able to emit light are known as light sources. Light rays can come from different sources. There are two types of sources of light.

1. Natural sources of light
2. Artificial sources of light

Natural Sources of light

Sources which emit light naturally are known as natural sources of light. The Sun is theprimary and the major source of natural light. Stars also produce light, in the same way as the Sun do. However, as they are much farther away than the Sun, the light from them are too weak. The moon provides light, particularly in the night. Some living organisms have the ability to produce light named by bioluminescence. It is the effect of certain chemical reactions occurring in the organism. Fireflies, jellyfish, glow worm, certain deep sea plants and some microorganisms can emit light naturally.

Artificial Sources of light

Apart from the natural sources, light can also be produced artificially. The different light sources that are able to produce light artificially can be put under three broad categories.

Do You Know?

Is the moon a luminous object?

The moon provides light as well, but it cannot produce light by its own. The light emitted by the Moon is the light of the Sun reflected towards the Earth. When we see the Moon, we see only the Moon's lighted part. Thus, half of the moon is always facing the Sun and receiving light from it. Hence, we receive light from the moon.

Artificial sources are man – made light sources such as flame of candle, incandescent lamp, neon lamp, Sodium lamp etc.

1. Incandescent Sources: When certain objects are heated to a high temperature, they begin to emit light. The glowing of hot iron rod is a kind of Incandescent light.

Example: Candle, incandescent lamp.

2. Gas Discharge Sources: Passing electricity through certain gases at a very low pressure (discharging) can produce light .

Example: Neon lamp, Sodium lamp

Do You Know?
We often use a kind of gas discharge lamp that uses fluorescence to produce visible light. The electric current in the gas excites mercury vapour, which produces short-wave ultraviolet light that then causes a phosphor coating on the inside of the lamp to glow in visible light.

Properties of light

In this section, we shall examine some properties of light. Light has some fundamental properties as mentioned below

- **Rectilinear propagation of light**
- **Reflection**
- **Speed**
- **Interaction of light with matter**
  - **Types of material according to permeability**
  - **Formation of shadows**
  - **Plane mirror and images**
- **Spectrum**

The path of light
How does light travel?

• Have you ever seen the scene of light penetrating through the branches of trees in denser forest?
• Have you ever seen the path of sun light entering through the hole of a cement grilbuilding?
• Have you ever seen the path of a laser light?

Pinhole Camera

Pin hole camera is a simple device which helps us to understand about the rectilinear propagation of light

The above picture shows a model of a pin– hole camera. O is small hole by a pin. XY is the object and Y'X' is the image of XY. As light travels in straight line, one light ray from X travels along the XO strikes the screen X'.

In similar way, another light ray staringfrom Y and travels along YO strikes the screen Y'. Similarly, all the rays in between X and Y fall on the screen between Y' and X'. Thus Y'X' becomes the image of XY. The image produced is temporary, if a simple paper is used. The image can be made permanent if the paper is replaced by a photographic plate.

Reflection

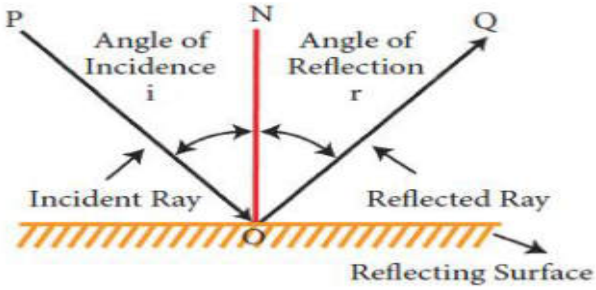
A mirror reflects our face. A still water body like a pond reflects the scenery around it. When we see our face in the mirror, we see the light rays from our face bouncing off the surface of the mirror. How therays of the light are reflected?

Take a plane mirror. Cover it with black paper. Cut a small slit as shown in the figure. Ifyou shine light on the mirror from a torch lightor sunlight, you will get a small ray of light. We can use this to study the properties of light.

Place a blank white sheet on a level ground out in the open. Choose a place where partly the sheet gets sunlight and partly it is in shadow. Hold the mirror with the slit facing the sun. You can see a straight ray of light reflected from the slit on the paper. Hold another mirror to reflect this ray. Observe well.

The light falling on the mirror is called as incident ray and the light reflected is called reflected ray.

Terms used in reflection of light.



Incident ray: The ray of light that falls on thesurface of the reflection materials. In figure, PO is the incident ray.

Reflected ray: The ray of light that comes from the point when the incident ray falls on the reflection material. In the figure, OQ is the reflected ray.

Point of incidence: The point of which are incident ray strikes the reflecting surface is the point of incidence. In the figure ‘O’ point of incidence.

Normal: The perpendicular line drawn from the point of incidence to the plane of reflecting surface is called normal. In figure, ON is the normal.

Angle of incidence: The angle formed between the incident ray PO and the normal 'ON' is angle of incidence. It is denoted by I Angle of reflection: The angle formed between the reflected ray OQ and the normal ON is angle of reflection. It is denoted by i

Laws of reflection:

1. The angle of incidence is always equal to the angle of reflection. i = r
2. The incident ray, the reflected ray and the normal at the point of incidence lie on the same plane.

Speed of light:

When lighting a bulb in a dark room, light spreads the whole room quickly. This is because the light travels very fast. Light travels three lakh kilometersper second in air or vacuum. In theory, nothing can travel faster than light

Interaction of light with matter

Take a piece of clear glass, a paper and a metal sheet. Shine a light from one side of each object and see if the light penetrate on the other side. Readily, we can see light enters and comesout of the other end of clear glass, whereas thelight is bit dim through a paper. Light does not pass through metal sheet. Depending upon permeability, materials can be classified into three categories.

Transparent Material:

Materials that allow light to pass through completely are known as transparent material.

Example: Eye glasses, clear drinking glass, clear water, face glasses used in buses.

Translucent Material:

Objects that allow light to pass through partially are called translucent material. For example, we cannot see the image of someone who stands behind a rough window glass, because it allows only a part of light from the person.

Shadows
How are shadows formed?

As we saw earlier, light is obstructed by certain materials. Light travels in a straight line. Hence it cannot go around such objects. That is why we see shadow. Shadow is always against, opposite side of light source. It is caused by opaque objects that stop light from propagating.

Parts of shadow

When an opaque object is placed in the path of light from a point source, a uniform dark shadow will appear on the screen. This is shadow

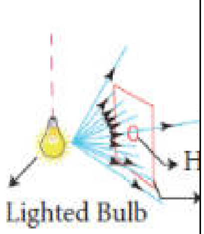
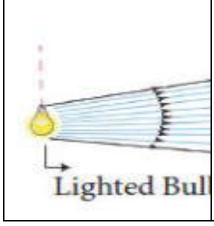
Opaque Material:

Materials that are not able to allow light to pass through, are called opaque material.

Example: Wall, thick card board, stone, etc. is called as umbra. When an opaque object isplaced in the path of light coming from a broad source of light, a small umbra will appear on the screen and an illuminated shadow area appears around umbra. This illuminated shadow area is called as penumbra. The penumbra always surrounds the umbra. The umbra is the darkest part of a shadow. In this part, light rays are completely prevented by the opaque object. The lighter shade of shadow is the penumbra.

Properties of shadow

1. All objects do not form shadows. Only opaque objects form shadows
2. Shadows will be formed in the opposite side of light source
3. It cannot be determined the characteristics of an object by its shadow.
4. The shadow will be always darker, whatever may be the color of light rays
5. Light source, opaque object are shadow all are in a straight line.
6. The size of shadow depends upon the distance between light source and object and the distance between object and the screen.

Arrangement	Activity	Observation	You Learn
	Place a lighter bulb in front of are rectangular card board with a hole at the center	A shadow with a spot light appears in the screen.	Light rays are passing only through the hole and are not allowed by the remaining part of card board
	Place a pencil in the path of light ray coming from a bulb	A shadow of pencil appears in the screen	The size of the shadow is proportional to the size of the opaque objects.

Eclipses

An eclipse is an incident, when any astronomical object is partially or fully obscured due to the placement of another astronomical object in the presence of light. Thus, solar and lunar eclipses are occurring that are due to the property of light known as the rectilinear propagation of light.

Solar eclipse

Solar eclipse occurs, when the moon arrives between the sun (S) and the earth(E). The shadow of the moon appears on the earth at A as shown in picture. Hence, those who are at the region A are unable to see the Sun instantly. This is solar eclipse. But, those who are at the region B and C are able to see the sun partially

Lunar eclipse

Lunar eclipse: Lunar eclipse occurs, when the earth (E) comes between the sun (S) and the moon (M). The earth prevents light coming from the sun and makes shadow on the moon. This is lunar eclipse

Plane Mirror and Reflection

A polished (or) smooth surface (like glass) which forms image by reflection is known as mirror. A plane mirror is a mirror with a flat reflective surface. A plane mirror makes an Image of objects in front of it.

Real and virtual images

We have seen images being formed in a pinhole camera and a mirror. Can we see what is different in both of these images? Firstly, the image of the pinhole camera was formed on a screen.While the image made by the mirror is not obtained on a screen. The images that are obtained on a screen are called 'real image' and that which cannot be obtained on a screen 'virtual image'. Also notice that the image on pinhole camera was upside down. While the mirror image was upright.

Properties of Image formed in a plane mirror
Image formed in a plane mirror is upright
Image formed in a plane mirror is virtual
The image is of the same size as the object
The distance of the image from the planemirror is equal to the distance of the object from the mirror
Image is laterally inverted.

Colour

Colour of sunlight : Light is a form ofenergy in the form of a wave that simulates that retina of our eyes. Visible light is a spectrum of a number of waves with different wavelength range from 400nm to 700nm (1nm = 10-9 metre) each wave has a definite wavelength represents a particular color. The band of visible light is VIBGYOR.

V - Violet
I - Indigo
B - Blue
G - Green
Y - Yellow
O - Orange
R – Red

Violet colour has shorter wavelength and red color has longer wavelength.

When light ray of particular wavelength(Colour) strikes the retina of our eye, our brainperceives that specific colour. When all colors of visible light strikes the retina of our eye at the same time, our brain perceives white. Th is shows, white is not a colour at all. But, it is the combination of all the colors of the visible light spectrum. If all the wavelength (colours) of visible light spectrum give appearance of white similarly, the observe of all there wavelength of visible light, will lead appearance of black

What is prism?

A prism is an object made up of a transparent material, like glass or plastic that has at least two flat surfaces that from an acute angle (less than 90O degrees).

Difference between the images formed in Pinhole camera and Plane mirror	
Images formed by hole camera	**Images formed in Plane mirror**
The image is real	The image is virtual
The image may not be equal to the size of the object	The image is equal to the size of the object
The image is inverted	The image is erect

Do you Know?

Why danger lights in vehicles are red in colour?

1. Red color is scattered the least by air molecules.
2. Red color has the highest wavelength of all the other colors. So red color is able to travel the longest distance through air, fog.

When white light is passed through a prismas shown in the figure, the colors of the rainbow emerge from the prism.

Newton Disc:

Newton suggested a process of mixing different colors to make white color by setting an arrangement as shown figure below. Newton Disc is a card board disc with seven equal sectorscolored red, yellow,orange, green, blue, indigo and violet. When the disc turned quickly, the retina receives the sensation of the spectrum simultaneously and disc appears white. Using this disc, one can explain that white is a combination of VIBGYOR

We know that white shirt will reflect white light and we have seen that white light consists of different colours. When we look at the white shirt through the yellow gelatin paper, we seeit as yellow in color. From this, we can say thatthe yellow gelatin paper did not allow any other color except yellow to pass through. Similarly, we conclude that red gelatin paper allows only red light and blue gelatin paper allows only the blue light.

Synthesis of colour

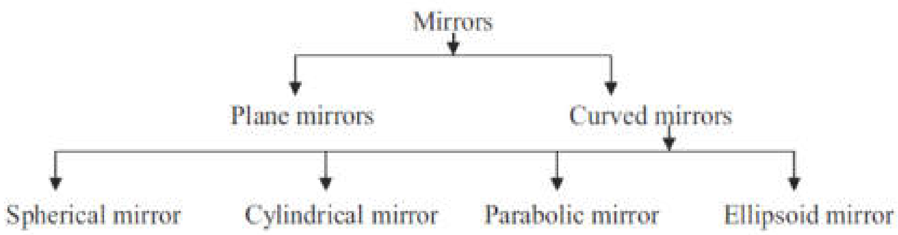
Synthesis of colour is the method of creating colour by mixing various proportion of two (or) three distinct colours of light. These distinct colours are Red, Green and Blue called as primary colours.

- Equal proportions of two primary colourcreate a secondary color.
- Magenta, Cyan and yellow are called secondary colour.
- Equal proportions of all three primary colour create white.

8^{th} term 1 Unit - 3. Light

Types of Mirrors

We use mirrors in our daily life for various purposes. We use them for decoration. In vehicles, they are used as rear view mirrors. They are also used in scientific apparatus, like telescope. The mirror is an optical device with a polished surface that reflects the light falling on it. A typical mirror is a glass sheet coated with aluminium or silver on one of its sides to produce an image. Mirrors have a plane or curved surface. Curved mirrors have surfaces that are spherical, cylindrical, parabolic and ellipsoid. The shape of a mirror determines the type of image it forms. Plane mirrors form the perfect image of an object. Whereas, curved mirrors produce images that are either enlarged or diminished. You would have studied about plane mirrors in your lower classes. In this section, you will study about spherical and parabolic mirrors.



Do You Know?

Method of coating a glass plate **with a thin layer of reflecting metals was in practice during the 16th century in Venice, Italy. They used an amalgam of tin and mercury for this purpose. Nowadays, a thin layer of molten aluminium or silver is used for coating glass plates that will then become mirrors.**

Spherical mirrors

Spherical mirrors are one form of curved mirrors. If the curved mirror is a part of a sphere, then it is called a 'spherical mirror'. It resembles the shape of a piece cut out from a spherical surface. One side of this mirror is silvered and the reflection of light occurs at the other side.

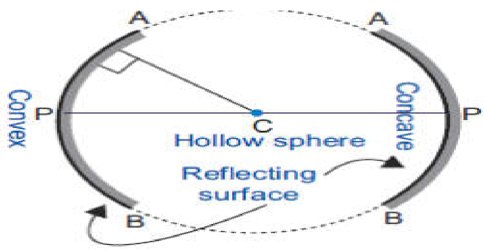


Figure 3.1 Spherical mirror

Concave mirrors

A spherical mirror, in which the reflection of light occurs at its concave surface, is called a concave mirror. These mirrors magnify theobject placed close to them. The most common example of a concave mirror is the make-up mirror.

Convex mirror

A spherical mirror, in which the reflection of light occurs at its convex surface, is called a convex mirror. The image formed by these mirrors is smaller than the object. Most common convex mirrors are rear viewing mirrors used in vehicles.

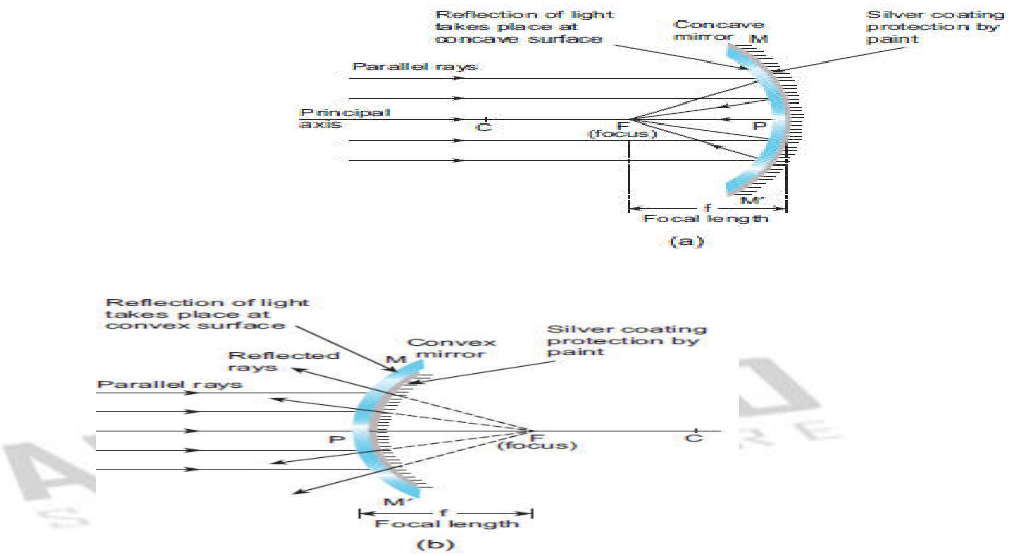


Figure 3.2 Concave and Convex mirrors

Do You Know?

Convex mirrors used in vehicles as rear-view mirrors are labeled with the safety warning: 'Objects in the mirror are closer than they appear' to warn the drivers. This is because inside the mirrors, vehicles will appear to be coming at a long distance.

Parabolic mirrors

A parabolic mirror is one type of curved mirror, which is in the shape of a parabola. It has a concave reflecting surface and this surface directs the entire incident beam of light to converge at its focal point.

In the same way, light rays generated by the source placed at this focal point will fall on this surface and they will be diverged in a direction, which is parallel to the principal axis of the parabolic mirror. Hence, the light rays will be reflected to travel a long distance, without getting diminished.

Parabolic mirrors, also known as parabolic reflectors, are used to collect or project energy such as light, heat, sound and radio waves. They are used in reflecting telescopes, radio telescopes and parabolic microphones. They are also used in solar cookers and solar water heaters.

Do You Know?

The principle behind the working of a parabolic mirror has been known since the Greco-Roman times. The first mention of these structures was found in the book, 'On Burning Mirrors', written by the mathematician Diocles. They were also studied in the 10th century, by a physicist called IbnSahl. The first parabolic mirrors were constructed by Heinrich Hertz, a German physicist, in the form of reflector antennae in the year 1888.

TERMS RELATED TO SPHERICAL MIRRORS

In order to understand the image formation in spherical mirrors, you need to know about some of the terms related to them.

Center of Curvature: It is the center of the sphere from which the mirror is made. It is denoted by the letter C in the ray diagrams. (A ray diagram represents the formation of an image by the spherical mirror. You will study about them in your next class).

Pole: It is the geometric centre of the spherical mirror. It is denoted by the letter P. Radius of Curvature: It is the distance between the center of the sphere and the vertex. It is shown by the letter R in ray diagrams. (The vertex is the point on the mirror's surface where the principal axis meets the mirror. It is also called as 'pole'.)

Principal Axis: The line joining the pole of the mirror and its center of curvature is called principal axis.

Focus: When a beam of light is incident on a spherical mirror, the reflected rays converge (concave mirror) at or appear to diverge from (convex mirror) a point on the principal axis. This point is called the 'focus' or 'principal focus'. It is also known as the focal point. It is denoted by the letter F in ray diagrams.

Focal length: The distance between the pole and the principal focus is called focal length (f) of a spherical mirror. There is a relation between the focal length of a spherical mirror and its radius of curvature. The focal length is half of the radius of curvature.

That is, focal length= $\frac{Radius of curvature}{2}$

Figure 3.4 Terms related to spherical mirror

PROBLEM 1
The radius of curvature of a spherical mirror is 20cm. Find its focal length
Solution:
Radius of curvature =20cm
Focal length (f0 = $\frac{Radius of curvature}{2}$
= $\frac{R}{2}$ = $\frac{20}{2}$ =10cm

PROBLEM 2
Focal length of a spherical mirror is 7 cm. What is its radius of curvature?
Solution:
Focal length = 7 cm
Radius of curvature (R) = 2 × focal length = 2 × 7 = 14 cm

IMAGES FORMED BY SPHERICAL MIRRORS

Images formed by spherical mirrors are of two types: i) real image and ii) virtual image. Real images can be formed on a screen, while virtual images cannot be formed on a screen. Image formed by a convex mirror is always erect, virtual and diminished in size. As a result, images formed by these mirrors cannot be projected on a screen.

The characteristics of an image are determined by the location of the object. As the object gets closer to a concave mirror, the image gets larger, until attaining approximately the size of the object, when it reaches the centre of curvature of the mirror. As the object moves away, the image diminishes in size and gets gradually closer to the focus, until it is reduced to a point at the focus when the object is at an infinite distance from the mirror.

The size and nature of the image formed by a convex mirror is given

Image formed by a convex mirror

Position Of The Object	**Position Of The Image**	**Image Size**	**Nature Of The Image**
At infinity	At F	Highly diminished, point sized	Virtual and erect
Between infinity the pole (P)	Between P and F	Diminished	Virtual erect

Concave mirrors form a real image and it can be caught on a screen. Unlike convex mirrors, concave mirrors show different image types. Depending on the position of the object in front of the mirror, the position, size and nature of the image will vary. Table 3.2 provides a summary of images formed by a concave mirror.

Table 3.2 Image formed by a concave mirror

POSITION OF THE OBJECT	POSITIOIN OF THE IMAGE	IMAGE SIZE	NATURE OF THE IMAGE
At infinity	At F	Highly diminished	Real and inverted
Beyond C	Between C and F	Diminished	Real and inverted
At C	At C	Same size as the object	Real and inverted
Between C and F	Beyond C	Magnified	Real and inverted
At F	At infinity	Highly magnified	Real and inverted
Between F and P	Behind the mirror	Magnified	Virtual and erect

You can observe from the table that a concave mirror always forms a real and inverted image except when the object is placed between the focus and the pole of the mirror. In this position, it forms a virtual and erect image.

Application of curved Mirrors
Concave mirrors

1. **Concave mirrors are used while applying make-up or shaving, as they provide a magnified image.**
2. **They are used in torches, search lights and head lights as they direct the light to a long distance.**
3. **They can collect the light from a larger area and focus it into a small spot. Hence, they are used in solar cookers.**
4. **They are used as head mirrors by doctors to examine the eye, ear and throat as they provide a shadow-free illumination of the organ.**
5. **They are also used in reflecting telescopes. Figure 3.3 Concave mirrors**

Convex mirrors

- **Convex mirrors are used in vehicles as rear view mirrors because they give an upright image and provide a wider field of view as they are curved outwards.**
- **They are found in the hallways of various buildings including hospitals, hotels, schools and stores. They are usually mounted on a wall or ceiling where hallways make sharp turns.**
- **They are also used on roads where there are sharp curves and turns.**

Not all the objects can produce the same effect as produced by the plane mirror. A ray oflight, falling on a body having a shiny, polished and smooth surface alone is bounced back. This bouncing back of the light rays as they fall on the smooth, shiny and polished surface is called reflection.

Reflection involves two rays: i) incident ray and ii) reflected ray. The incident ray is the light ray in a medium falling on the shiny surface of a reflecting body. After falling on the surface, this ray returns into the same medium. This ray is called the reflected ray. An imaginary line perpendicular to the reflecting surface, at the point of incidence of the light ray, is called the normal.

The relation between the incident ray, the reflected ray and the normal is given as the law of reflection. The laws of reflection are as follows:

- The incident ray, the reflected ray and the normal at the point of incidence, all lie in the same plane.
- The angle of incidence and the angle of reflection are always equal.

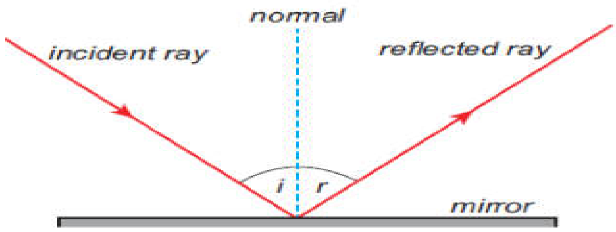


Figure 3.7Reflection of light

Do You Know?
Silver metal is the best reflector of light. That's why a thin layer of silver is deposited on the side of materials like plane glass sheets, to make mirrors.

TYPES OF REFLECTION

You have learnt that not all bodies can reflect light rays. Th e amount of reflection depends on the nature of the reflecting surface of a body. Based on the nature of the surface, reflection can be classified into two types namely, i) regular reflection and ii) irregular reflection.

Regular reflection

When a beam of light (collection of parallel rays) falls on a smooth surface, it gets reflected. After reflection, the reflected rays will be parallel to each other. Here, the angle of incidence and the angle of reflection of each ray will be equal. Hence, the law of reflection is obeyed in this case and thus a clear image is formed. This reflection is called 'regular reflection' or 'specular reflection'. Example: Reflection of light by a plane mirror and reflection of light from the surface of still water.

Irregular reflection

In the case of a body having a rough or irregular surface, each region of the surface is inclined at different angles. When light falls on such a surface, the light rays are reflected at different angles. In this case, the angle of incidence and the angle of reflection of each ray are not equal. Hence, the law of reflection is not obeyed in this case and thus the image is not clear. Such a reflection is called 'irregular reflection' or 'diff used reflection'. Example: Reflection of light from a wall.

MULTIPLE REFLECTIONS

You can see three images. How is it possible to have three images with two mirrors? In the activity given above, you observed that for a body kept in between two plane mirrors, which were inclined to each other, you could see many images. This is because, the 'image' formed by one mirror acts as an 'object' for the other mirror. The image formed by the first mirror acts as an object for the second mirror and the image formed by the second mirror acts as an object for the first mirror. Th us, we have three images of a single body. This is known as multiple reflection. This type of reflections can be seen in show rooms and saloons.

The number of images formed, depends on the angle of inclination of the mirrors. If the angle between the two mirrors is a factor of 360°, then the total number of reflections is finite. If θ (Theta) is the angle of inclination of the plane mirrors, the number of images formed = $\frac{360}{0}$-1. As you decrease this angle, the number of images formed increases. When they are parallel to each other, the number of images formed becomes infinite.

Problem.3
If two plane mirrors are inclined to each other at an angle of 90°, find the number of images formed.
Solution:
Angle of inclination = 90°
Number of images formed =
$\frac{360^0}{\theta} - \frac{360^o}{90^o}$ **– 1 = – 1 = 4 -1 = 3**

Kaleidoscope

It is a device, which functions on the principle of multiple reflection of light, to produce numerous patterns of images. It has two or more mirrors inclined with each other. It can be designed from inexpensive materials and the colourful image patterns formed by this will be pleasing to you. This instrument is used as a toy for children.

Periscope

It is an instrument used for viewing bodies or ships, which are over and around another body or a submarine. It is based on the principle of the law of reflection of light. It consists of a long outer case and inside this case mirrors or prisms are kept at each end, inclined at an angle of 45°. Light coming from the distant body, falls on the mirror at the top end of the periscope and gets reflected vertically downward. This light is reflected again by the second mirror kept at the bottom, so as to travel horizontally and reach the eye of the observer. In some complex periscopes, opticfibre is used instead of mirrors for obtaining a higher resolution. Th e distance between the mirrors also varies depending on the purpose of using the periscope.

Uses

• It is used in warfare and navigation of the submarine.
• In military it is used for pointing and firing guns from a 'bunker'. • Photographs of important places can be taken through periscopes without trespassing restricted military regions.
• Fibre optic periscopes are used by doctors as endoscopes to view internal organs of the body.

REFRACTION OF LIGHT

We know that when a light ray falls on a polished surface placed in air, it is reflected into the air itself. When it falls on a transparent material, it is not reflected completely, but a part of it is reflected and a part of it is absorbed and most of the light passes through it. Th rough air, light travels with a speed of 3 x10^8 m s-1, but it cannot travel with the same speed in water or glass, because, optically denser medium such as water and glass offer some resistance to the light rays.

So, light rays travelling from a rarer medium like air into a denser medium like glass or water are deviated from their straight line path. Th is bending of light about the normal, at the point of incidence; as it passes from one transparent medium to another is called refraction of light.

When a light ray travels from the rarer medium into the denser medium, it bends towards the normal and when it travels from the denser medium into the rarer medium, it bends away from the normal. You can observe this phenomenon with the help of the activity given below.

In this activity, the light rays actually travel from the water (a denser medium) into the air (a rarer medium). As you saw earlier, when a light ray travels from a denser medium to a rarer medium, it is deviated from its straight line path. So, the pencil appears to be bent when you see it through the glass of water.

Refractive Index

Refraction of light in a medium depends on the speed of light in that medium. When the speed of light in a medium is more, the bending is less andwhen the speed of light is less, the bending is more.

The amount of refraction of light in a medium is denoted by a term known as refractive index of the medium, which is the ratio of the speed of light in the air to the speed of light in that particular medium. It is also known as the absolute refractive index and it is denoted by the Greek letter 'μ' (pronounced as 'mew').

$$\mu = \frac{Speedoflighinair(c)}{Speedoflight\,\text{int}\,hemedium(v)}$$

Refractive index is a ratio of two similar quantities (speed) and so, it has no unit. Since, the speed of light in any medium is less than its speed in air, refractive index of any transparent medium is always greater than 1.
Refractive indices of some common substances are given in Table 3.3.

Substances	Refractive Index
Air	1.0
Water	1.33
Ether	1.36
Kerosene	1.41
Ordinary Glass	1.5
Quartz	1.56
Diamond	2.41

In general, the refractive index of one medium with respect to another medium is given by the ratio of their absolute refractive indices.

$$\mu_2 \frac{Absoluterefactiveindexofthe\sec ondmedium}{Absoluterefactiveindexofthefivemedum}$$

$${}_1\mu_2 = \frac{\frac{c}{v_2}}{\frac{c}{v_1}} \qquad \text{or} \qquad {}_1\mu_2 = \frac{v_1}{v_2}$$

Thus, the refractive index of one medium with respect to another medium is also given by the ratio of the speed of light in first medium to its speed in the second medium.

PROBLEM 4
Speed of light in air is 3 × 108 m s-1 and the speed of light in a medium is 2 ×108 ms-1. Find the refractive index of the medium with respect to air.
Solution:

Refractive index (μ)= $\frac{Speedoflightinair(c)}{Speedoflight\text{int}hemedum(v)}$

$$\mu = \frac{3X10^8}{2X10^8} = 1.5$$

PROBLEM 5
Refractive index of water is 4/3 and the refractive index of glass is 3/2. Find the refractive index of glass with respect to the refractive index of water.
Solution:

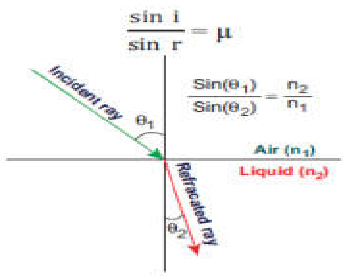
$${}_w\mu_g = \frac{\text{Refractive index of glass}}{\text{Refractive index of water}} = \frac{\frac{3}{2}}{\frac{4}{3}} = \frac{9}{8} = 1.125$$

Snell's Law of Refraction

Refraction of light rays, as they travel from one medium to another medium, obeys two laws, which are known as Snell's laws of refraction. They are:

I) The incident ray, the refracted ray and the normal at the point of intersection, all lie in the same plane.

II) The ratio of the sine of the angle of incidence (i) to the sine of the angle of refraction (r) is equal to the refractive index of the medium, which is a constant.



Snell's Law

In the above activity, you can see that the first prism splits the white light into seven coloured light rays and the second prism recombines them into white light, again. Thus, it is clear that white light consists of seven colours. You can also recall the Newton's disc experiment, which you studied in VII standard. Splitting of white light into its seven constituent colours (wavelength), on passing through a transparent medium is known as dispersion of light.

Why does dispersion occur? It is because, light of different colours present in white light have different wavelength and they travel at different speeds in a medium. You know that refraction of a light ray in a medium depends on its speed. As each coloured light has a different speed, the constituent coloured lights are refracted at different extents, inside the prism. Moreover, refraction of a light ray is inversely proportional to its wavelength.

Thus, the red coloured light, which has a large wavelength, is deviated less while the violet coloured light, which has a short wavelength, is deviated more.

The most common usage of mirror writing can be found on the front of ambulances, where the word "AMBULANCE" is often written in very large mirrored text.

Lateral inversion

You might have heard about inversion. But what is lateral inversion? The word lateral comes from the Latin word latus which means side. Lateral inversion means sidewise inversion. It is the apparent inversion of left and right that occurs in a plane mirror. Why do plane mirrors reverse left and right, but they do not reverse up and down? Well, the answer is surprising. Mirrors do not actually reverse left and right and they do not reverse up and down also. What actually mirrors do is reverse inside out. Look at the image below (Figure 6.2) and observe the arrows, which indicate the light ray from the object falling on the mirror. The arrow from the object's head is directed towards the top of the mirror and the arrow from the feet is directed towards the bottom. The arrow from left hand goes to the left side of the mirror and the arrow from the right hand goes to the right side of the mirror. Here, you can see that there is no switching. It is an optical illusion. Thus, the apparent lateral inversion we observe is not caused by the mirror but the result of our perception.

Real and Virtual Image

If the light rays coming from an object actually meet, after reflection, the image formed will be a real image and it is always inverted. A real image can be produced on a screen. When the light rays coming from an object do not actually meet, but appear to meet when produced backwards, that image will be virtual image. The virtual image is always erect and cannot be caught on a screen (Figure
binoculars, cameras and projectors are used in educational, scientifi c and entertainment fields.

Rules for the construction of image formed by spherical mirrors

From each point of an object, number of rays travel in all directions. To find the position and nature of the image formed by a concave mirror, we need to know the following rules.

Rule 1: A ray passing through the centre of curvature is reflected back along its own path (Figure 5).

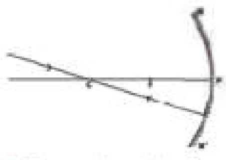


Figure 5 Ray passing centre of curvature

Rule 2: A ray parallel to the principal axis passes through the principal focus after reflection (Figure 6).

Figure 6 Ray parallel to prinicpal axis

Rule 3: A ray passing through the focus gets reflected and travels parallel to the principal axis (Figure 7).

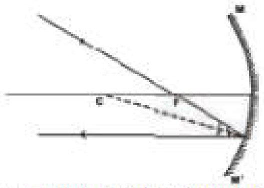


Figure 7 Ray travelling through the principal focus

Rule 4: A ray incident at the pole of the mirror gets reflected along a path such that the angle of incidence (APC) is equal to the angle of reflection (BPC) (Figure 8).

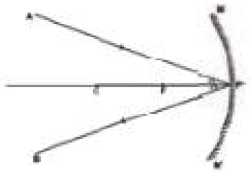


Figure 8 Angle of incidence equal to angle of reflection

Concave Mirror

Ray diagrams for the formation of images

We shall now find the position, size and nature of image by drawing the ray diagram for a small linear object placed on the principal axis of a concave mirror at different positions.

Case-I: When the object is far away (at infinity), the rays of light reaching the concave mirror are parallel to each other (Figure 10).

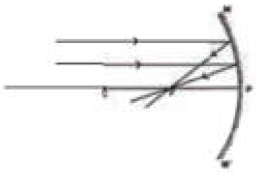


Figure 10 Object at inifinity

Position of the Image: The image is at the principal focus F.
Nature of the Image: It is (i) real, (ii) inverted and (iii) highly diminished in size.

Case-II: When the object is beyond the centre of curvature (Figure 11).
Position of the image: Between the principal focus F and centre of curvature C.

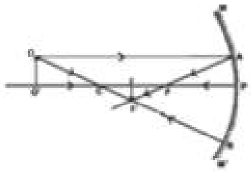


Figure 11 Object beyond the centre of curvature

Nature of the image: Real, inverted and smaller than object.
Case – III: When the object is at the centre of curvature (Figure 12).
Position of the image: The image is at the centre of curvature itself.
Nature of the image: It is i) Real, ii) inverted and iii) same size as the object.

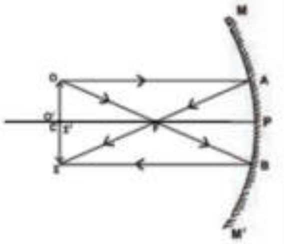


Figure 12 Object at the centre of curvature

Case – IV: When the object is in between the centre of curvature C and principal focus F (Figure 13).
Position of the image: The image is beyond C

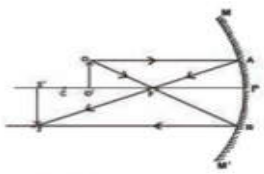


Figure 13 Object in between centre of curvature and principal focus

Nature of the image: It is i)Real ii) inverted and iii) magnified.

Case – V: When the object is at the principal focus F (Figure 14).
Position of the image: Theoretically, the image is at infinity.
Nature of the image: No image can be captured on a screen nor any virtual image can be seen.

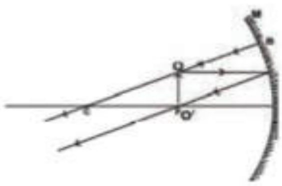
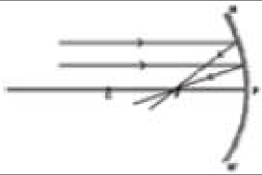
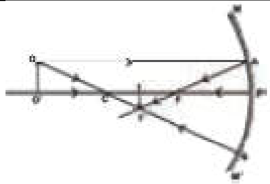
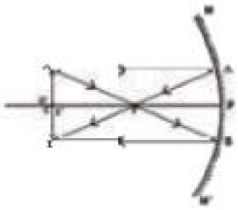
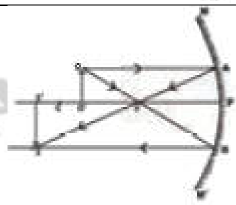
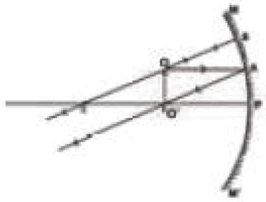
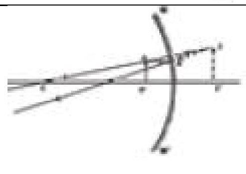


Figure 14 Object at principal focus

Case – VI: When the object is in between the focus F and the pole P (Figure 15). Position of the image: The image is behind the mirror.
Nature of the image: It is virtual,erect and magnified.

S. No	Position of Object	Ray Diagram	Position of Image	Size of Image	Nature of Image
1.	At infinity		At the principal focus	Point size	Real and Inverted
2.	Beyond the Centre of Curvature C		Between F and C	Smaller than the object	Real and Inverted
3.	At the Centre of Curvature C		A to C	Same size	Real and Inverted
4.	Between C and F		Beyond C	Magnified	Real and inverted
5.	At the principal focus F		At infinity	Infinitely large	Real and Inverted
6.	Between the principal focus F and the pole P of the mirror		Behind the mirror	Magnified	Virtual and Erect

Sign convention for measurement of distances

We follow a set of sign conventions called the cartesian sign convention. In this convention the pole (P) of the mirror is taken as the origin. The principal axis is taken as the x axis of the coordinate system (Figure 16).The object is always placed on the left side of the mirror.
All distances are measured from the pole of the mirror.

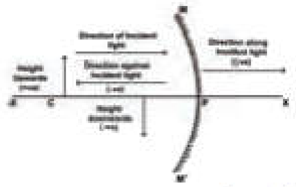


Figure 16 Sign convention for spherical mirrors

- Distances measured in the direction of incident light are taken as positive and those measured in the opposite direction are taken as negative.
- All distances measured perpendicular to and above the principal axis are considered to be positive.
- All distances measured perpendicular to and below the principal axis are considered to be negative.

Type of mirror	u	v		f	R	Height of the subject	Height of the image	
		real	virtual				real	virtual
Concave mirror	-	-	+	-	-		-	+
Convex mirror	-	No real image	+	+	+		No real image	+

Mirror equation

The expression relating the distance of the object u, distance of image v and focal length f of a spherical mirror is called the mirror equation. It is given as:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Linear magnification (m)

Magnification produced by a spherical mirror gives the how many times the image of an object is magnified with respect to the object size.
It can be defined as the ratio of the height of the image (//.) to the height of the object (h).

$$m = \frac{h_i}{h_o}$$

The magnification can be related to object distance (u) and the image distance (v)

$$m = -\frac{v}{u}$$

$$\therefore m = \frac{h_i}{h_o} = -\frac{v}{u}$$

Note: A negative sign in the value of magnification indicates that the image is real. A positive sign in the value of magnification indicates that the virtual image.

Uses of concave mirror

Dentist's head mirror:

In dentist's head mirror, a parallel beam of light is made to fall on the concave mirror. This mirror focuses the light beam on a small area of the body (such as teeth, throat etc.).

Make-up mirror:

When a concave mirror is held near the face, an upright and magnified image is seen. Here, our face will be seen magnified.

Other applications:

Concave mirrors are also used as reflectors in torches, head lights in vehicles and search lights to get powerful beams of light. Large concave mirrors are used in solar heaters.

Stellar objects are at an infinite distance. Therefore, the image formed by a concave mirror would be diminished, and inverted. Yet, astronomical telescopes use concave mirrors

Convex Mirror

Image Formation

Any two rays can be chosen to draw the position of the image in a convex mirror (Figure 6.10): a ray that is parallel to the principal axis (rule 1) and a ray that appears to pass through the centre of curvature (rule 2).

Note: All rays behind the convex mirror shall be shown with dotted lines.

The ray OA parallel to the principal axis is reflected along AD. The ray OB retraces its path. The two reflected rays diverge but they appear to intersect at I when produced backwards. Thus II' is the image of the object OO'. It is virtual, erect and smaller than the object.

Uses of convex mirrors

Convex mirrors are used as rear-view mirrors in vehicles. It always forms a virtual, erect, small-sized image of the object. As the vehicles approach the driver from behind, the size of the image increases. When the vehicles are moving away from the driver, then image size decreases. A convex mirror provides a much wider field of view (it is the observable area as seen through eye / any optical device such as mirror) compared to plane mirror. Convex mirrors are installed on public roads as traffic safety device. They are used in acute bends of narrow roads such as hairpin bends in mountain passes where direct view ofoncoming vehicles is restricted. It is also used in blind spots in shops.

In the rear view mirror, the following sentence is written. "Objects in the mirror are closer than they appear". Why?

Speed of light

In early seventeenth century the Italian scientist Galileo Galilee (1564–1642) tried to measure the speed of light as it travelled from a lantern on a hill top about a mile (1.6 km) away from where he stood. His attempt was bound to fail, because he had no accurate clocks or timing instruments.

In 1665 the Danish astronomer Ole Roemer first estimated the speed of light by observing one of the twelve moons of the planet Jupiter. As these moons travel around the planet, at a set speed, it would take 42 hours to revolve around Jupiter. Roemer made a time schedule of the eclipses for the whole year. He made first observation in June and second observation in December. Roemer estimated the speed of light to be about 220,000 km per second.

In 1849 the first land based estimate was made by Armand Fizeau. Today the speed of light in vacuum is known to be almost exactly 300,000 km per second.

Refraction of light

This activity explains the refraction of light. The bending of light rays when they pass obliquely from one medium to another medium is called refraction of light.

Cause of refraction

Light rays get deviated from their original path while entering from one transparentmedium to another medium of different optical density. This deviation (change in direction) in the path of light is due to the change in velocity of light in the different medium. The velocity of light depends on the nature of the medium in which it travels. Velocity of light in a rarer medium (low optical density) is more than in a denser medium (high optical density).

Refraction of light from a plane transparent surface

When a ray of light travels from optically rarer medium to optically denser medium, it bends towards the normal. (Figure 22)

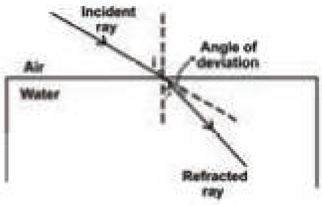


Figure 22 Light ray travelling from rarer to denser medium

When a ray of light travels from an optically denser medium to an optically rarer medium it bends away from the normal. (Figure 23)

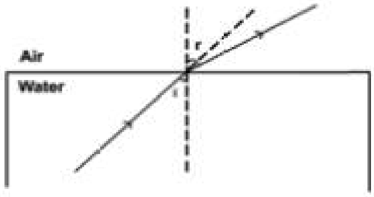


Figure 23 Light ray travelling from denser to rarer medium

A ray of light incident normally on a denser medium goes without any deviation. (Figure 24).

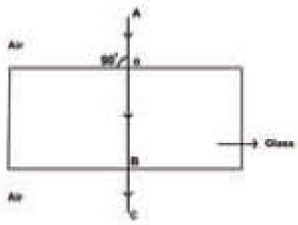


Figure 24 Incident of light ray in denser medium

The laws of refraction of light

The incident ray, the refracted ray and the normal to the interface of two transparent media at the point of incidence, all lie in the same plane.

The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant for a light of a given colour and for the given pair of media. This law is also known as Snell's law of refraction.

If i is the angle of incidence and r is the angle of refraction, then

$$\frac{\sin i}{\sin r} = \text{constant}$$

This constant is called the refractive index of the second medium with respect to the first medium. It is generally represented by the Greek letter, $_1\mu_2$ (mew)

Note: The refractive index has no unit as it is the ratio of two similar quantities

Verification of laws of refraction

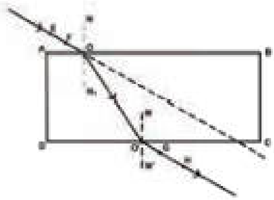


Figure 25 Verification of laws of refraction

Speed of light in different media

Light has the maximum speed in vacuum and it travels with different speeds in different media. The speed of light in some media is given below.

Note: The refractive index of a medium is also defined in terms of speed of light in different media

$$\mu = \frac{speed\ of light\ in\ vacuum\ in\ air(c)}{\text{speed of light in the vacuum (v)}}$$

in general, $1\mu2 = \frac{speedoflightinmedium\ 1}{\text{speed of light in medium 2}}$

Total internal reflection

When light travels from denser medium into a rarer medium, it gets refracted away from the normal. While the angle of incidence in the denser medium increases the angle of refraction also increases and it reaches a maximum value of $r = 90^o$ for a particular value. This angle of incidence is called critical angle (Figure 6.12). The angle of incidence at which the angle of refraction is 90^o is called the critical angle. At this angle, the refracted ray grazes the surface of separation between the two media.

When the angle of incidence exceeds the value of critical angle, the refracted ray is not possible. Since $r > 90^o$ the ray is totally reflected back to the same medium. This is called as total internal reflection.

Conditions to achieve total internal reflection

In order to achieve total internal refelection the following conditions must be met.

- Light must travel from denser medium to rarer medium. (Example: From water to air).
- The angle of incidence inside the denser medium must be greater than that of the critical angle.

Total internal reflection in nature

Mirage:

On hot summer days, patch of water may be on the road. This is an illusion. In summer, the air near the ground becomes hotter than the air at higher levels. Hotter air is less dense, and has smaller refractive index than the cooler air. Thus, a ray of light bends away from the normal and undergoes total internal reflection. Total internal reflection is the main cause for the spectacular brilliance of diamonds and twinkling of stars.

Optical fibres:

Optical fibres are bundles of high-quality composite glass/quartz fibres. Each fibre consists of a core and cladding. The refractive index of the material of the core is higher than that of the cladding. Optical fibres work on the phenomenon of total internal reflection. When a signal in the form of light is directed at one end of the fibre at a suitable angle, it undergoes repeated total internal reflection along the length of the fibre and finally comes out at the other end. Optical fibres are extensively used for transmitting audio and video signals through long distances. Moreover, due to their flexible nature, optical fibers enable physicians to look and work inside the body through tiny incisions without having to perform surgery.

An Indian-born physicist NarinderKapany is regarded as the Father of Fibre Optics.

10th Standard
Unit 2: Optics

PROPERTIES OF LIGHT

Let us recall the properties of light and the important aspects on refraction of light.

- **Light is a form of energy.**
- **Light always travels along a straight line.**
- **Light does not need any medium for its propagation. It can even travel through vacuum.**
- **The speed of light in vacuum or air is, c = 3 × $10^8 ms^{-1}$.**
- **Since, light is in the form of waves, it is characterized by a wavelength (λ) and a frequency (v), which are related by the following equation: c = v λ (c - velocity of light).**
- **Different coloured light has different wavelength and frequency.**
- **Among the visible light, violet light has the lowest wavelength and red light has the highest wavelength.**
- **When light is incident on the interface between two media, it is partly reflected and partly refracted.**

SCATTERING OF LIGHT

When sunlight enters the Earth's atmosphere, the atoms and molecules of different gases present in the atmosphere refract the light in all possible directions. This is called as 'Scattering of light'. In this phenomenon, the beam of light is redirected in all directions when it interacts with a particle of medium. The interacting particle of the medium is called as 'scatterer'.

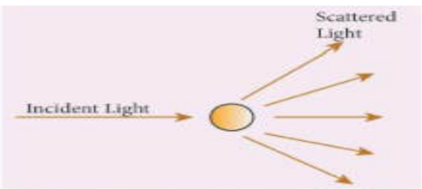


Figure 2.1 Scattering of light

Types of scattering

When a beam of light, interacts with a constituent particle of the medium, it undergoes many kinds of scattering. Based on initial and final energy of the light beam, scattering can be classified as,

Elastic scattering

- If the energy of the incident beam of light and the scattered beam of light are same, then it is called as 'elastic scattering'.

Inelastic scattering

- If the energy of the incident beam of light and the scattered beam of light are not same, then it is called as 'inelastic scattering'. The nature and size of the scatterer results in different types of scattering. They are

1) **Rayleigh scattering**
2) **Mie scattering**
3) **Tyndall scattering**
4) **Raman scattering**

Rayleigh scattering

The scattering of sunlight by the atoms or molecules of the gases in the earth's atmosphere is known as Rayleigh scattering.

Rayleigh's scattering law

Rayleigh's scattering law states that, "The amount of scattering of light is inversely proportional to the fourth power of its wavelength".

$$\text{Amount of scattering 'S'} \propto \frac{1}{\lambda^4}$$

According to this law, the shorter wavelength colours are scattered much more than the longer wavelength colours.

When sunlight passes through the atmosphere, the blue colour (shorter wavelength) is scattered to a greater extent than the red colour (longer wavelength). This scattering causes the sky to appear in blue colour.

At sunrise and sunset, the light rays from the Sun have to travel a larger distance in the atmosphere than at noon. Hence, most of the blue lights are scattered away and only the red light which gets least scattered reaches us. Therefore, the colour of the Sun is red at sunrise and sunset.

Mie scattering

Mie scattering takes place when the diameter of the scatterer is similar to or larger than the wavelength of the incident light. It is also an elastic scattering. The amount of scattering is independent of wave length.

Mie scattering is caused by pollen, dust, smoke, water droplets, and other particles in the lower portion of the atmosphere.

Mie scattering is responsible for the white appearance of the clouds. When white light falls on the water drop, all the colours are equally scattered which together form the white light.

Tyndall Scattering

When a beam of sunlight, enters into a dusty room through a window, then its path becomes visible to us. This is because, the tiny dust particles present in the air of the room scatter the beam of light. This is an example of Tyndall Scattering
The scattering of light rays by the colloidal particles in the colloidal solution is called Tyndall Scattering or Tyndall Effect.

Do you Know: Colloid is a microscopically small substance that is equally dispersed throughout another material. Example: Milk, Ice cream, muddy water, smoke

Raman scattering

When a parallel beam of monochromatic (single coloured) light passes through a gas or liquid or transparent solid, a part of light rays are scattered.

The scattered light contains some additional frequencies (or wavelengths) other than that of incident frequency (or wavelength). This is known as Raman scattering or Raman Effect.

Raman Scattering is defined as **"The interaction of light ray with the particles of pure liquids or transparent solids, which leads to a change in wavelength or frequency."**

The spectral lines having frequency equal to the incident ray frequency is called 'Rayleigh line' and the spectral lines which are having frequencies other than the incident ray frequency are called 'Raman lines'. The lines having frequencies lower than the incident frequency is called stokes lines and the lines having frequencies higher than the incident frequency are called Antistokes lines. You will study more about Raman Effect in higher classes.

LENSES

A lens is an optically transparent medium bounded by two spherical refracting surfaces or one plane and one spherical surface.

Lens is basically classified into two types. They are: (i) Convex Lens (ii) Concave Lens

- **Convex or bi-convex lens:** It is a lens bounded by two spherical surfaces such that it is thicker at the centre than at the edges. A beam of light passing through it, is converged to a point. So, a convex lens is also called as converging lens.

- **(ii) Concave or bi-concave Lens:** It is a lens bounded by two spherical surfaces such that it is thinner at the centre than at the edges. A parallel beam of light passing through it, is diverged or spread out. So, a concave lens is also called as diverging lens.

Other types of Lenses

- **Plano-convex lens:** If one of the faces of a bi-convex lens is plane, it is known as a plano-convex lens.

- **Plano-concave lens:** If one of the faces of a bi-concave lens is plane, it is known as a plano-concave lens.

All these lenses are shown in Figure 2.2 given below:

IMAGES FORMED DUE TO REFRACTION THROUGH A CONVEX AND CONCAVE LENS

When an object is placed in front of a lens, the light rays from the object fall on the lens. Th e position, size and nature of the image formed can be understood only if we know certain basic rules.

Rule-1: When a ray of light strikes the convex or concave lens obliquely at its optical centre, it continues to follow its path without any deviation (Figure 2.3).

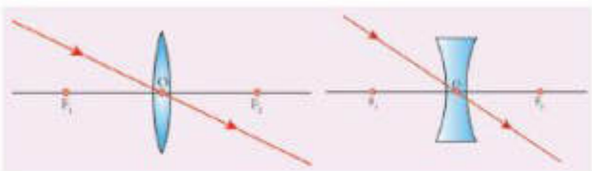


Figure 2.3 Rays passing through the optical centre

Rule-2: When rays parallel to the principal axis strikes a convex or concave lens, the refracted rays are converged to (convex lens) or appear to diverge from (concave lens) the principal focus (Figure 2.4).

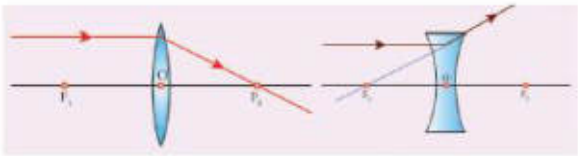


Figure 2.4 Rays passing parallel to the optic axis

Rule-3: When a ray passing through (convex lens) or directed towards (concave lens) the principal focus strikes a convex or concave lens, the refracted ray will be parallel to the principal axis (Figure 2.5).

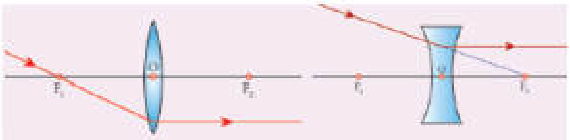


Figure 2.5 Rays passing through or directed towards the principal focus

REFRACTION THROUGH A CONVEX LENS

Let us discuss the formation of images by a convex lens when the object is placed at various positions.

Object at infinity

When an object is placed at infinity, a real image is formed at the principal focus. Th e size of the image is much smaller than that of the object (Figure 2.6).

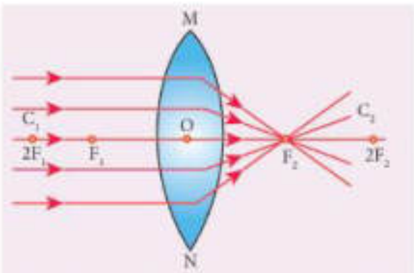


Figure 2.6 Object at infinity

Object placed beyond C (>2F)

When an object is placed behind the center of curvature(beyond C), a real and inverted image is formed between the center of curvature and the principal focus. Th e size of the image is the same as that of the object (Figure 2.7).

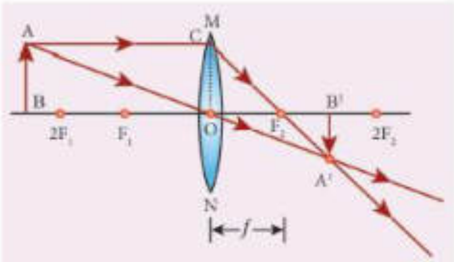


Figure 2.7 Object placed beyond C (>2F)

Object placed at C

When an object is placed at the center of curvature, a real and inverted image is formed at the other center of curvature. Th e size of the image is the same as that of the object (Figure 2.8).

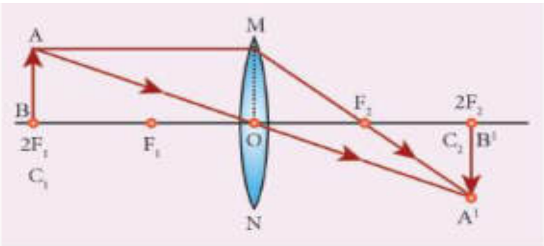


Figure.2.8 Object placed at C

Object placed between F and C

When an object is placed in between the center of curvature and principal focus, a real and inverted image is formed behind the center of curvature. The size of the image is bigger than that of the object (Figure 2.9).

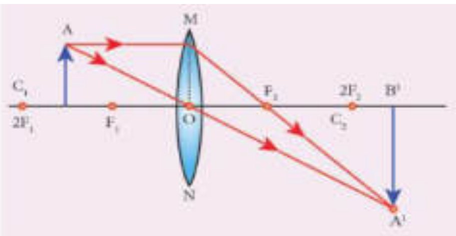


Figure 2.9 Object placed between F and C

Object placed at the principal focus F

When an object is placed at the focus, a real image is formed at infinity. The size of the image is much larger than that of the object (Figure 2.10).

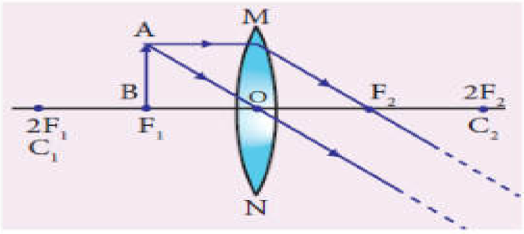


Figure 2.10 Object placed at the principal focus F

Object placed between the principal focus F and optical centre O

When an object is placed in between principal focus and optical centre, a virtual image is formed. The size of the image is larger than that of the object (Figure 2.11).

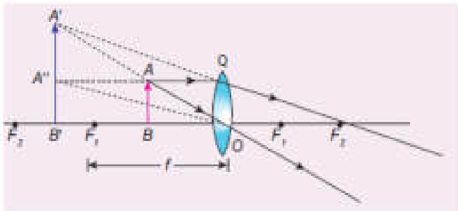


Figure 2.11 Object placed between the principal focus F and optical centre O

APPLICATIONS OF CONVEX LENSES

- **Convex lenses are used as camera lenses**
- **They are used as magnifying lenses**
- **They are used in making microscope, telescope and slide projectors**
- **They are used to correct the defect of vision called hypermetropia**

REFRACTION THROUGH A CONCAVE LENS

Let us discuss the formation of images by a concave lens when the object is placed at two possible positions.

Object at Infinity

When an object is placed at infinity, a virtual image is formed at the focus. The size of the image is much smaller than that of the object (Figure 2.12).

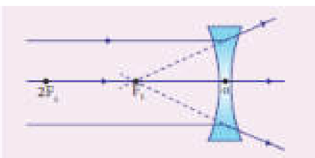


Figure 2.12 Concave lens-Object at infinity

Object anywhere on the principal axis at a finite distance

When an object is placed at a finite distance from the lens, a virtual image is formed between optical center and focus of the concave lens. The size of the image is smaller than that of the object (Figure 2.13).

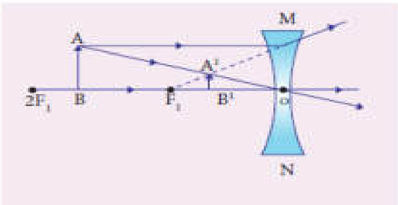


Figure 2.13 Concave lens-Object at a finite distance

But, as the distance between the object and the lens is decreased, the distance between the image and the lens also keeps decreasing. Further, the size of the image formed increases as the distance between the object and the lens is decreased. This is shown in (figure 2.14).

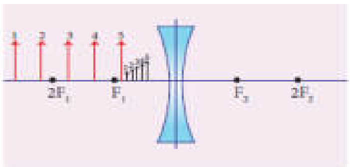


Figure 2.14 Concave lens-Variation in position and size of image with object distance

APPLICATIONS OF CONCAVE LENSES

- Concave lenses are used as eye lens of 'Galilean Telescope'
- They are used in wide angle spy hole in doors.
- They are are used to correct the defect of vision called 'myopia'

LENS FORMULA

Like spherical mirrors, we have lens formula for spherical lenses. The lens formula gives the relationship among distance of the object (u), distance of the image (v) and the focal length (f) of the lens. It is expressed as

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad \ldots\ldots\ldots\ldots\ 2.2$$

It is applicable to both convex and concave lenses. We need to give an at most care while solving numerical problems related to lenses in taking proper signs of different quantities.

SIGN CONVENTION

Cartesian sign conventions are used for measuring the various distances in the ray diagrams of spherical lenses. According to cartesian sign convention,

- ❖ The object is always placed on the left side of the lens.
- ❖ All the distances are measured from the optical centre of the lens.
- ❖ The distances measured in the same direction as that of incident light are taken as positive.
- ❖ The distances measured against the direction of incident light are taken as negative.
- ❖ The distances measured upward and perpendicular to the principal axis is taken as positive.
- ❖ The distances measured downward and perpendicular to the principal axis is taken as negative.

MAGNIFICATION OF A LENS

Like spherical mirrors, we have magnification for spherical lenses. Spherical lenses produce magnification and it is defined as the ratio of the height of the image to theheight of an object. Magnification is denoted by the letter 'm'. If height of the object is *h* and height of the image is *h* ´, the magnification produced by lens is,

$$m = \frac{height\ of\ the\ image}{height\ of\ the\ object} = \frac{h'}{h} \quad \ldots\ldots (2.3)$$

Also it is related to the distance of the object (*u*) and the distance of the image (*v*) as follows:

$$m = \frac{Distance\ of\ the\ image}{Distance\ of\ the\ object} = \frac{v}{u} \quad \ldots\ldots (2.4)$$

If the magnification is greater than 1, then we get an enlarged image. On the other hand, if the magnification is less than 1, then we get a diminished image.

LENS MAKER'S FORMULA

All lenses are made up of transparent materials. Any optically transparent material will have a refractive index. The lens formula relates the focal length of a lens with the distance of object and image. For a maker of any lens, knowledge of radii of curvature of the lens is required. This clearly indicates the need for an equation relating the radii of curvature of the lens, the refractive index of the given material of the lens and the required focal length of the lens. The lens maker's formula is one such equation. It is given as

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \cdots\cdots\cdots (2.5)$$

where μ is the refractive index of the material of the lens; $R1$ and $R2$ are the radii of curvature of the two faces of the lens; f is the focal length of the lens.

POWER OF A LENS

When a ray of light falls on a lens, the ability to converge or diverge these light rays depends on the focal length of the lens. This ability of a lens to converge (convex lens) or diverge (concave lens) is called as its power. Hence, the power of a lens can be defined as the degree of convergence or divergence of light rays. Power of a lens is numerically defined as the reciprocal of its focal length.

$$P = \frac{1}{f} \cdots\cdots\cdots\cdots\cdots (2.6)$$

The SI unit of power of a lens is dioptre. It is represented by the symbol D. If focal length is expressed in 'm', then the power of lens is expressed in 'D'. Thus 1D is the power of a lens, whose focal length is 1metre. $1D = 1m^{-1}$.

By convention, the power of a convex lens is taken as positive whereas the power of a concave lens is taken, as negative.

More to Know: The lens formula and lens maker's formula are applicable to only thin lenses. In the case of thick lenses, these formulae with little modifications are used.

Table 2.1 Differences between a Convex Lens and a Concave Lens

S.No	Convex Lens	Concave Lens
1	A convex lens is thicker in the	A concave lens is thinner in the

	middle than at edges.	middle than at edges.
2	It is a converging lens.	It is a diverging lens.
3	It produces mostly real images.	It produces virtual images.
4	It is used to treat hypermeteropia.	It is used to treat myopia.

Unit 6 – Optics

Example

What is the height of the mirror needed to see the image of a person fully on the mirror?

Solution

Let us assume a person of height h is standing in front of a vertical plane mirror. The person could see his/her head when light from the head falls on the mirror and gets reflected to the eyes. Same way, light from the feet falls on the mirror and gets reflected to the eyes.

If the distance between his head *H* and eye *E* is *h*1 and distance between his feet *F* and eye *E* is *h*2. The person's total height *h* is, *h* = *h*1 + *h*2

By the law of reflection, the angle of incidence and angle of reflection are the same in the two extreme reflections. The normals are now the bisectors of angles between incident and reflected rays in the two reflections. By geometry, the height of the mirror needed is only half of the height of the person.

$$\frac{h_1 + h_2}{2} = \frac{h}{2}$$

Refractive index

Refractive index of a transparent medium is defined as the ratio of speed of light in vacuum (or air) to the speed of light in that medium.

$$\left.\begin{array}{r}\text{refractive}\\ \text{index } n \text{ of a}\\ \text{medium}\end{array}\right\} = \frac{\text{speed of light in vacuum } (c)}{\text{speed of light in medium } (v)}$$

$$n = \frac{c}{v}$$

Refractive index of a transparent medium gives an idea about the speed of light in that medium.

Example

One type of transparent glass has refractive index 1.5. What is the speed of light through this glass?

Solution

$$n = \frac{c}{v}; \qquad v = \frac{c}{n}$$

$$v = \frac{3\times10^8}{1.5} = 2\times10^8 \text{ m s}^{-1}$$

Light travels with a speed of 2×10^8 ms^{-1}

Refractive index does not have unit. The smallest value of refractive index is for vacuum, which is 1. For any other medium refractive index is greater than 1. Refractive index is also called as optical density of the medium. Higher the refractive index of a medium, greater is its optical density and speed of light through the medium is lesser and vice versa.

Refraction index of different media

Media	Refraction index
Vacuum	1.00
Air	1.0003
Carbon dioxide gas	1.0005
Ice	1.31
Pure Water	1.33
Ethyl alcohol	1.36
Quartz	1.46
Vegetable oil	1.47
Olive oil	1.48
Acrylic	1.49
Table salt	1.51
Glass	1.52
Sapphire	1.77
Zircon	1.92
Qubic zirconia	2.16
Diamond	2.42
Gallium phosphide	3.50

Apparent depth

It is a common observation that the bottom of a tank filled with water appears raised. An equation could be derived for the apparent depth for viewing in the near normal direction.

Light from the object *O* at the bottom of the tank passes from denser medium (water) to rarer medium (air) to reach our eyes. It deviates away from the normal in the rarer medium at the point of incidence *B*. The refractive index of the denser medium is *n*1 and rarer medium is *n*2. Here, *n*1 >*n*2. The angle of incidence in the denser medium is *i*and the angle of refraction in the rarer medium is *r*. The lines and *OD* are parallel. Thus angle ∠*DIB* is also *r*. The angles *i*and *r* are very small as the diverging light from *O* entering the eye is very narrow. The Snell's law in product form for this refraction is,

$$n_1 \sin i = n_2 \sin r$$

As the angles *i*and *r* are small, we can approximate, sin *i*≈ tan *i*;

$$n_1 \tan i = n_2 \tan \mathrm{i}$$

In triangles Δ*DOB* and Δ*DIB*,

$$\tan(i) = \frac{DB}{DO} \text{ and } \tan(r) = \frac{DB}{DI}$$

$$n_1 \frac{DB}{DO} = n_2 \frac{DB}{DI}$$

DB is cancelled on both sides, *DO* is the actual depth *d* and *DI* is the apparent depth *d*'.

$$n_1 \frac{1}{d} = n_2 \frac{1}{d'}$$

$$\frac{d'}{d} = \frac{n_2}{n_1}$$

Rearranging the above equation for the apparent depth d',

$$d' = \frac{n_2}{n_1} d$$

As the rarer medium is air and its refractive index *n*2 can be taken as 1, (*n*2=1). And the refractive index *n*1 of denser medium could then be taken as *n*, (*n*1=*n*).

In that case, the equation for apparent depth becomes,

$$d' = \frac{d}{n}$$

The bottom appears to be elevated by d– d′

$$d - d' = d - \frac{d}{n} \text{ or } d - d' = d\left(1 - \frac{1}{n}\right)$$

Atmospheric refraction: Due to refraction of light through different layers of atmosphere which vary in refractive index, the path of light deviates continuously when it passes through atmosphere. For example, the Sun is visible a little before the actual sunrise and also until a little after the actual sunset due to refraction of light through the atmosphere. By actual sunrise what we mean is the actual crossing of the sun at the horizon. Figure shows the actual and apparent positions of the sun with respect to the horizon. The figure is highly exaggerated to show the effect. The apparent shift in the direction of the sun is around half a degree and the corresponding time difference between actual and apparent positions is about 2 minutes. Sun appears flattened (oval shaped) during sun rise and sunset due to the same phenomenon.

The same is also applicable for the positions of stars as shown in Figure. The stars actually do not twinkle. They appear twinkling because of the movement of the atmospheric layers with varying refractive indices which is clearly seen in the night sky.

Effects due to total internal reflection

Glittering of diamond

Diamond appears dazzling because the total internal reflection of light happens inside the diamond. The refractive index of only diamond is about 2.417. It is much larger than that for ordinary glass which is about only 1.5. The critical angle of diamond is about 24.4°. It is much less than that of glass. A skilled diamond cutter makes use of this larger range of angle of incidence (24.4° to 90° inside the diamond), to ensure that light entering the diamond is total internally reflected from the many cut faces before getting out. This gives a sparkling effect for diamond.

Mirage and looming

The refractive index of air increases with its density. In hot places, air near the ground is hotter than air at a height. Hot air is less dense. Hence, in still air the refractive index of air increases with height. Because of this, light from tall objects like a tree, passes through a medium whose refractive index decreases towards the ground. Hence, a ray of light successively deviates away from the normal at different layers of air and undergoes total internal reflection when the angle of incidence near the ground exceeds the critical angle. This gives an illusion as if the light comes from somewhere below the ground. For of the shaky nature of the layers of air, the observer feels as if the object is getting reflected by a pool of water or wet surface beneath the object. This phenomenon is called mirage.

In the cold places the refractive index increases towards the ground because the temperature of air close to the ground is lesser than the temperature above the surface of earth. Thus, the density and refractive index of air near the ground is greater than at a height. In the cold regions like glaciers and frozen lakes and seas, the reverse effect of mirage will happen. Hence, an inverted image is formed little above the surface. This phenomenon is called looming.

Prisms making using of total internal reflection

Prisms can be designed to reflect light by 90^0 or by 180^0 by making use of total internal reflection. In the first two cases, the critical angle ic for the material of the prism must be less than 45^0. This is true for both crown glass and flint glass. Prisms are also used to invert images without changing their size.

Radius of illumination (Snell's window)

When a light source like electric bulb is kept inside a water tank, the light from the source travels in all direction inside the water. The light that is incident on the water surface at an angle less than the critical angle will undergo refraction and emerge out from the water. The light incident at an angle greater than critical angle will undergo total internal reflection. The light falling particularly at critical angle graces the surface.

On the other hand, when light entering the water from outside is seen from inside the water, the view is restricted to a particular angle equal to the critical angle ic. The restricted illuminated circular area is called Snell's window.

The angle of view for water animals is restricted to twice the critical angle 2*ic*. The critical angle for water is 48.6^0. Thus the angle of view is 97.2^0. The radius *R* of the circular area depends on the depth *d* from which it is seen and also the refractive indices of the media. The radius of Snell's window can be deduced with the illustration.

Light is seen from a point *A* at a depth *d*. The Snell's law in product form, equation for the refraction happening at the point *B* on the boundary between the two media is,

$$n_1 \sin i_c = n_2 \sin 90^0$$

$$n_1 \sin i_c = n_2 \qquad \because \sin 90^0 = 1$$

$$\sin i_c = \frac{n_2}{n_1}$$

From the right angle triangle ΔABC:

$$\sin i_c = \frac{CB}{AB} = \frac{R}{\sqrt{d^2 + R^2}}$$

Equating the above two equation 6.34 and equation 6.35, $\frac{R}{\sqrt{d^2 + R^2}} = \frac{n_2}{n_1}$

Squaring on both sides, $\frac{R^2}{R^2 + d^2} = \left(\frac{n_2}{n_1}\right)^2$

Taking reciprocal, $\frac{R^2 + d^2}{R^2} = \left(\frac{n_1}{n_2}\right)^2$

On further simplifying,

$$1 + \frac{d^2}{R^2} = \left(\frac{n_1}{n_2}\right)^2; \qquad \frac{d^2}{R^2} = \left(\frac{n_1}{n_2}\right)^2 - 1;$$

$$\frac{d^2}{R^2} = \frac{n_1^2}{n_2^2} - 1 = \frac{n_1^2 - n_2^2}{n_2^2}$$

Again taking reciprocal and rearranging,

$$\frac{R^2}{d^2} = \frac{n_2^2}{n_1^2 - n_2^2}; \qquad R^2 = d^2\left(\frac{n_2^2}{n_1^2 - n_2^2}\right)$$

The radius of illumination is,

$$R = d\sqrt{\frac{n_2^2}{(n_1^2 - n_2^2)}} \qquad (6.35)$$

If the rarer medium outside is air, then, $n_2 = 1$, and we can take $n_1 = n$

$$R = d\left(\frac{1}{\sqrt{n^2 - 1}}\right) \text{ (or) } R = \frac{d}{\sqrt{n^2 - 1}}$$

Optical Fiber

Transmitting signals through optical fibres is possible due to the phenomenon of total internal reflection. Optical fibres consists of inner part called core and outer part called cladding (or) sleeving. The refractive index of the material of the core must be higher than that of the cladding for total internal reflection to happen. Signal in the form of light is made to incident inside the core-cladding boundary at an angle greater than the critical angle. Hence, it undergoes repeated total internal reflections along the length of the fibre without undergoing any refraction. The light travels inside the core with no appreciable loss in the intensity of the light. Even while bending the optic fiber, it is done in such a way that the condition for total internal reflection is ensured at every reflection.

Acceptance angle in optical fibre

To ensure the critical angle incidence in the core-cladding boundary inside the optical fibre, the light should be incident at a certain angle at the end of the optical fiber while entering in to it. This angle is called *acceptance angle*. It depends on the refractive indices of the core *n*1, cladding *n*2 and the outer medium *n*3. Assume the light is incident at an angle called acceptance angle *ia*at the outer medium and core boundary at *A*.

The Snell's law in the product form, equation (6.19) for this refraction at the point *A*.

$$n_3 \sin i_a = n_1 \sin r_a$$

To have the total internal reflection inside optical fibre, the angle of incidence at the core-cladding interface at B should be atleast critical angle ic. Snell's law in the product form, equation (6.19) for the refraction at point B is,

$$n_1 \sin i_c = n_2 \sin 90^\circ$$

$$n_1 \sin i_c = n_2 \qquad \because \sin 90^\circ = 1$$

$$\therefore \sin i_c = \frac{n_2}{n_1}$$

From the right angle triangle ΔABC,

$$i_c = 90^\circ - r_a$$

Now, equation (6.39) becomes,

$$\sin(90^\circ - r_a) = \frac{n_2}{n_1}$$

Using trigonometry, $\cos r_a = \frac{n_2}{n_1}$

$$\sin r_a = \sqrt{1-\cos^2 r_a}$$

Substituting for $\cos r_a$

$$\sin r_a = \sqrt{1-\left(\frac{n_2}{n_1}\right)^2} = \sqrt{\frac{n_1^2 - n_2^2}{n_1^2}}$$

Substituting this in equation (

$$n_3 \sin i_a = n_1 \sqrt{\frac{n_1^2 - n_2^2}{n_1^2}} = \sqrt{n_1^2 - n_2^2}$$

On further simplification,

$$\sin i_a = \frac{\sqrt{n_1^2 - n_2^2}}{n_3} \text{ (or) } \sin i_a = \sqrt{\frac{n_1^2 - n_2^2}{n_3^2}}$$

$$i_a = \sin^{-1}\left(\sqrt{\frac{n_1^2 - n_2^2}{n_3^2}}\right)$$

If outer medium is air, then n3 = 1. The acceptance angle ia becomes,

$$i_a = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)$$

Light can have any angle of incidence from 0 to ia with the normal at the end of the optical fibre forming a conical shape called acceptance cone called numerical aperture NA of the optical fibre.

$$NA = n_3 \sin i_a = \sqrt{n_1^2 - n_2^2}$$

If outer medium is air, then *n*3 = 1. The numerical aperture *NA* becomes,

$$NA = \sin i_a = \sqrt{n_1^2 - n_2^2}$$

An endoscope is an instrument used by doctors which has a bundle of optical fibres that are used to see inside a patient's body. Endoscopes work on the phenomenon of total internal reflection. The optical fibres are inserted in to the body through mouth, nose or a special hole made in the body. Even operations could be carried out with the endoscope cable which has the necessary instruments attached at their ends

Dispersion of white light through prism

So far the angle of deviation produced by a prism is discussed for monochromatic light (i.e. light of single colour). When white light enter in to a prism, the effect called dispersion takes place. Dispersion is splitting of white light into its constituent colours. This band of colours of light is called its spectrum. When a narrow beam of parallel rays of white light is incident on the face of a prism and the refracted beam is received on a white screen, a band of colours is obtained in the order, recollected by the word: VIBGYOR i.e., Violet, Indigo, Blue, Green, Yellow, Orange and Red.Violet is the most deviated and red is the least deviated colour.

The colours obtained in a spectrum depend on the nature of the source of the light used. Each colour of light is associated with a definite wavelength. Red light is at the longer wavelength end (700 nm) while the violet light is at the shorter wavelength end (400 nm). Therefore the violet ray travels with a smaller velocity in glass prism than red ray.

Dispersion takes place because light of different wave lengths travel with different speeds inside the prism. In other words, the refractive index of the material of the prism is different for different colours. For violet, the refractive index is high and for red the refractive index is the low. In Vacuum, all the colours travel with the same speed.

The speed of light is independent of wavelength in vacuum. Therefore, vacuum is a non-dispersive medium in which all colours travel with the same speed.

Refractive indices for different wavelengths

Colour	Wavelength (nm)	Crown glass	Flint glass
Violet	396.9	1.533	1.663
Blue	486.1	1.523	1.639
Yellow	589.3	1.517	1.627
Red	656.3	1.515	1.622

Scattering of sunlight

When sunlight enters the atmosphere of the earth, the atmospheric particles present in the atmosphere change the direction of the light. This process is known as scattering of light.

If the scattering of light is by atoms and molecules which have size a very less than that of the wave length λ of light a<<λ, the scattering is called Rayleigh's scattering. The intensity of Rayleigh's scattering is inversely proportional to fourth power of wavelength.

$$I \propto \frac{1}{\lambda^4}$$

According to equation 6.114, violet colour which has the shortest wavelength gets much scattered during day time. The next scattered colour is blue. As our eyes are more sensitive to blue colour than violet colour the sky appears blue during day time. But, during sunrise and sunset, the light from sun travels a greater distance through the atmosphere. Hence, the blue light which has shorter wavelength is scattered away and the less-scattered red light of longer wavelength manages to reach our eye. This is the reason for the reddish appearance of sky during sunrise.

Rainbow is an example of dispersion of sunlight through droplets of water during rainy days. Rainbow is observed during a rainfall or after the rainfall or when we look at a water fountain provided the sun is at the back of the observer. When sunlight falls on the water drop suspended in air, it splits (or dispersed) into its constituent seven colours. Thus, water drop suspended in air behaves as a glass prism. Primary rainbow is formed when light entering the drop undergoes one total internal reflection inside the drop before coming out from the drop as shown in figure. The angle of view for violet to red in primary rainbow is 40^0 to 42^0. A secondary rainbow appears outside of a primary rainbow and develops when light entering a raindrop undergoes two internal reflections. The angle of view for red to violet in a secondary rainbow is, 52^o to 54^o.

If light is scattered by large particles like dust and water droplets present in the atmosphere which have size a greater than the wavelength λ of light, a >> λ, the intensity of scattering is equal for all the wavelengths. It is happening in clouds which contains large amount of dust and water droplets. Thus, in clouds all the colours get equally scattered irrespective of wavelength. This is the reason for the whitish appearance of cloud. But, the rain clouds appear dark because of the condensation of water droplets on dust particles that makes the cloud become opaque.

If earth has no atmosphere there would not have been any scattering and the sky would appear dark. That is why sky appears dark for the astronauts who could see the sky from above the atmosphere.

Theories on light

Light is a form of energy that is transferred from one place to another. A glance at the evolution of various theories of light put forward by scientists will give not only an over view of the nature of light but also its propagation and some phenomenon demonstrated by it.

Corpuscular theory

Sir Isaac Newton (1672) gave the corpuscular theory of light which was also suggested earlier by Descartes (1637) to explain the laws of reflection and refraction. According this theory, light is emitted as tiny, massless (negligibly small mass) and perfectly elastic particles called corpuscles. As the corpuscles are very small, the source of light does not suffer appreciable loss of mass even if it emits light for a long time. On account of high speed, they are unaffected by the force of gravity and their path is a straight line in a medium of uniform refractive index. The energy of light is the kinetic energy of these corpuscles. When these corpuscles impinge on the retina of the eye, the vision is produced. The different size of the corpuscles is the reason for different colours of light. When the corpuscles approach a surface between two media, they are either attracted or repelled. The reflection of light is due to the repulsion of the corpuscles by the medium and refraction of light is due to the attraction of the corpuscles by the medium.

This theory could not explain the reason why the speed of light is lesser in denser medium than in rarer medium and also the phenomena like interference, diffraction and polarisation.

Wave theory

Christian Huygens (1678) proposed the wave theory to explain the propagation of light through a medium. According to him, light is a disturbance from a source that travels as longitudinal mechanical waves through the ether medium that was presumed to pervade all space as mechanical wave requires medium for its propagation. The wave theory could successfully explain phenomena of reflection, refraction, interference and diffraction of light.

Later, the existence of ether in all space was proved to be wrong. Hence, this theory could not explain the propagation of light through vacuum. The phenomenon of polarisation could not be explained by this theory as it is the property of only transverse waves.

Electromagnetic wave theory

Maxwell (1864) proved that light is an electromagnetic wave which is transverse in nature carrying electromagnetic energy. He could also show that no medium is necessary for the propagation of electromagnetic waves. All the phenomenon of light could be successfully explained by this theory.

Nevertheless, the interaction phenomenon of light with matter like photoelectric effect, Compton effect could not be explained by this theory.

Quantum theory

Albert Einstein (1905), endorsing the views of Max Plank (1900), was able to explain photoelectric effect (discussed in Unit 7) in which light interacts with matter as photons to eject the electrons. A photon is a discrete packet of energy. Each photon has energy E of,

$$E = hv$$

Where, h is Plank's constant ($h = 6.625 \times 10^{-34}$ J s) and v is frequency of electromagnetic wave.

As light has both wave as well as particle nature it is said to have dual nature. Thus, it is concluded that light propagates as a wave and interacts with matter as a particle.

Wave Nature of Light

Light is a transverse, electromagnetic wave. The wave nature of light was first illustrated through experiments on interference and diffraction. Like all electromagnetic waves, light can travel through vacuum. The transverse nature of light is demonstrated in polarization.

Wave optics

Wave optics deals with the wave characteristics of light. With the help of wave optics, we are going to learn in details the phenomena of interference, diffraction and polarization. Even the law of reflection and refraction are proved only with the help of wave optics. Though light propagates as a wave, its direction of propagation is still represented as a ray.

An example for wave propagation is the spreading of circular ripples on the surface of still water from a point at which a stone is dropped. The molecules or particles of water are moving only up and down (oscillate) when a ripple passes out that part. All these particles on the circular ripple are in the same phase of vibration as they are all at the same distance from the center. The ripple represents a wave front. A wave front is the locus of points which are in the same state or phase of vibration. When a wave propagates it is treated as the propagation of wave front. The wave front is always perpendicular to the direction of the propagation of the wave. As the direction of ray is in the direction of propagation of the wave, the wave front is always perpendicular to the ray.

The shape of a wavefront observed at a point depends on the shape of the source and also the distance at which the source is located. A point source located at a finite distance gives spherical wavefronts. An extended (or) line source at finite distance gives cylindrical wavefronts. The plane wavefronts are received from any source that is located at infinity.

Huygens' Principle

Huygens principle is a geometrical construction which gives the shape of the wave front at any time if we know its shape at t = 0. According to Huygens principle, each point of the wave front is the source of secondary wavelets emanating from these points spreading out in all directions with the speed of the wave. These are called as secondary wavelets. The common tangent, in other words the envelope to all these wavelets gives the position and shape of the new wave front at a later time. Thus, Huygens'principle explains the propagation of a wave front.

The propagation of a spherical and plane wave front is explained in using Huygens' principle. Let, AB be the wave front at a time, t = 0. According to Huygens' principle, every point on AB acts as a source of secondary wavelet which travels with the speed of the wave (speed of light c). To find the position of the wave front after a time t, circles of radius equal to ct are drawn with points P, Q, R ... etc., as centers on AB. The tangent or forward envelope of the small circles is the new wave front at that instant. The wave front will be a spherical wave front from a point object which is at a finite distance and it is a plane wave front if the source of light is at a large distance (infinity).

There is one shortcoming in the above Huygens' construction for propagation of a wave front. It could not explain the absence of back wave which also arises in the above construction. According to electromagnetic wave theory, the back wave is ruled out inherently. However, Huygens' construction diagrammatically explains the propagation of the wave front.

Optical Instruments
Simple microscope

A simple microscope is a single magnifying (converging) lens of small focal length. The idea is to get an erect, magnified and virtual image of the object. For this the object is placed between F and P on one side of the lens and viewed from other side of the lens. There are two magnifications to be discussed for two kinds of focussing.

- Near point focusing – The image is formed at near point, i.e. 25 cm for normal eye. This distance is also called as least distance D of distinct vision. In this position, the eye feels comfortable but there is little strain on the eye. This is shown.

- Normal focusing – The image is formed at infinity. In this position the eye is most relaxed to view the image.

Magnification in near point focusing

The near point focusing is shown. Object distance u is less than f. The image distance is the near point D. The magnification m is given by the relation,

$$m = \frac{v}{u}$$

With the help of lens equation, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ the magnification can further be written as,

$$m = 1 - \frac{v}{f} \quad (6.173)$$

Substituting for v with sign convention, $v = -D$

$$m = 1 + \frac{D}{f} \quad (6.174)$$

Magnification in normal focusing (angular magnification)

The normal focusing is shown. We will now find the magnification for the image formed at infinity. If we take the ratio of height of image to height of object

$\left(m = \frac{h'}{h}\right)$ to find the magnification, we will not get a practical relation, as the image will also be of infinite size when the image is formed at infinity. Hence, we can practically use the angular magnification. The angular magnification is defined as the ratio of angle subtended by the image with aided eye to the angle subtended by the object with unaided eye.

$$m = \frac{\theta_i}{\theta_0}$$

$$\tan\theta_0 \approx \theta_0 = \frac{h}{D}$$

$$\tan\theta_i \approx \theta_i = \frac{h}{f}$$

The angular magnification is,

$$m = \frac{\theta_i}{\theta_0} = \frac{h/f}{h/D}$$

$$m = \frac{D}{f}$$

This is the magnification for normal focusing.

The magnification for normal focusing is one less than that for near point focusing. But, the viewing is more comfortable in normal focusing than near point focusing. For large values of D/f, the difference in magnification is usually small. In subsequent discussions, we shall only consider the normal focusing.

Resolving power of microscope

The diagram related to the calculation of resolution of microscope is illustrated. A microscope is used to see the details of the object under observation. The ability of microscope depends not only in magnifying the object but also in resolving two points on the object separated by a small distance *dmin*. Smaller the value of *dmin*better will be the resolving power of the microscope.

The radius of central maxima is already derived as equation

$$r_o = \frac{1.22\lambda v}{a}$$

In the place of focal length f we have the image distance v. If the difference between the two points on the object to be resolved is d_{min}, then the magnification m is,

Compound microscope

The diagram of a compound microscope is shown. The lens near the object, called the objective, forms a real, inverted, magnified image of the object. This serves as the object for the second lens which is the eyepiece. Eyepiece serves as a simple microscope that produces finally an enlarged and virtual image. The first inverted image formed by the objective is to be adjusted close to, but within the focal plane of the eyepiece so that the final image is formed nearly at infinity or at the near point. The final image is inverted with respect to the original object. We can obtain the magnification for a compound microscope.

Magnification of compound microscope

From the ray diagram, the linear magnification due to the objective is,

$$m_o = \frac{h'}{h} \quad (6.186)$$

From the Figure 6.85, $\tan\beta = \frac{h}{f_o} = \frac{h'}{L}$, then

$$\frac{h'}{h} = \frac{L}{f_o} \quad (6.187)$$

$$m_o = \frac{L}{f_o} \quad (6.188)$$

Here, the distance *L* is between the first focal point of the eyepiece to the second focal point of the objective. This is called the tube length *L* of the microscope as *fo*and*fe*are comparatively smaller than *L*.

If the final image is formed at *P* (near point focussing), the magnification *me* of the eyepiece is,

$$m_e = 1 + \frac{D}{f_e}$$

The total magnification m in near point focusing is,

$$m = m_o m_e = \left(\frac{L}{f_o}\right)\left(1 + \frac{D}{f_e}\right)$$

If the final image is formed at infinity (normal focusing), the magnification me of the eyepiece is,

$$m_e = \frac{D}{f_e}$$

The total magnification m in normal focusing is,

$$m = m_o m_e = \left(\frac{L}{f_o}\right)\left(\frac{D}{f_e}\right)$$

Astronomical telescope

An astronomical telescope is used to get the magnification of distant astronomical objects like stars, planets, moon etc. The image formed by astronomical telescope will be inverted. It has an objective of long focal length and a much larger aperture than the eyepiece as shown. Light from a distant object enters the objective and a real image is formed in the tube at its second focal point. The eyepiece magnifies this image producing a final inverted image.

Magnification of astronomical telescope

The magnification m is the ratio of the angle β subtended at the eye by the finalimage to the angle α which the object subtends at the lens or the eye.

$$m = \frac{\beta}{\alpha}$$

From the diagram, $m = \frac{h / f_e}{h / f_o}$

$$m = \frac{f_o}{f_e}$$

The length of the telescope is approximately, $L = f_o + f_e$

Terrestrial telescope

A terrestrial telescope is used to see object at long distance on the surface of earth. Hence, image should be erect. A terrestrial telescope has an additional erecting lens to make the final image erect as shown.

Reflecting telescope

Modern telescopes use a concave mirror rather than a lens for the objective. It is rather difficult and expensive to make lenses of large size which form images that are free from any optical defect. Telescopes with mirror objectives are called reflecting telescopes. They have several advantages. Only one surface it to be polished and maintained. Support can be given from the entire back of the mirror rather than only at the rim for lens. Mirrors weigh much less compared to lens. But the one obvious problem with a reflecting telescope is that the objective mirror would focus the light inside the telescope tube. One must havean eye piece inside obstructing some light. This problem could also be overcome by introducing a secondary mirror which would take the light outside the tube for view as shown.

Spectrometer

The spectrometer is an optical instrument used to study the spectra of different sources of light and to measure the refractive indices of materials. It is shown. It consists of basically three parts. They are (i) collimator (ii) prism table and (iii) Telescope.

Collimator

The collimator is an arrangement to produce a parallel beam of light. It consists of a long cylindrical tube with a convex lens at the inner end and a vertical slit at the outer end of the tube. The distance between the slit and the lens can be adjusted such that the slit is at the focus of the lens. The slit is kept facing the source of light. The width of the slit can be adjusted. The collimator is rigidly fixed to the base of the instrument.

Prism table

The prism table is used for mounting the prism, grating etc. It consists of two circular metal discs provided with three levelling screws. It can be rotated about a vertical axis passing through its centre and itspositioncan be read with verniers V_1 and V_2 . The prism table can be raised or lowered and can be fixed at any desired height.

Telescope

The telescope is an astronomical type. It consists of an eyepiece provided with cross wires at one end and an objective lens at its other end. The distance between the objective lens and the eyepiece can be adjusted so that the telescope forms a clear image at the cross wires, when a parallel beam from the collimator is incident on it.

The telescope is attached to an arm which is capable of rotation about the same vertical axis as the prism table. A circular scale graduated in half degree is attached to it. Both the telescope and prism table are provided with radial screws for fixing them in a desired position and tangential screws for fine adjustments.

Adjustments of the spectrometer

The following adjustments must be made before doing the experiment using spectrometer.

- **Adjustment of the eyepiece**The telescope is turned towards an illuminated surface and the eyepiece is moved to and fro until the cross wires are clearly seen.
- **Adjustment of the telescope** The telescope is adjusted to receive parallel rays by turning it towards a distant object and adjusting the distance between the objective lens and the eyepiece to get a clear image on the cross wire.
- **Adjustment of the collimator**The telescope is brought along the axial line with the collimator. The slit of the collimator is illuminated by a source of light. The distance between the slit and the lens of the collimator is adjusted until a clear image of the slit is seen atthe cross wire of the telescope. Since the telescope is already adjusted for parallel rays, a well-defined image of the slit can be formed, only when the light rays emerging from the collimator are parallel.

- **Levelling the prism table**The prism table is adjusted or levelled to be in horizontal position by means of levelling screws and a spirit level.

Determination of refractive index of material of the prism

The preliminary adjustments of the telescope, collimator and the prism table of the spectrometer are made. The refractive index of the prism can be determined by knowing the angle of the prism and the angle of minimum deviation.

The prism is placed on the prism table with its refracting edge facing the collimator as shown. The slit is illuminated by a sodium light (monochromotic light). The parallel rays coming from the collimator fall on the two faces AB and AC. The telescope is rotated to the position T_1 until the image of the slit formed by the reflection at the face AB is made to coincidewith the vertical cross wire of the telescope. The readings of the verniers are noted. The telescope is then rotated to the position $T_2$where the image of the slit formed by the reflection at the face AC coincideswiththe vertical cross wire. The readings are again noted.

The difference between these two readings gives the angle rotated by the telescope, which is twice the angle of the prism. Half of this value gives the angle of the prism A.

Angle of minimum deviation (D)

The prism is placed on the prism table so that the light from the collimator falls on a refracting face, and the refracted image is observed through the telescope as shown. The prism table is now rotated so that the angle of deviation decreases. A stage comes when the image stops for a moment and if we rotate the prism table further in the same direction, the image is seen to recede and the angle of deviation increases. The vertical cross wire of the telescope is made to coincide with the image of the slit where it turns back. This gives the minimum deviation position.

The readings of the verniers are noted. Now, the prism is removed and the telescope is turned to receive the direct ray and the vertical cross wire is made to coincide with theimage. The readings of the verniers are noted. The difference between the two readings gives the angle of minimum deviation D. The refractive index of the material of the prism n is calculated using the formula,

$$n = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

The refractive index of a liquid may be determined in the same way using a hollow glass prism filled with the given liquid.

The eye

Eye is a natural optical instrument given by God to the human beings. The internal structure and the Physics aspect of the functioning of different parts of human eye. As the eye lens is flexible, its focal length can be changed to some extent. When the eye is fully relaxed, the focal length is maximum and when it is strained the focal length is minimum. The image must be formed on the retina for a clear vision. The diameter of eye for a normal adult is about 2.5 cm. Hence, the image-distance, in other words, the distance between eye lens and retina is fixed always at 2.5 cm for a normal eye. We can just discuss the optical functioning of eye without giving importance to the refractive indices of the two liquids, aqueous humor and virtuous humor present in the eye A person with normal vision can see objects kept at infinity in the relaxed condition with maximum focal length f_{max} of the eye as shown. Also at a distance of 25 cm in the strained conditionwith minimum focal length f_{min} of the eye as shown.

Let us find fmax and fmin of human eye from the lens equation given below.

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$$

When the object is at infinity, $u = -\infty$, and $v = 2.5$ cm (distance between eye lens and retina), the eye can see the object in relaxed condition with f_{max}. Substituting these values in the lens equation gives,

$$\frac{1}{f_{max}}=\frac{1}{2.5\ cm}-\frac{1}{-\infty}$$

$$f_{max}=2.5\ cm$$

When the object is at near point, u = –25 cm, and v = 2.5 cm, the eye can see the object in strained condition with f_{min}. Substituting these values in the lens equation gives,

$$\frac{1}{f_{min}}=\frac{1}{2.5\ cm}-\frac{1}{-25\ cm}$$

$$f_{min}=2.27\ cm$$

See, the small variation of $f_{max} - f_{min}$ = 0.23cm of the focal length of eye lens makes objects visible from infinity to near point for a normal person. Now, we can discuss some common defects of vision in the eye.

Nearsightedness (myopia)

A person suffering from nearsightedness or myopia cannot see distant objects clearly. This may result because the lens has too short focal length due to thickening of the lens or larger diameter of the eyeball than usual. These people have difficulty in relaxing their eye more than what is needed to overcome this difficulty. Thus, they need correcting lens.

The parallel rays coming from the distant object get focused before reaching the retina as shown. But, these persons can see objects which are nearer. Let x be the maximum distance up to which a person with nearsightedness can see as shown. To overcome this difficulty, the virtual image of the object at infinity should be formed at a distance x from the eye using a correcting lens as shown.

The focal length of the correcting lens for a myopic eye can be calculated using the lens equation.

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

Here, u = –∞, v = –x. Substituting these values in the lens equation gives,

$$\frac{1}{f} = \frac{1}{-x} - \frac{1}{-\infty}$$

Focal length f of the correcting lens is,

$f = -x$

The negative sign in the above result suggests that the lens should be a concave lens. Basically, the concave lens slightly diverges the parallel rays from infinity and makes them focus now at the retina which got earlier focused before reaching retina in the unaided condition.

Farsightedness (hypermetropia)

A person suffering from farsightedness or hypermetropia or hyperopia cannot clearly see objects close to the eye. It occurs when the eye lens has too long focal length due to thining of eye lens or shortening of the eyeball than normal. The least distance for clear vision for these people is appreciably more than 25 cm and the person has to keep the object inconveniently away from the eye. Thus, reading or viewing smaller things held in the hands is difficult for them. This kind of farsightedness arising due to aging is called presbyopia as the aged people cannot strain their eye more to reduce the focal length of the eye lens.

The rays coming from the object at near point get focused beyond the retina as shown. But, these persons can see objects which are far say, more than 25 cm. Let y be the minimum distance from the eye beyond which a person with farsightedness can see as shown. To overcome this difficulty, the virtual image of the object at y should be formed at a distance of 25 cm (near point) from the eye using a correcting lens as shown.

The focal length of the correcting lens for a hypermetropic eye can be calculated using the lens equation.

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

Here, u = –y, v = –25 cm. Substituting these values in the lens equation gives,

$$\frac{1}{f} = \frac{1}{-y} - \frac{1}{-25cm}$$

Simplifying the above equation gives,

$$\frac{1}{f} = \frac{1}{25cm} - \frac{1}{y} = \frac{y - 25cm}{y \times 25cm}$$

$$f = \frac{y \times 25cm}{y - 25cm}$$

The focal length calculated using above formula will be positive as y is always greater than 25 cm. The positive sign of the focal length suggests that the lens should be a convex lens. In principle, the convex lens slightly converges the rays coming from beyond y and makes them focus now at the retina which got earlier focused beyond retina for the unaided eye.

Astigmatism

Astigmatism is the defect arising due to different curvatures along different planes in the eye lens. Astigmatic person cannot see all the directions equally well. The defect due to astigmatism is more serious than myopia and hyperopia. The remedy to astigmatism is using of lenses with different curvatures in different planes to rectify the defect. In general, these specially made glasses with different curvature for different planes are called as cylindrical lenses.

Due to aging people may develop combination of more than one defect. If it is the combination of nearsightedness and farsightedness then, such persons may need a converging glass for reading purpose and a diverging glass for seeing at a distance. Bifocal lenses and progressive lenses provide solution for these problems.

Sound

8th term – 3

Unit 1

SOUND

Production of Sound

Sound is produced when an object is set tovibrate. Vibration means a kind of rapid to and fromotion of an object. This to and fro motion of thebody causes the substances around it to vibrate.Thus sound spreads to the surroundings. The substance through which sound is transmitted is called medium. Sound moves through a medium from the point of generation to the listener. We can understand the production of sound with the help of some activities.

On plucking the rubber band, it starts vibrating. You can hear a feeble humming sound as long as the rubber band is vibrating. The humming sound stops as soon as the rubber band stops vibrating. This confirms that sound is produced by vibrating bodies. You can see this kind of vibrations in stringed musical instruments, such as guitar and sitar also.

This activity shows that vibrating pan produces sound. In this case vibrations can be felt by touching the pan. But in some cases vibrations are visible.

The above activities show that sound is produced when an object is set to vibrate. The sound produced by vibration is propagated from one location to another. When it reaches our ear we hear the sound.

Propagation of Sound

When you call your friend who is standing at a distance, your friend is able to hear your voice. How your friend is able to hear your voice? He is able to hear because your sound travels from one place to another. As we saw earlier sound is a form of energy and it needs a medium to travel. This can be understood from the activity given below.

Thomas Alva Edison, in 1877 invented the phonograph, a device that played the recorded sound.

It is clear from this experiment that sound cannot travel in vacuum and it needs a medium like air. Sound travels in water and solids also. The speed of sound is more in solids than in liquids and it is very less in gases.

The speed of sound is the distance travelled by it in on We second. It is denoted by 'v'. It is represented by the expression, $v = n \lambda$, where 'n' is the frequency and 'λ' is the wavelength.

Problem 1

A sound has a frequency of 50 Hz and a Wave length of 10 m. What is the speed of the sound

Solution

Given, $n = 50\ Hz,\ \lambda = 10m$

$$v = n\lambda$$

$$v = 50 \times 10$$

$$v = 500\ ms^{-1}$$

Problem 2

A sound has a frequency of 5 Hz and a speed of 25 ms-1. What is the wavelength of the sound?

Solution

Given, $n = 5\ Hz,\ v = 25\ ms^{-1}$

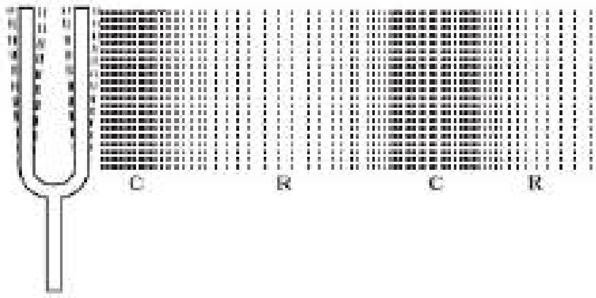
$$v = n\lambda$$

$$\lambda = v/n = 25/5 = 5\ m$$

The speed of sound depends on the properties of the medium through which it travels, like temperature, pressure and humidity. In any medium, as the temperature increases the speed of sound also increases. For example, the speed of sound in air is 331 ms-1 at 0°C and 344 ms-1 at 22°C. The speed of sound at a particular temperature in various media are listed in Table.

State	Substance	Speed (ms-1)
Speed (ms-1)	Aluminum	6420
	Steel	5960
	Iron	5950
Liquid	Sea Water	1530
	Distilled Water	1498
Gases	Aluminum	6420
	Steel	965
	Iron	346
	Iron	316

We saw that sound travels in different medium with different speed. Now let us see how it travels in a medium. When a body vibrates, the particle of the medium in contact with the vibrating body is first displaced from its equilibrium position. It then exerts a force on the adjacent particle. This process continues in the medium till the sound reaches the ear of the person. In order to understand this let us consider a vibrating tuning fork. When a vibrating tuning fork moves forward, it pushes and compresses the air in front of it, creating a region of high pressure. This region is called a compression (C), as shown in. When it moves backward, it creates a region of low pressure called rarefaction (R). These compressions and rarefactions produce the sound wave, which propagates through the medium.



Vibrating tuning fork

Sound Waves

Sound is a form of energy. It is transferred through the air or any other medium, in the form of mechanical waves. Mechanical wave is a disturbance, which propagates in a medium due to the repeated periodic motion of the particles of the medium, from their mean position. The disturbance which is caused by the vibrations of the particles is passed over to the next particle. It means that the energy is transferred from one particle to another as a wave motion.

Characteristic of wave motion

1. **In wave motion, only the energy is transferred not the particles.**
2. **The velocity of the wave motion is different from the velocity of the vibrating particle.**
3. **For the propagation of a mechanical wave, the medium must possess the properties of inertia, elasticity, uniform density and minimum friction among the particles.**

How do astronauts communicate with each other? The astronauts have devices in their helmets which transfer the sound waves from their voices into radio waves and transmit it to the ground (or other astronauts in space). This is exactly the same as how radio at your home works.

Types of mechanical wave

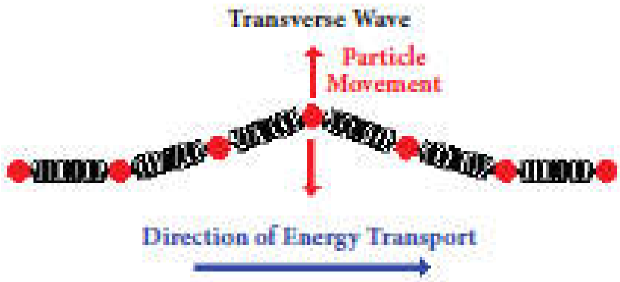
There are two types of mechanical wave. They are

1. Transverse wave

2. Longitudinal wave

Transverse wave

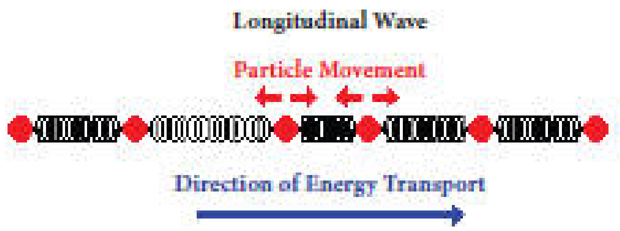
In a transverse wave the particles of the medium vibrate in a direction, which is perpendicular to the direction of propagation of the wave. E.g. Waves in strings, light waves, etc. Transverse waves are produced only in solids and liquids.



Transverse wave

Longitudinal wave

In a longitudinal wave the particles of the medium vibrate in a direction, which is parallel to the direction of propagation of the wave. E.g. Waves in springs, sound waves in a medium. Longitudinal waves are produced in solids, liquids and also in gases.



Longitudinal wave

Properties of Sound

All sounds that you hear are not the same. There are some properties that differentiate one kind of sound from another. We will study about these properties now.

Loudness

It is defined as the characteristic of a sound that enables us to distinguish a weak or feeble sound from a loud sound. The loudness of a sound depends on its amplitude. Higher the amplitude louder will be the sound and viceversa. When a drum is softly beaten, a weak sound is produced. However, when it is beaten strongly, a loud sound is produced. The unit of loudness of sound is decibel (dB).

Pitch

The pitch is the characteristic of sound that enables us to distinguish between a flat sound and a shrill sound. Higher the frequency of sound, higher will be the pitch. High pitch adds shrillness to a sound. The sound produced by a whistle, a bell, a flute and a violin are high pitch sounds.

Normally, the voice of a female has a higher pitch than a male. That is why a female's voice is shriller than a male's voice. Some examples of low pitch sound are the roar of a lion and the beating of a drum.

Quality or Timbre

The quality or timbre is the characteristic of sound that enables us to distinguish between two sounds that have the same pitch and amplitude. For example in an orchestra, the sounds produced by some musical instruments may have the same pitch and loudness. Yet, you can distinctly identify the sound produced by each instrument.

Audibility and Range

According to the frequency we can classify the sound into three types. They are:

- Audible sound
- Infrasonic sound
- Ultrasonic sound

Audible sound

Sound with frequency ranging from 20 Hz to 20000 Hz is called sonic sound or audible sound. These sounds can be heard by the human beings only. Human ears cannot hear sounds with frequencies below 20 Hz or above 20000 Hz. So, the above range is called as audible range of sound.

Infrasonic sound

A sound with a frequency below 20 Hz is called as subsonic or infrasonic sound. Humans cannot hear the sound of this frequency, but some animals like dog, dolphin, etc., can hear. Uses of infrasonic sound are given below.

- **It is employed in the Earth monitoring system.**
- **It is also used in the study of the mechanism of the human heart.**

Ultrasonic sound

A sound with a frequency greater than 20000 Hz is called as ultrasonic sound. Animals such as bats, dogs, dolphins, etc., are able to hear certain ultrasonic sounds as well. Some of the uses of ultrasonic sounds are given below.

- **It is extensively used in medical applications like 'sonogram'.**
- **It is used in the SONAR system to detect the depth of the sea and to detect enemy submarines.**
- **It is also employed in dish washers.**
- **Another important application of ultra sound is the Galton's whistle. This whistle is inaudible to the human ear, but it can be heard by the dogs. It is used to train the dogs for investigation.**

A bat can hear the sounds of frequencies higher than 20,000 Hz. Bats produce ultrasonic sound during screaming. These ultrasonic waves help them to locate their way and the prey.

Musical Instruments

Some sounds are pleasing to the ear and make you happy. The sound that provides a pleasing sensation to the ear is called 'music'. Music is produced by the regular patterns of vibrations. Musical instruments are categorized into four types as given below.

- Wind instruments
- Reed instruments
- Stringed instruments
- Percussion instruments

Wind instruments

In a wind instrument the sound is produced by the vibration of air in a hollow tube. The frequency is varied by changing the length of the vibrating air column. Trumpet, Flute, Shehnai and Saxophone are some well-known wind instruments.

Reed instruments

A reed instrument contains a reed. Air, which is blown through the instrument, causes the reed to vibrate, which in turn produces the specific sound. Examples of reed instruments include Harmonium and Mouth Organ.

Stringed instruments

Stringed instruments make use of a string or wire to produce vibrations and hence the specific sound. These instruments also have hollow boxes that amplify the sound that is produced. The frequency of sound is varied by varying the length of the vibrating wire. Violin, Guitar, Sitar are some of the examples of stringed instruments.

A guitar string has a number of frequencies at which it will naturally vibrate. These natural frequencies are known as the harmonics of the guitar string. The natural frequency, at which an object vibrates, depends upon the tension of the string, the linear density of the string and the length of the string.

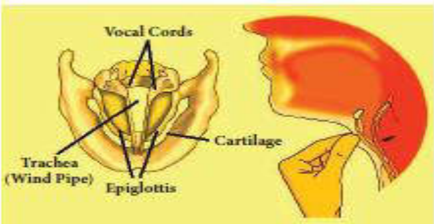
Musical instruments

Percussion instruments

Percussion instruments produce a specific sound when they are struck, scrapped or clashed together. They are the oldest type of musical instruments. There is an amazing variety of percussion instruments all over the world. Percussion instruments like the drum and tabla consist of a leather membrane, which is stretched across a hollow box called the resonator. When a membrane is hit, it starts vibrating and produces the sound.

Sound produced by Humans

In a human being, the sound is produced in the voice box, called the larynx, which is present in the throat. It is located at the upper end of the windpipe. The larynx has two ligaments called 'vocal cords', stretched across it. The vocal cords have a narrow slit through which air is blown in and out. When a person speaks, the air from the lungs is pushed up through the trachea to the larynx. When this air passes through the slit, the vocal cords begin to vibrate and produce a sound. By varying the thickness of the vocal cords, the length of the air column in the slit can be changed. This produces sounds of different pitches. Males generally have thicker and longer vocal cords that produce a deeper, low pitch sound in comparison with females.



Structure of Larynx

Mechanism of Human Ear

The ear is the important organ for all animals to hear a sound. We are able to hear sound through our ears. The human ear picks up and interprets high frequency vibrations of air. Ears of aquatic animals are designed to pick up high frequency vibrations in water. The outer and visible part of the human ear is called pinna (curved in shape). It is specially designed to gather sound from the environment, which then reaches the ear drum (tympanic membrane) through the ear canal. When the sound wave strikes the drum, the ossicles move inward and outward to create the vibrations. These vibrations are then picked up by special types of cells in the inner ear. From the inner ear the vibrations are sent to the brain in the form of signals. The brain perceives these signals as sounds.

Human EarNoise Pollution

Any sound that is unpleasant to the ear is called noise. It is the unwanted, irritating and louder sound. Noise is produced by the irregular and non-periodic vibrations. Noise gives you stress. The disturbance produced in the environment by loud and harsh sounds from various sources is known as noise pollution. Busy roads, airplanes, electrical appliances such as mixer grinder, washing machine and un-tuned radio cause noise pollution. Use of loudspeakers and crackers during the festivals also contributes to the noise pollution. The major source of noise pollution is from the industries. Noise pollution is the bi-product of industrialisation, urbanisation and modern civilisation.

Health hazards due to noise pollution

Noise creates some health hazards. Some of them are listed below.

- **Noise may cause irritation, stress, nervousness and headache.**
- **Long term exposure to noise may change the sleeping pattern of a person.**
- **Sustained exposure to noise may affect hearing ability. Sometimes, it leads to loss of hearing.**
- **Sudden exposure to louder noise may cause a heart attack and unconsciousness.**
- **It causes lack of concentration in one's work. Noise of horns, loud speakers, etc., cause disturbances leading to lack of concentration.**
- **Noise pollution affects a person's peace of mind. It adds to the existing tensions of modern living. These tensions results in disease like high blood pressure or short tempered nature.**

Controlling noise pollution

We studied about the harmful effects of noise pollution. Hence, it becomes necessary for us to reduce it. Noise pollution can be significantly reduced by adopting the following steps.

- **Strict guidelines should be set for the use of loudspeakers on social, religious and political occasions.**
- **All automobiles should have effective silencers.**
- **People should be encouraged to refrain from excessive honking while driving.**
- **Industrial machines and home appliances should be properly maintained.**
- **All communication systems must be operated in low volumes.**
- **Residential areas should be free from heavy vehicles.**
- **Green corridor belt should be set up around the industries as per the regulations of the pollution control board.**
- **People working in noisy factories should wear ear plugs.**
- **People should be encouraged to plant trees and use absorbing materials like curtains and cushions in their home.**

Hearing Loss

You may have hearing loss without realizing it. The following are the symptoms of hearing loss.

- Ear ache
- A feeling of fullness or fluid in the ear.
- Ringing in your ears

Hearing loss is caused by various reasons. Some of them are listed below.

- Aging
- Ear infections if not treated
- Certain medicines
- Genetic disorders
- A severe blow to the head
- Loud noise

9th book
Unit – 8 Sound

Production of sound

- In your daily life you hear different sounds from different sources. But, haveyou ever thought how sound is produced? To understand the production of sound, let us do an activity.

- When you strike the tuning fork on the rubber pad, it starts vibrating. These vibrations cause the nearby molecules to vibrate. Thus, vibrations produce sound.

Propagation of Sound Waves

Sound needs a medium for propagation

- Sound needs a material medium like air, water, steel etc., for its propagation. It cannot travel through vacuum. This can be demonstrated by the Bell – Jar experiment.

- An electric bell and an airtight glass jar are taken. The electric bell is suspended inside the airtight jar. The jar is connected to a vacuum pump, as shown in Figure 8.1. If the bell is made to ring, we will be able to hear the sound of the bell. Now, when the jar is evacuated with the vacuum pump, the air in the jar is pumped out gradually and the sound becomes feebler and feebler. We will not hear any sound, if the air is fully removed (if the jar has vacuum).

Sound is a wave

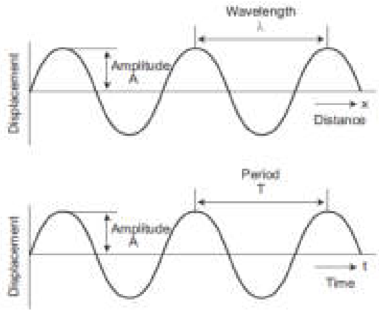
- Sound moves from the point of generation to the ear of the listener through a medium. When an object vibrates, it sets the particles of the medium around to vibrate. But, the vibrating particles do not travel all the way from the vibrating object to the ear. A particle of the medium in contact with the vibrating object is displaced from its equilibrium position. It then exerts a force on an adjacent particle. As a result of which the adjacent particle gets displaced from its position of rest. After displacing the adjacent particle the first particle comes back to its original position. This process continues in the medium till the sound reaches our ears. It is to be noted that only the disturbance created by a source of sound travels through the medium not the particles of the medium. All the particles of the medium restrict themselves with only a small to and fro motion called vibration whichenables the disturbance to be carried forward. This disturbance which is carried forward in a medium is called wave.

Longitudinal nature of sound waves

- From the above activity you can see that in some parts of the coil, the turns are closer together. These are regions of compressions. In between these regions of compressions we have regions where the coil turns are far apart called rarefactions. As the coil oscillates, the compressions and rarefactions move along the coil. The waves that propagates with compressions and rarefactions are called longitudinal waves. In longitudinal waves the particles of the medium move to and fro along the direction of propagation of the wave. Sound also is a longitudinal wave. Sound can travel only when there are particles which can be compressed and rarefied. Compressions are the regions where particles are crowded together. Rarefactions are the regions of low pressure where particles are spread apart. A sound wave is an example of a longitudinal mechanical wave. Figure 8.2 represents the longitudinal nature of sound wave in the medium.

Characteristics of a Sound Wave

- A sound wave can be described completely by five characteristics namely amplitude, frequency, time period, wavelength and velocity or speed.



Amplitude (A)

- The maximum displacement of the particles of the medium from their original undisturbed positions, when a wave passes through the medium is called amplitude of the wave. If the vibration of a particle has large amplitude, the sound will be loud and if the vibration has small amplitude, the sound will be soft. Amplitude is denoted as A. Its SI unit is meter (m).

Frequency (n)

- The number of vibrations (complete waves or cycles) produced in one second is calledfrequency of the wave. It is denoted as n. The SI unit of frequency is s–1 (or) hertz (Hz). Human ear can hear sound of frequency from 20 Hz to 20,000 Hz. Sound with frequency less than 20 Hz is called infrasonic sound. Sound with frequency greater than 20,000 Hz is called ultrasonic sound. Human beings cannot hear infrasonic and ultrasonic sounds.

Time period (T)

- The time required to produce one complete vibration (wave or cycle) is called time period of the wave. It is denoted as T. The SI unit of time period is second (s). Frequency and time period are reciprocal to each other.

Wavelength (λ)

- The minimum distance in which a sound wave repeats itself is called its wavelength. In a sound wave, the distance between the centers of two consecutive compressions or two consecutive rarefactions is also called wavelength. The wavelength is usually denoted as λ (Greek letter, lambda). The SI unit of wavelength is metre (m).

Velocity or speed (v)

- The distance travelled by the sound wave in one second is called velocity of the sound. The SI unit of velocity of sound is m s–1.

Distinguishing different Sounds

- Sounds can be distinguished from one another in terms of the following three different factors.

1. Loudness
2. Pitch
3. Timbre (or quality)

1. Loudness and Intensity

- Loudness is a quantity by virtue of which a sound can be distinguished from another one, both having the same frequency. Loudness or softness of sound depends on the amplitudeof the wave. If we strike a table lightly, we hear a soft sound because we produce a sound wave of less amplitude. If we hit the table hard we hear a louder sound. Loud sound can travel a longer distance as loudness is associated with higher energy. A sound wave spreads out from its source. As it move away from the source its amplitude decreases and thus its loudness decreases. Figure 8.4 shows the wave shapes of a soft and loud sound of the same frequency.

- The loudness of a sound depends on the intensity of sound wave. Intensity is defined as the amount of energy crossing per unit area per unit time perpendicular to the direction of propagation of the wave.

- The intensity of sound heard at a place depends on the following five factors.

i. **Amplitude of the source.**
ii. **Distance of the observer from the source.**
iii. **Surface area of the source.**
iv. **Density of the medium.**
v. **Frequency of the source.**

- The unit of intensity of sound is decibel (dB). It is named in honour of the Scottish-born scientist Alexander Graham Bell who invented telephone.

2. Pitch

- Pitch is one of the characteristics of sound by which we can distinguish whether a sound is shrill or base. High pitch sound is shrill and low pitch sound is flat. Two music sounds produced by the same instrument with same amplitude, will differ when their vibrations are of different frequencies. Figure 8.6 consists of two waves representing low pitch and high pitch sounds.

3. Timbre or Quality

- Timbre is the characteristic which distinguishes two sounds of same loudness and pitch emitted by two different instruments. A sound of single frequency is called a tone and a collection of tones is called a note. Timbre is then a general term for the distinguishable characteristics of a tone.

Speed of Sound

- The speed of sound is defined as the distance travelled by a sound wave per unit time as it propagates through an elastic medium.

$$\textbf{speed (v)} = \frac{Distance}{Time}$$

- If the distance traveled by one wave is taken as one wavelength (λ), and the time taken for this propagation is one time period (T), then

$$\textbf{speed (V)} = \frac{onewavelengh\ (\gamma)}{onetimeperiod\ (T)} \quad \textbf{(or)} \quad \textbf{v} = \frac{\gamma}{T}$$

As, $T = \frac{1}{n}$, the speed (v) of sound is also written as, v = n λ.
The speed of sound remains almost the same for all frequencies in a given medium under the same physical conditions.

Speed of sound in different media

- Sound propagates through a medium at a finite speed. The sound of thunder is heard a little later than the flash of light is seen. So, we can make out that sound travels with a speed which is much less than the speed of light. The speed of sound depends on the properties of the medium through which it travels.

- The speed of sound is less in gaseous medium compared to solid medium. In any medium the speed of sound increases if we increase the temperature of the medium. For example the speed of sound in air is 330 m s–1 at 0 °C and 340 m s–1 at 25 °C. The speed of sound at a particular temperature in various media is listed in Table 8.1.

State	Medium	Speed in m s-1
solids	Aluminum	6420
	Nickel	6040
	Steel	5960
	Iron	5950
	Brass	4700
	Glass	3980
Liquids	Water	1531
	Water (distilled)	1498
	Ethanol	1207
	Methanol	1103
Gases	Hydrogen	1284
	Helium	965
	Air	340
	Oxygen	316
	Sulphur dioxide	213

Sound travels about 5 times faster in water than in air. Since the speed of sound in sea water is very large (being about 1530 m s-1 which is more than 5500 km/h-1), two whales in the sea which are even hundreds of kilometres away can talk to each other very easily through the sea water.

Reflection of Sound

- Sound bounces off a surface of solid or a liquid medium like a rubber ball that bounces off from a wall. An obstacle of large size which may be polished or rough is needed for the reflection of sound waves. The laws of reflection are:
- The angle in which the sound is incident is equal to the angle in which it is reflected.
- Direction of incident sound, the reflected sound and the normal are in the same plane.

Uses of multiple reflections of sound
Musical instruments

- Megaphones, loud speakers, horns, musical instruments such as nathaswaram, shehnai and trumpets are all designed to send sound in a particular direction without spreading it in all directions. In these instruments, a tube followed by a conical opening reflects sound successively to guide most of the sound waves from the source in the forward direction towards the audience.

Stethoscope

- Stethoscope is a medical instrument used for listening to sounds produced in the body. In stethoscopes, these sounds reach doctor's ears by multiple reflections that happen in the connecting tube.

Echo

- When we shout or clap near a suitable reflecting surface such as a tall building or a mountain, we will hear the same sound again a little later. This sound which we hear is called an echo. The sensation of sound persists in our brain for about 0.1s.

- Hence, to hear a distinct echo the time interval between the original sound and the reflected sound must be at least 0.1s. Let us consider the speed of sound to be 340 m s–1 at 25° C.The sound must go to the obstacle and return to the ear of the listener on reflection after 0.1 s. The total distance covered by the sound from the point of generation to the reflecting surface and back should be at least 340 m s–1 × 0.1 s = 34 m.

- Thus, for hearing distinct echoes, the minimum distance of the obstacle from the source of sound must be half of this distance i.e. 17 m. This distance will change with the temperature of air. Echoes may be heard more than once due to successive or multiple reflections. The roaring of thunder is due to the successive reflections of the sound from a number of reflecting surfaces, such as the clouds at different heights and the land.

Reverberation

- A sound created in a big hall will persist by repeated reflection from the walls until it is reduced to a value where it is no longer audible. The repeated reflection that results in this persistence of sound is called reverberation. In an auditorium or big hall excessive reverberation is highly undesirable. To reduce reverberation, the roof and walls of the auditorium are generally covered with sound absorbing materials like compressed fiberboard, flannel cloths, rough plaster and draperies. The seat materials are also selected on the basis oftheir sound absorbing properties. There is aseparate branch in physics called acoustics which takes these aspects of sound in to account while designing auditoria, opera halls, theaters etc.

Ultrasonic Sound or Ultrasound

- Ultrasonic sound is the term used for soundwaves with frequencies greater than 20,000 Hz.These waves cannot be heard by the human ear, but the audible frequency range for other animals includes ultrasound frequencies. For example, dogs can hear ultrasonic sound. Ultrasonic whistles are used in cars to alert deer to oncoming traffic so that they will not leap across the road in front of cars.

- An important use of ultrasound is inexamining inner parts of the body. The ultrasonic waves allow different tissues such as organs and bones to be 'seen' or distinguished by bouncing of ultrasonic waves by the objects examined. The waves are detected, analysed and stored in a computer. An echogram is an image obtained by the use of reflected ultrasonic waves. It is usedas a medical diagnostic tool. Ultrasonic sound is having application in marine surveying also.

Applications of ultrasonic waves

- **Ultrasounds can be used in cleaning technology. Minute foreign particles can be removed from objects placed in a liquid bath through which ultrasound is passed.**
- **Ultrasounds can also be used to detect cracks and flaws in metal blocks.**
- **Ultrasonic waves are made to reflect from various parts of the heart and form the image of the heart. This technique is called 'echo cardiography'.**
- **Ultrasound may be employed to break small 'stones' formed in the kidney into fine grains. These grains later get flushed out with urine.**

SONAR

- SONAR stands for sound Navigation and Ranging. Sonar is a device that uses ultrasonic waves to measure the distance, direction and speed of underwater objects. Sonar consists of a transmitter and a detector and is installed at the bottom of boats and ships.

- The transmitter produces and transmits ultrasonic waves. These waves travel through water and after striking the object on the seabed, get reflected back and are sensed by the detector. The detector converts the ultrasonic waves into electrical signals which are appropriately interpreted. The distance of the object that reflected the sound wave can be calculated by knowing the speed of sound in water and the time interval between transmission and reception of the ultrasound.

- Let the time interval between transmission and reception of ultrasound signal be 't'. Then, the speed of sound through sea water is $2d / t = v$

- This method is called echo-ranging. Sonar technique is used to determine the depth of the sea and to locate underwater hills, valleys, submarine, icebergs etc.

Electrocardiogram (ECG)

- The electrocardiogram (ECG) is one of the simplest and oldest cardiac investigations available. It can provide a wealth of useful information and remains an essential part of the assessment of cardiac patients. In ECG, the sound variation produced by heart is converted into electric signals. Thus, an ECG is simply a representation of the electrical activity of the heart muscle as it changes with time. Usually it is printed on paper for easy analysis. The sum of this electrical activity, when amplified and recorded for just a few seconds is known as an ECG.

Structure of Human Ear

- How do we hear? We are able to hear with the help of an extremely sensitive device called the ear. It allows us to convert pressure variations in air with audible frequencies into electric signals that travel to the brain via the auditory nerve. The auditory aspect of human ear is discussed below.

- The outer ear is called 'pinna'. It collects the sound from the surroundings. The collected sound passes through the auditory canal. At the end of the ear is eardrum or tympanic membrane. When a compression of the medium reaches the eardrum the pressure on the outside of the membrane increases and forces the eardrum inward. Similarly, the eardrum moves outward when a rarefaction reaches it. In this way the eardrum vibrates. The vibrations are amplified several times by three bones (the hammer, anvil and stirrup) in the middle ear. The middle ear transmits the amplified pressure variations received from the sound wave to the inner ear. In the inner ear, the pressure variations are turned into electrical signals by the cochlea. These electrical signals are sent to the brain via the auditory nerve and the brain interrupts them as sound.

Unit – 5 ACOUSTICS

SOUND WAVES

- When you think about sound, the questions that arise in your minds are: How is sound produced? How does sound reach our ears from various sources? What is sound? Is it a force or energy? Let us answer all these questions.
- By touching a ringing bell or a musical instrument while it is producing music, you can conclude that sound is produced by vibrations. The vibrating bodies produce energy in the form of waves, which are nothing but sound waves
- Suppose you and your friend are on theMoon. Will you be able to hear any sound produced by your friend? As the Moon doesnot have air, you will not be able to hear anysound produced by your friend. Hence, youunderstand that the sound produced due to the vibration of different bodies needs a material medium like air, water, steel, etc, forits propagation. Hence, sound can propagate through a gaseous medium or a liquid medium or a solid medium.

Longitudinal Waves

- Sound waves are longitudinal waves that can travel through any medium (solids,liquids, gases) with a speed that dependson the properties of the medium. As soundtravels through a medium, the particles of the medium vibrate along the direction ofpropagation of the wave. This displacement involves the longitudinal displacements of the individual molecules from their mean positions. This results in a series of high and low pressure regions called compressions and rarefactions.

Categories of sound waves based on their frequencies

- (i) Audible waves ‐ These are sound waves with a frequency ranging between 20 Hz and 20,000 Hz. These are generated by vibrating bodies such as vocal cords, stretched strings etc.

- (ii) Infrasonic waves ‐ These are sound waves with a frequency below 20 Hz that cannot be heard by the human ear. e.g., waves produced

during earth quake, ocean waves, sound produced by whales, etc.

- (iii) Ultrasonic waves ‐ These are sound waves with a frequency greater than 20 kHz, Human ear cannot detect these waves, but certain creatures like mosquito, dogs, bats,dolphins can detect these waves. e.g., wavesproduced by bats.

Difference between the sound and light waves

s.no	sound	light
1	Medium is required for the propagation.	Medium is not required for the propagation.
2	Sound waves are longitudinal.	Light waves are transverse.
3	Wavelength ranges from 1.65 cm to 1.65 m.	Wavelength ranges from 4 × 10-7 m to 7 × 10-7 m.
4	Sound waves travel in air with a speed of about 340 ms-1 at NTP	Light waves travel in air with a speed of 3 × 108 ms-1.

Velocity of sound waves

- When you talk about the velocity associated with any wave, there are two velocities, namely particle velocity and wave velocity. SI unit of velocity is ms-1.

Particle velocity:

- The velocity with which the particles of the medium vibrate in order to transfer the energyin the form of a wave is called particle velocity.Wave velocity:

- The velocity with which the wave travels through the medium is called wave velocity. In other words, the distance travelled by a sound wave in unit time is called the velocity of a sound wave.

∴ Velocity =Distance/Time taken

- If the distance travelled by one wave istaken as one wavelength

(λ) and, the time taken for this propagation is one time period (T), then, the expression for velocity can be written as

$$\therefore V = \lambda/T \quad (5.1)$$

- Therefore, velocity can be defined as the distance travelled per second by a sound wave.Since, Frequency (n) =1/T, equation can be written as

$$V = n\lambda \quad (5.2)$$

- Velocity of a sound wave is maximum in solids because they are more elastic in nature than liquids and gases. Since, gases are least elastic in nature, the velocity of sound is the least in a gaseous medium.

So, $v_S > v_L > v_G$

Effect of density:

- The velocity of sound in a gas is inversely proportional to the square root of the density of the gas. Hence, the velocity decreases as the density of the gas increases.

v /√‾1d

Effect of temperature:

- The velocity of sound in a gas is directly proportional to the square root of its temperature. The velocity of sound in a gas increases with the increase in temperature. $V \propto \sqrt{T}$. Velocity at temperature T is given by the following equation:

$v_T = (v_o + 0.61\ T)\ ms^{-1}$

- Here, v_o is the velocity of sound in the gas at 0° C. For air, $v_o = 331\ ms^{-1}$. Hence, the velocity of sound changes by $0.61\ ms^{-1}$ when the temperature changes by one degree celsius.

Effect of relative humidity:

- When humidity increases, the speed of sound increases. That is why you can hear sound from long distances clearly during rainy seasons. Speed of sound waves in different media are given in table

s.no	Nature of the medium	Name of the medium	Speed of sound (in ms^{-1})
1	Solid	Copper	5010
2		Iron	5950
3		Aluminium	6420
4	Liquid	Kerosene	1324
5		Water	1493
6		Sea water	1533
7	Gas	Air	331
8		Air	343

Factors affecting velocity of sound

- In the case of solids, the elastic properties and the density of the solids affect the velocity of sound waves. Elastic property of solids ischaracterized by their elastic moduli. The speed of sound is directly proportional to the square root of the elastic modulus and inversely proportional to the square root of the density. Thus the velocity of sound in solids decreases as the density increases whereas the velocity of sound increases when the elasticity of the material increases. In the case of gases, the following factors affect the velocity of sound waves.

REFLECTION OF SOUND

- When you speak in an empty room, you hear a soft repetition of your voice. This is nothing but the reflection of the sound waves that you produce. Let us discuss about the reflection of sound in detail through the following activity.When sound waves travel in a given medium and strike the surface of another medium, they can be bounced back into the first medium. This phenomenon is known as reflection. In simple the reflection and refraction of sound is actually similar to the reflection of light. Thus, the bouncing of sound waves from the interface between two media is termed as the reflection of sound. The waves that strike the interface are termed as the incident wave and the waves that bounce back are termed as the reflected waves.

Laws of reflection

- Like light waves, sound waves also obey some fundamental laws of reflection.

The following two laws of reflection are applicable to sound waves as well.

- The incident wave, the normal to the reflecting surface and the reflected wave at the point of incidence lie in the same plane.

- The angle of incidence ∠i is equal to the angle of reflection ∠r.

- The sound waves that travel towards the reflecting surface are called the incident waves. The sound wavesbouncing back from the reflecting surface are called reflected waves. For all practical purposes, the point of incidence and the point of reflection is the same point on the reflectingsurface.

- A perpendicular line drawn at the point of incidence is called the normal. The angle which the incident sound wave makes with the normal is called the angle of incidence, ‘i’. The angle which the reflected wave makes with the normal is called the angle of reflection, ‘r’.

Reflection at the boundary of a denser medium

- A longitudinal wave travels in a medium in the form of compressions and rarefactions. Suppose a compression travelling in air from left to right reaches a rigid wall. The compression exerts a force F on the rigid wall. In turn, the wall exerts an equal and opposite reaction R = - F on the air molecules.

- This results in a compression near the rigid wall Thus, a compression travelling towards the rigid wall is reflected back as a compression. That is the direction of compression is reversed

Reflection at the boundary of a rarer medium

- Consider a wave travelling in a solid medium striking on the interface between the solid and the air. The compression exerts a force F on the surface of the rarer medium. As a rarer medium has smaller resistance for any deformation, the surface of separation is pushed backwards. As the particles of the rarer medium are free to move, a rarefaction is produced at the interface.Thus, a compression is reflected as a rarefaction and a rarefaction travels from right to left.

More to know:
What is meant by rarer and denser medium?
The medium in which the velocity of sound increases compared to other medium is called rarer medium. (Water is rarer compared to air for sound).The medium in which the velocity of sound decreases compared to other medium is called denser medium. (Air is densercompared to water for sound)

Reflection of sound in plane and curved surfaces

- When sound waves are reflected from aplane surface, the reflected waves travel in adirection, according to the law of reflection.The intensity of the reflected wave is neither decreased nor increased. But, when the sound waves are reflected from the curved surfaces,the intensity of the reflected waves is changed.When reflected from a convex surface, the reflected waves are diverged out and the intensity is decreased. When sound is reflected from a concave surface, the reflected waves are converged and focused at a point. So the intensity of reflected waves is concentrated at a point. Parabolic surfaces are used when it is required to focus the sound at a particular point.

- Hence, many halls are designed with parabolic reflecting surfaces. In elliptical surfaces, sound from one focus will always be reflected to the other focus, no matter where it strikes the wall.

- This principle is used in designing whispering halls. In a whispering hall, the speech of a person standing in one focus can be heard clearly by a listener standing at the other focus.

Whispering Gallery

One of the famous whispering galleries is in St. Paul's cathedral church in London. It is built with elliptically shaped walls. When a person is talking at one focus, his voice can be heard distinctly at the other focus. It is due to the multiple reflections of sound waves from the curved walls.

ECHOES

- An echo is the sound reproduced due to the reflection of the original sound from various rigid surfaces such as walls, ceilings, surfaces of mountains, etc.

- If you shout or clap near a mountain or near a reflecting surface, like a building you can hear the same sound again. The sound, which you hear is called an echo. It is dueto the reflection of sound. One does not experience any echo sound in a small room.This does not mean that sound is not reflected in a small room. This is because smaller rooms do not satisfy the basic conditions for hearing an echo.

Conditions necessary for hearing echo

1. The persistence of hearing for human ears is 0.1 second. This means that you can hear two sound waves clearly, if the time interval between the two sounds is at least 0.1 s. Thus, the minimum time gap
between the original sound and an echo must be 0.1 s.

2. The above criterion can be satisfied only when the distance between the source of sound and the reflecting surface would satisfy the following equation:

Velocity = distance travelled by sound / time taken

$$V = 2d/t$$

$$d = vt/2$$

Since, t = 0.1 second, then $d = v \times 0.1/2 = v/20$

- Thus the minimum distance required to hear an echo is 1/20th part of the magnitude of the velocity of sound in air. If you consider the velocity of sound as 344 ms^{-1},the minimum distance required to hear anecho is 17.2 m.

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Applications of echo

- Some animals communicate with each other over long distances and also locate objects by sending the sound signals and receiving the echo as reflected from the targets.

- The principle of echo is used in obstetric ultrasonography, which is used to create real-time visual images of the developingEmbryo or fetus in the mothers uterus.This is a safe testing tool, as it does not useany harmful radiations.

- Echo is used to determine the velocity of sound waves in any medium.

Measuring velocity of sound by echo method Apparatus required:

- A source of sound pulses, a measuring tape, a sound receiver, and a stop watch.

Procedure:

1. Measure the distance 'd' between the source of sound pulse and the reflecting surface using the measuring tape.

2. The receiver is also placed adjacent to the source. A sound pulse is emitted by the source.

3. The stopwatch is used to note the time interval between the instant at which the sound pulse is sent and the instant at which the echo is received by the receiver. Note the time interval as 't'.

4. Repeat the experiment for three or four times. The average time taken for the given number of pulses is calculated.

Calculation of speed of sound:

- The sound pulse emitted by the source travels a total distance of 2d while travelling from the source to the wall and then back to the receiver. The time taken for this has been observed to be 't'. Hence, the speed of soundwave is given by:

Speed of sound =distance travelled/time taken = 2d/t.

APPLICATIONS REFLECTION OF SOUND
Sound board

- These are basically curved surfaces (concave), which are used in auditoria and halls to improve the quality of sound. This board is placed such that the speaker is at the focus of the concave surface. The sound of the speaker is reflected towards the audience thus improving the quality of sound heard by the audience.

Ear trumpet

- Ear trumpet is a hearing aid, which is useful by people who have difficulty in hearing.In this device, one end is wide and the other end is narrow. The sound from the sources fall into the wide end and are reflected by its walls into the narrow part of the device. This helps in concentrating the sound and the sound enters the ear drum with more intensity. This enables a person to hear the sound better.

Mega phone

- A megaphone is a horn-shaped device used to address a small gathering of people. Its one end is wide and the other end is narrow. When a person speaks at the narrow end, the sound of his speech is concentrated by the multiple reflections from the walls of the tube.Thus, his voice can be heard loudly over a long distance.

DOPPLER EFFECT

- The whistle of a fast moving train appears to increase in pitch as it approaches a stationary listener and it appears to decreaseas the train moves away from the listener.

- This apparent change in frequency was first observed and explained by Christian Doppler (1803-1853), an Austrian Mathematician and Physicist. He observed that the frequency of the sound as received by a listener is different from the original frequency produced by thesource whenever there is a relative motion between the source and the listener.

- This is known as Doppler effect This relative motion could be due to various possibilities as follows:

(i) **The listener moves towards or away from a stationary source**
(ii) The source moves towards or away from a stationary listener
(iii) Both source and listener move towards or away from one other
(iv) The medium moves when both source and listener are at rest

- For simplicity of calculation, it is assumed that the medium is at rest. That is the velocityof the medium is zero.Let S and L be the source and the listener moving with velocities vS and vL respectively.

- Consider the case of source and listener moving towards each other (Figure 5.7). As the distance between them decreases, the apparentfrequency will be more than the actual source frequency.

- Let n and n' be the frequency of the sound produced by the source and the sound observed by the listener respectively. Then,the expression for the apparent frequency n' is

$$n' = (v + v L / v - vs)n$$

- Here, v is the velocity of sound waves in the given medium. Let us consider different possibilities of motions of the source and the listener. In all such cases, the expression for the apparent frequency

s.no	Position of source and listener	Note	Expression for apparent frequency
1	1.Both source and listener move 2.They move towards each other	a)Distance between source and listener decreases. b)Apparent frequency is more than actual frequency	$n' =(v+vL/v-vs)n$
2	1.Both source and listener move 2.They move away from each other	Distance between source and listener increases. b) Apparent frequency is less than actual frequency. c) vS and vL become opposite to that in case-1.	$n'=v-(vL/v+vs)n$
3	Both source and listener move They move one behind the other Source follows the listener	a)Apparent frequency depends on the velocities of the source and the listener. b) vS becomes opposite to that in case-2.	$n' = (v - vL/v - vs)n$
4	Both source and listener move They move one behind the other Listener follows the source	a)Apparent frequency depends on the velocities of the source and the listener. b)vS and vL become opposite to that in case-3.	$n' =(v + Vl/v + vs)n$
5	Source at rest Listener moves towards the source	a)Distance between source and listener decreases. b)Apparent frequency is more than actual frequency.	$n' =(v + vL/v)\ n$

		c) vS = 0 in case-1.	
6	Source at rest Listener moves away from the source	a)Distance between source and listener increases. b)Apparent frequency is less than actual frequency. c) vS = 0 in case-2.	$n' = (v - vL/v)\, n$
7	Listener at rest Source moves towards the listener	a)Distance between source and listener decreases. b)Apparent frequency is more than actual frequency. c) vL = 0 in case-1.	$n' = (v/v - vs)n$
8	Listener at rest Source moves away from the listener	a) Distance between source and listener increases. b) Apparent frequency is less than actual frequency. c) vL = 0 in case-2.	$n' = (v/v + vs)n$

- Suppose the medium (say wind) is moving with a velocity W in the direction of the propagation of sound. For this case, the velocity of sound, 'v' should be replaced with (v + W). If the medium moves in a direction opposite to the propagation of sound, then 'v' should be replaced with (v - W).

Conditions for no Doppler effect

- Under the following circumstances, there will be no Doppler effect and the apparent frequency as heard by the listener will be thesame as the source frequency.

(i) **When source (S) and listener (L) both areat rest.**
(ii) When S and L move in such a way that distance between them remains constant.
(iii) When source S and L are moving in mutually perpendicular directions.
(iv) If the source is situated at the center of the circle along which the listener is moving.

Applications of Doppler effect

(a) To measure the speed of an automobile

- An electromagnetic wave is emitted by a source attached to a police car. The wave is reflected by a moving vehicle, which acts as a moving source. There is a shift in the frequency of the reflected wave. From the frequency shift, the speed of the car can be determined. This helps to track the over speeding vehicles

(b) Tracking a satellite

- The frequency of radio waves emitted bya satellite decreases as the satellite passes away from the Earth. By measuring the change in the frequency of the radio waves, the location

of the satellites is studied.

(c) RADAR (Radio Detection And Ranging)

- In RADAR, radio waves are sent, and the reflected waves are detected by the receiver of the RADAR station. From the frequencychange, the speed and location of the aeroplanes and aircrafts are tracked.

(d) SONAR

- In SONAR, by measuring the change in the frequency between the sent signal and received signal, the speed of marine animals and submarines can be determined.