HEAT

6^{th} Standard - Term-II

Unit 1: Heat

Introduction

- We are all familiar with heat. We feel it on our body when the sun shines, we use heat for cooking our food, We reduce the heat by adding ice cubes while preparing fruit juice. Let us learn about sources of 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 to do 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**

- When electric current fows through a conductor, heat energy is produced. The water heater, 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 80₀C.

- 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? Neela says 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.

The temperature determines the direction of flow of heat.

1. You are holding a hot cup of coffee. Would the Heat energy transfer from

❖ Your body to the coffee, or

❖ The coffee to your body?

2. You are standing outside on a summer day. It is 40°C outside (notethat normal body temperature is 37°C). Would the Heat energy transfer from.

❖ Your body to the air particles, or

❖ The air particles to your body?

3. You are standing outside on a winter day. It is 23°C outside. Would the heat energy transfer from:

❖ Your body to the air particles, or

❖ The air particles to your body?

- Two objects are said to be in **thermal contact** if they can exchange heat energy. **Thermal equilibrium** exists when two objects in thermal contact no longer affect each other's temperature. For example, if a pot of milk from the refrigerator is set on the kitchen table, the two objects are in thermal contact. After certain period, their temperatures are the same, and they are said to be in thermal equilibrium.

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.

Numerical problems

- I put a kettle containing 1 litre of cold water on the gas stove, and it takes 5 minutes to reach the boiling point. My friend puts on a small electric kettle, containing ½ litre of cold water, and it takes 5 minutes to get up to boiling point. Which gives more heat in 5 minutes?

  - the gas supply; or
  - the electricity supply?

  Can you say how many times as much?

1. One calorie heat energy is needed to raise the temperature of the water from 30oC to 31oC. How much heat energy is needed to raise the temperature of the water from 30oC to 35oC.

- The main source of heat is sun, we can obtain heat from combustion, friction, and electricity.
- Heat is an energy that raises the temperature of a thing by causing the molecules in that thing to move faster
- Heat is the total Kinetic energy of constituent particles of objects.
- SI unit of Heat is joule (J).
- The measurement of warmness or coldness of a substance is known as its temperature.
- SI unit of temperature is kelvin.
- Temperature determines the direction of flow of heat when two bodies are placed in contact.
- Two objects are said to be in thermal contact if they can affect each other's temperature.
- Thermal equilibrium exists when two objects in thermal contact no longer affect each other's temperature.

- Most substances expand when heated and contract when cooled. The expansion of a substance on heating is called the thermal expansion of that substance.

- 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. Summer day Winder day

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

Introduction

- You shiver when it is cold outside and sweat when it is hot outside, but how can you measure those weather temperatures? Temperature is involved in many aspects of our daily lives, including our own bodies and health; the weather; and how hot the stove must be in order to cook food. The measurement of warmness or coldness of a substance is known as its temperature. It is a measure of the average kinetic energy of the particles in an object. Temperature is related to how fast the atoms within a substance

Temperature Units:

- There are three units which are used to measure the temperature: Degree Celsius, Fahrenheit and Kelvin.
    - **Degree Celsius:** Celsius is written as °C and read as degree. For example 20°C; it is read as twenty degree Celsius. Celsius is called as Centigrade as well.
    - **Fahrenheit:** Fahrenheit is written as °F for example 25°F; it is read as twenty five degree Fahrenheit.
    - **Kelvin:** Kelvin is written as K. For example 100K; it is read as hundred Kelvin.
    - The SI unit of temperature is kelvin (K).

Measuring Temperature

- The temperature of the object is well approximated with the kinetic energy of the substances. The high temperature means that the molecules within the object are moving at a faster rate. But the question arises, how to measure it? Molecules in any substance are very small to analyze and calculate its movement (Kinetic energy) in order to measure its temperature. You must use an indirect method to measure the kinetic energy of the molecules of a substance. We studied that solids expands when heat is supplied to it. Like solid substances, liquids are also affected by heat.

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

Thermometer:

- Thermometer is the most common instrument to measure temperature. There are various kinds of thermometers. Some of them are like glass tubes which look thin and are filled with some kind of liquid. Why Mercury or Alcohol is used in Thermometer? Mostly Alcohol and Mercury are used in thermometers as they remain in liquid form even with a change of temperature in them. A small change in the temperature causes change in volume of a liquid. We measure this temperature by measuring expansion of a liquid in thermometer.

Properties of Mercury:-

- Its expansion is uniform. (For equal amounts of 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 low freezing point (−39°C). Hence a wide range of temperatures can be measured using a mercury thermometer

Properties of Alcohol

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

Types of Thermometers

- There are different types of thermometers for measuring the temperatures of different things like air, our bodies, food and many other things. Among these, the commonly used thermometers are clinical thermometers and laboratory thermometers.

Clinical Thermometer

- These thermometers are used to measure the temperature of a human body, at home, clinics and hospitals. All clinical thermometers have a kink that prevents the mercury from flowing back into the bulb when the thermometer is taken out of the patient's mouth, so that the temperature can be noted conveniently. There are temperature scales on either side of the mercury thread, one in Celsius scale and the other in Fahrenheit scale. Since the Fahrenheit scale is more sensitive than the Celsius scale, body temperature is measured in F only. A clinical thermometer indicates temperatures from a minimum of 35°C or 94°F to a maximum of 42°C or 108°F.

Precautions to be Followed While Using a Clinical Thermometer

- ❖ The thermometer should be washed before and after use, preferably with an antiseptic solution.
- ❖ Jerk the thermometer a few times to bring the level of the mercury down.
- ❖ Before use, the mercury level should be below 35°C or 94°F.
- ❖ Do not hold the thermometer by its bulb.
- ❖ Keep the mercury level along your line of sight and then take the reading.
- ❖ Handle the thermometer with care. If it hits against some hard object, it may break.
- ❖ Do not place the thermometer in a hot flame or in the hot sun.

Laboratory Thermometers

- Laboratory thermometers are used to measure the temperature in school and other laboratories for scientific research. They are also used in the industry as they can measure temperatures higher than what clinical thermometers can record. The stem and the bulb of a lab thermometer are longer when compared to that of a clinical thermometer and there is no kink in the lab thermometer. A laboratory thermometer has only the Celsius scale ranging from −10°C to 110°C.

Precautions to be Followed While Using a Laboratory Thermometer

- Do not tilt the thermometer while measuring the temperature. Place it upright.
- Note the reading only when the bulb has been surrounded by the substance from all sides.

Do you know?

- In humans, the average internal temperature is 37°C (98.6°F), though it varies among individuals. However, no person always has exactly the same temperature at every moment of the day. Temperatures cycle regularly up and down through the day according to activities 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 concern over the use of mercury in thermometers. Mercury is a toxic substance and is very difficult to dispose of if a thermometer breaks. These days, digital thermometers are available which do not use mercury. Instead, it has a sensor which can measure the heat coming out from the body directly and from that can measure the temperature of the body. Digital thermometers are mainly used to take the body temperature.

Caution

- Alex wanted to measure the temperature of hot milk using a clinical thermometer. His teacher stopped him from doing so. We are advised not to use a clinical thermometer for measuring the temperature of any object other than human body. Also we are advised to avoid keeping it in the sun or near a flame. Why? A clinical thermometer has small temperature range. The glass will crack/ burst due to excessive pressure created by expansion of mercury.

Do you know?

Maximum - Minimum thermometer

- The maximum and minimum temperatures of the previous day reported in weather reports are measured by a thermometer called the maximum – minimum thermometer.

Scales of thermometers

Celsius scale

- Celsius is the common unit of measuring temperature, termed after Swedish astronomer, Anders Celsius in 1742, before that it was known as Centigrade as thermometers using this scale are calibrated from (Freezing point of water) 0°C to 100°C (boiling point of water).

- In Greek, 'Centium' means 100 and 'Gradus' means steps, both words make it centigrade and later Celsius.

Fahrenheit Scale

- Fahrenheit is a Common unit to measure human body temperature. It is termed after the name of a German Physicist Daniel Gabriel Fahrenheit. Freezing point of water is taken as 32°F and boiling point 212°F. Thermometers with Fahrenheit scale are calibrated from 32°F to 212°F.

Kelvin scale

- Kelvin scale is termed after Lord Kelvin. It is the SI unit of measuring temperature and written as K also known as absolute scale as it starts from absolute zero 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

Do you know?

- Most of the people in the world use the Celsius scale to measure temperature for day to day purpose. The Kelvin scale has been designed in such a way, it is not only an absolute temperature scale, but also 1°C change is equal to a 1K change. This makes the conversion from Celsius to absolute temperature scale (Kelvin scale) easy, just the addition or subtraction of a constant 273.15

- But in United States they prefer to use the Fahrenheit scale. The problem is, converting Fahrenheit to absolute scale (Kelvin) is not easy.

- To sort out this problem they use The Rankine scale. It named after the Glasgow University engineer and physicist Rankine, who proposed it in 1859. It is an absolute temperature scale, and has the property of having a 1°R change is equal to a 1°F change. Fahrenheit users who need to work with absolute temperature can be converted to Rankine by

$$R = F + 459.67$$

8th Standard
Term II
Unit 1. Heat

Introduction

- All the substances in our surrounding are made up of atoms and molecules. These atom sand molecules are always at vibratory motion. Due to this motion substances have an energy known as heat energy. This energy flows from hot substances to cold substances or from hot region to cold region of a substance. When heat energy is supplied to any substance it increases the energy of the atoms and molecules in it and so they start vibrate. These atoms and molecules which vibrate make other atoms and molecules to vibrate. Thus, heat energy is transferred from one part of the substance to other part. We can see this heat energy transfer in our daily life also. Heat energy brings about lot of changes. You will learn about this in this lesson. You will also study about transfer of heat and measurement of heat change know about the working of thermos flask.

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 of atoms 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. Thus the 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 through empty 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, $C' = Q / \Delta T$

- 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 the temperature of the contents. A stirrer is inserted through another hole for stirring the content in the vessel. The vessel is filled with liquid which is 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

Introduction

- All substances in our surrounding are made up of molecules. These molecules are generally at motion and posses kinetic energy. At the same time each molecule exerts a force of attraction on other molecules and so they posses potential energy. The sum of the kinetic and potential energy is called the internal energy of the molecules. This internal energy, when flows out, is called heat energy. This energy is more in hot substances and less in cold substances and flows from hot substances to cold substances. In this lesson you will study about how this heat transfer takes place. Also you will study about the effect of heat, heat capacity, change of state and latent heat.

Effects of Heat

- When a substance is heated, the following things can happen.

Expansion:

- When heat is added to a substance, the molecules gain energy and vibrate and force other molecules apart. As a result, expansion takes place. You would have seen some space being left in railway tracks. It is because, during summer time, more heat causes expansion in tracks. Expansion is greater for liquids than solids and it is maximum in gases.

Change in State:

- When you heat ice cubes, they become water and water on further heating changes into vapour. So, solid becomes liquid and liquid becomes gas, when heat is added. The reverse takes place when heat is removed.

Change in Temperature:

- When heat energy is added to a substance, the kinetic energy of its particles increases and so the particles move at higher speed. This causes rise in temperature. When a substance is cooled, that is, when heat is removed, the molecules lose heat and its temperature falls.

Chemical changes:

- Since heat is a form of energy it plays a major role in chemical changes. In some cases, chemical reactions need heat to begin and also heat determines the speed at which reactions occur. When we cook food, we light the wood and it catches fire and the food particles become soft because of the heat energy. These are all the chemical changes taking place due to heat.

Transfer of Heat

- Heat does not stay where we put it. Hot things get colder and cold things get hotter. Heat is transferred from one place to another till their temperatures become equal. Heat transfer takes place when heat energy flows from an object with higher temperature to an object with lower temperature.

- When a dog keeps out its tongue and breathes hard, the moisture on the tongue turns into water and it evaporates. Since, heat energy is needed to turn a liquid into a gas, heat is removed from dog's tongue. This helps to cool the body of the dog.

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 line temperatures in the three temperature scales are shown in Table.

Temperature	Kelvins (K)	Degre Celcius (°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

Specific Heat Capacity

- Our might have felt that the land is cool in the morning and hot during day time. But, water in a lake will be almost at a particular temperature both in the morning as well as in the afternoon. Both are subjected to same amount of heat energy from the Sun, but they react differently. It is because both of them have different properties. In general, the amount of heat energy absorbed or lost by a body is determined by three factors.

1. Mass of the body
2. Change in temperature of the body
3. Nature of the material of the body

We can understand this from the following observations.

Observation:1

- Quantity of heat required to raise the temperature of 1 litre of water will be more than the heat required to raise the temperature of 500 ml of water. If Q is the quantity of heat absorbed and m is the mass of the body, then $Q \propto m$ (7.1)

Observation: 2

- Quantity of heat energy (Q) required to raise the temperature of 250 ml of water to 100°C is more than the heat energy required to raise the temperature to 50 °C. Here, $Q \propto \Delta T$, where ΔT is the change in temperature of the body.

Thus, heat lost or gained by a substance when its temperature changes by ΔT is,

$$Q \propto m\Delta T$$
$$Q = mC\Delta T$$

- From the above equations, the absolute temperature and energy of a system are proportional to each other. The proportionality constant is the specific heat capacity (C) of the substance.

$$\therefore C = Q/m\Delta T$$

- Thus, specific heat capacity of a substance is defined as the amount of heat required to raise the temperature of 1 kg of the substance by 10C or 1 K. The SI unit of specific heat capacity is Jkg-1 K-1. The most commonly used units of specific heat capacity are J/kg°C and J/g°C.

- Among all the substances, water has the highest specific heat capacity and its value is 4200 J/kg°K. So, water absorbs a large amount of heat for unit rise in temperature. Thus, water is used as a coolant in car radiators and factories to keep engines and other machinery parts cool. It is because of this same reason, temperature of water in the lake does not change much during day time.

Water in its various form, has different specific heat capacities.

Water (Liquid state) = 4200 $JKg^{-1} K^{-1}$
Ice (Solid state) = 2100 $JKg^{-1} K^{-1}$
Steam (Gaseous state) = 460 $JKg^{-1} K^{-1}$

Heat capacity or Thermal capacity

- Now, you are familiar with specific heat capacity. It is the heat required to raise the temperature of a unit mass of a body by 1°C. But, heat capacity is the heat required to raise the temperature of the entire mass of the body by 1°C. Thus, heat capacity or thermal capacity is defined as the amount of heat energy required to raise the temperature of a body by 1°C. It is denoted by C'.

$$\text{Heat Capacity} = \frac{\textit{Quantity of heat required}}{\textit{Raise in Temperature}}$$

$$C^{I} = Q/T$$

SI unit of heat capacity is J/K. It is also expressed in cal/oC, kcal/oC or J/oC.

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 below In 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 any temperature 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.

Points to Remember

- Heat is transferred from hot region to cold region.
- Heat is transferred in three forms: conduction, convection and radiation.
- Conduction takes place in solids and convection takes place in liquids and gases.
- Radiation takes place in the form of electromagnetic waves.
- There are three scales of temperature: Fahrenheit scale, Celsius or Centigrade scale and Kelvin or Absolute scale.
- Amount of heat energy absorbed or lost by a body is determined by three factors: mass of the body, change in temperature of the body, nature of the material of the body.
- The SI unit of specific heat capacity is Jkg-1 K-1.
- Among all the substances, water has the highest specific heat capacity.
- SI unit of heat capacity is J/K.
- Depending upon the temperature, pressure and transfer of heat, matter is converted from one state to another.

10th Standard

Unit 3. Thermal Physics

INTRODUCTION

- Sun is the primary source of thermal energy for all living organisms. Thermal energy is the cause and temperature is the effect. All living organisms need a particular temperature for their survival. In the kitchen, a container with a steel bottom is placed on the induction stove. Do you know why? All of us have a common man's understanding of thermal energy and temperature. But, in this chapter, you shall learn about thermal energy and temperature in a scientific manner. We shall also discuss about how thermal energy is transferred and the effects of thermal energy.

TEMPERATURE

- Temperature is defined as the degree of hotness of a body. The temperature is higher for a hotter body than for a colder body. It is also be defined as the property which determines whether a body is in equilibrium or not with the surroundings. (or average kinetic enegy of the molecules). Further, temperature is the property, which determines the direction of flow of heat. It is a scalar quantity. The SI unit of temperature is kelvin (K). There are other commonly used units of temperature such as degree celsius (°C) and degree fahrenheit (°F).Absolute scale (kelvin scale) of temperature

- The temperature measured in relation to absolute zero using the kelvin scale is known as absolute temperature. It is also known as the thermodynamic temperature. Each unit of the thermodynamic scale of temperature is defined as the fraction of 1/273.16th part of the thermodynamic temperature of the triple point of water. A temperature difference of 1°C is equal to that of 1K. Zero Kelvin is the absolute scale of tempeture of the body.

The relation between the different types of scale of temperature:

- Celsius and Kelvin: $K = C + 273$,
- Fahrenheit and Kelvin: $[K] = (F + 460) \times 5/9$

0 K = –273°C.

Thermal equilibrium

- Two or more physical systems or bodies are said to be in thermal equilibrium if there is no net flow of thermal energy between the systems. Heat energy always flows from one body to the other due to a temperature difference between them. Thus, you can define thermal equilibrium in another way. If two bodies are said to be in thermal equilibrium, then, they will be at the same temperature. What will happen if two bodies at different temperatures are brought in contact with one other? There will be a transfer of heat energy from the hot body to the cold body until a thermal equilibrium is established between them.

- When a cold body is placed in contact with a hot body, some thermal energy is transferred from the hot body to the cold body. As a result, there is some rise in the temperature of the cold body and decrease in the temperature of the hot body. This process will continue until these two bodies attain the same temperature.

THERMAL ENERGY

- If you leave a cup of hot milk on a table for some time, what happens? The hotness of the milk decreases after some time. Similarly, if you keep a bottle of cold water on a table, the water becomes warmer after some time. What do you infer from these observations? In the case of hot milk, there is a flow of energy from the cup of milk to the environment. In the second case, the energy is transferred from the environment to the water bottle. This energy is termed as "thermal energy".

- When a hot object is in contact with another cold object, a form of energy flows from the hot object to the cold object, which is known as thermal energy. Thus, thermal energy is a form of energy which is transferred between any two bodies due to the difference in their temperatures. Thermal energy is also known as 'heat energy' or simply 'heat'.

- Heat energy is the agent, which produces the sensation of warmth and makes bodies hot. The process in which heat energy flows from a body at a higher temperature to another object at lower temperature is known as heating. This process of transmission of heat may be done in any of the ways like conduction, convection or radiation. Heat is a scalar quantity. The SI unit of heat energy absorbed or evolved is joule (J) .

- During the process of transferring heat energy, the body at lower temperature is heated while the body at higher temperature is cooled. Thus, sometimes, this process of transfer of heat energy is termed as 'cooling'. But, in most of the cases the term 'heating' is used instead of 'cooling'. When the thermal energy is transferred from one body to another, this results in the rise or lowering of the temperature of either of the bodies.

Characteristic features of heat energy transfer

- Heat always flows from a system at higher temperature to a system at lower temperature.
- The mass of a system is not altered when it is heated or cooled.
- For any exchange of heat, the heat gained by the cold system is equal to heat lost by the hot system. Heat gained = Heat lost

Other units of Heat energy

- Though the SI unit of heat energy is joule, there are some other commonly used units.

Calorie: One calorie is defined as the amount of heat energy required to rise the temperature of 1 gram of water through 1°C.

Kilocalorie: One kilocalorie is defined as the amount of heat energy required to rise the temperature of 1 kilogram of water through 1°C.

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)

V_o - Original volume

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

α_V - 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 L_1. 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 L_2.

- 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 L_3. Now, the difference between the levels L_1 and L_3 is called as **apparent expansion,** and the difference between the levels L_2 and L_3 is called **real expansion**. The real expansion is always more than that of apparent expansion.

Real expansion = $L_3 - L_2$
Apparent expansion = $L_3 - L_1$

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.

$$V \alpha T$$
or
$$V / T = \text{constant}$$

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. $V \alpha n$
(or) V/N= constant

- Avogadro's number (N_A) is the total number of atoms per mole of the substance. It is equal to 6.023×10^{23} /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,**

$PV = constant$ (3.1)

According to Charles's law,

$V/T = constant$ (3.2)

According to Avogadro's law,

$V/n = constant$ (3.3)

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

$PV/nT = constant$ (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, N_A.

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

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

$PV/\mu NAT = constant$

- The value of the constant in the above equation is taken to be k_B, 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

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

$PV = RT$ (3.6)

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

Points to Remember

❖ The SI unit of heat energy absorbed or evolved is joule (J)

❖ Heat always flows from a system at higher temperature to a system at lower temperature.

❖ Temperature is defined as the degree of hotness of a body. The SI unit of temperature is kelvin (K).

❖ All the substances will undergo one or more of the following changes when heated:

i) Temperature of the substance rises.
ii) The substance may change state from solid to liquid or gas.

iii) The substance will expand when heated.

- ❖ All forms of matter (solid, liquid and gas) undergo expansion on heating.

- ❖ For a given rise in temperature, a liquid will have more expansion than a solid and a gaseous substance has the highest expansion than the other two.

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

- ❖ For a given heat energy, the real expansion is always more than that of apparent expansion.

- ❖ 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.

- ❖ Ideal gas equation, also called as equation of state is PV = RT. Here, R is known as universal gas constant whose value is 8.31 J $mol^{-1}K^{-1}$

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 L_1 = 50 ml
Level of the liquid L_2 = 48.5 ml
Level of the liquid L_3 = 51.2 ml

Apparent expansion = $L_3 - L_1$

$= 51.2\ ml - 50\ ml = 1.2ml$

Real expansion = $L_3 - L_1$

$= 51.2\ ml - 48.5ml = 2.7ml$

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 = 20cm^3
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

Heat and temperature:

- Heat is not a quantity. When we use the word 'heat', it is the energy in transit but not energy stored in the body.

Temperature is the degree of hotness or coolness of a body.

Boyle's law, Charles' law and ideal gas law:

- $P \propto \frac{1}{V}$ is known as Boyle's law.
- $V \propto T$ is known as Charles' law.
- $PV = \mu N_A kT = \mu RT$

- One mole of any substance is the amount of that substance which contains Avogadro number (N_A) of particles (such as atoms or molecules). The Avogadro's number N_A is defined as the number of carbon atoms contained in exactly 12 g of ^{12}C.

$N_A = 6.023 \times 10^{23} \text{mol}^{-1}$

Heat capacity and Specific Heat Capacity

- 'Heat capacity' is the amount of heat energy required to raise the temperature of the given body from T to T + ΔT.

  Heat capacity $S = \frac{\Delta Q}{\Delta T}$

- Specific heat capacity of a substance (s) is defined as the amount of heat energy required to raise the temperature of 1kg of a substance by 1 Kelvin or 1°C

$$s = \frac{1}{m}\left(\frac{\Delta Q}{\Delta T}\right)$$

- Where s depends only on the nature of substance and not on amount of substance

- ΔQ =Amount of heat energy ΔT = Change in temperature m = Mass of the substance. The SI unit for specific heat capacity is $kg^{-1}\,K^{-1}$. Heat capacity and specific heat capacity are always positive quantities. Water has the highest value of specific heat capacity. So it is used as coolant in power stations and reactors. When two objects of same mass are heated (or cooled) at equal rates, the object with smaller specific heat capacity will have a faster temperature increase (or drop).

- Molar specific heat capacity(C) is defined as heat energy required to increase the temperature of one mole of substance by 1K or $1°C$

$$C = \frac{1}{\mu}\left(\frac{\Delta Q}{\Delta T}\right)$$

- μ is the number of moles in a substance. SI unit of specific heat capacity is $J\,mol^{-1}K^{-1}$. It is a positive quantity.

Thermal expansion of solid, liquid and Gas:

- ❖ Thermal expansion is the tendency of matter to change in shape, area, and volume due to a change in temperature.

- ❖ Railroad tracks and bridges have expansion joints to allow them to expand and contract freely with temperature changes. **Liquids**, have less intermolecular forces than solids and hence they expand more than solids. This is the principle behind the mercury thermometers. In hot air balloons when gas particles get heated, they expand and take up more space.

- ❖ The expansion in length is called **linear expansion**. Similarly the expansion in area is termed as **area expansion** and the expansion in volume is termed as **volume expansion**.

- When the lid of a glass bottle is tight, keep the lid near the hot water which makes it easier to open. It is because the lid has higher thermal expansion than glass.

- When the hot boiled egg is dropped in cold water, the egg shell can be removed easily. It is because of the different thermal expansions of the shell and egg.

area expansion $\approx 2 \times$ linear expansion
volume expansion $\approx 3 \times$ linear expansion

Anomalous expansion of water:

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

- Since ice have lower density than water at $4°C$ 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.

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

Here s_1 and s_2 specific heat capacity of hot sample and water respectively.

Heat transfer:

Conduction:

- The quantity of heat transferred through a unit length of a material in a direction normal to unit surface area due to a unit temperature difference under steady state conditions is known as thermal conductivity of a material.

$$\frac{Q}{t} = \frac{KA\Delta T}{L}$$

Where K is the coefficient of thermal conductivity. SI unit of thermal conductivity is $Js^{-1}m^{-1}K^{-1}$ or $W\ m^{-1}K^{-1}$

- Silver and aluminium are used to make cooking vessels as they have high thermal conductivity.

- The state at which temperature attains constant value everywhere and there is no further transfer of heat anywhere is called steady state.

Convection:

- Land has less specific heat capacity than water. This causes land breeze and sea breeze.

- Water in cooking pot is an example of convection. Water at bottom heats, become less dense and rises up. The water at top is cooler and denser, so falls to the bottom. This back and forth movement is convectional current.

- The air molecules near heater becomes hot, less dense and rises up. The cooler air at top is denser and comes down. This process is used in room heating.

Radiation:

- The visible radiation coming from the Sun is at the temperature of 5700 K and the Earth re emits the radiation in the infrared range into space which is at a temperature of around 300K.

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.

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

- 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.

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

- 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:

$$W = \int_{V_i}^{V_f} P dV$$

- 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 (C_v). If pressure is kept constant, it is called molar specific heat capacity at constant pressure (C_p).

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

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,

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

- ❖ 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,

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

$$\Delta U = Q - P\Delta V$$

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

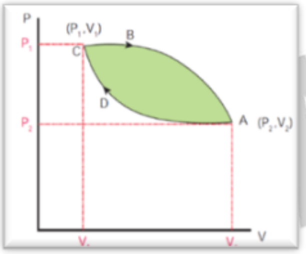
- In automobiles the petrol engine undergoes four processes. First the piston is adiabatically compressed to some volume as shown in the Figure (a). In the second process (Figure (b)), the volume of the air-fuel mixture is kept constant and heat is being added. As a result the temperature and pressure 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.

Process		Heat Q	Temperature & internal	Pressure	Volume	Equation of state	Work done (ideal gas)
Isothermal	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	$\frac{V}{T} = constant$	$W = P[V_f - V_i] > 0$
	Compressi	$Q < 0$	Decrease	Consta	Decrea		$W = P\Delta V < 0$
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		$W_{adia} = \frac{\mu R}{\gamma - 1}[T_i - T_f] < 0$

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.

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 T_H. 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:

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

❖ 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.

$Q_L + W = Q_H$

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 Chloro flouro 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.

FAST FACTS

a) When the piston is compressed so quickly that there is no time to exchange heat to the surrounding, the temperature of the gas increases rapidly. This principle is used in the diesel engine. The air-gasoline mixture is compressed so quickly (adiabatic compression) that the temperature increases enormously, which is enough to produce a spark.

b) All reversible processes are quasi-static but all quasi- static processes need not be reversible. For example when we push the piston very slowly, if there is friction between cylinder wall and piston some amount of energy is lost to surroundings, which cannot be retrieved back.

c) The efficiency of diesel engines has maximum up to 44% and the efficiency of petrol engines are maximum up to 30%. Now a days typical bikes give a mileage of 50 km per Liter of petrol. This implies only 30% of 1 Liter of petrol is converted into mechanical work and the remaining 70% goes out as wasted heat.

d) In earthern pot, the cooling process is not due to any cyclic process. The cooling occurs due to evaporation of water molecules which oozes out through pores of the pot. Even though the heat flows from cold water to open atmosphere, it is not a violation of second law of thermodynamics. The water inside the pot is an open thermodynamic system, so the entropy of water + surrounding always increases.
