Polymer Process Engineering
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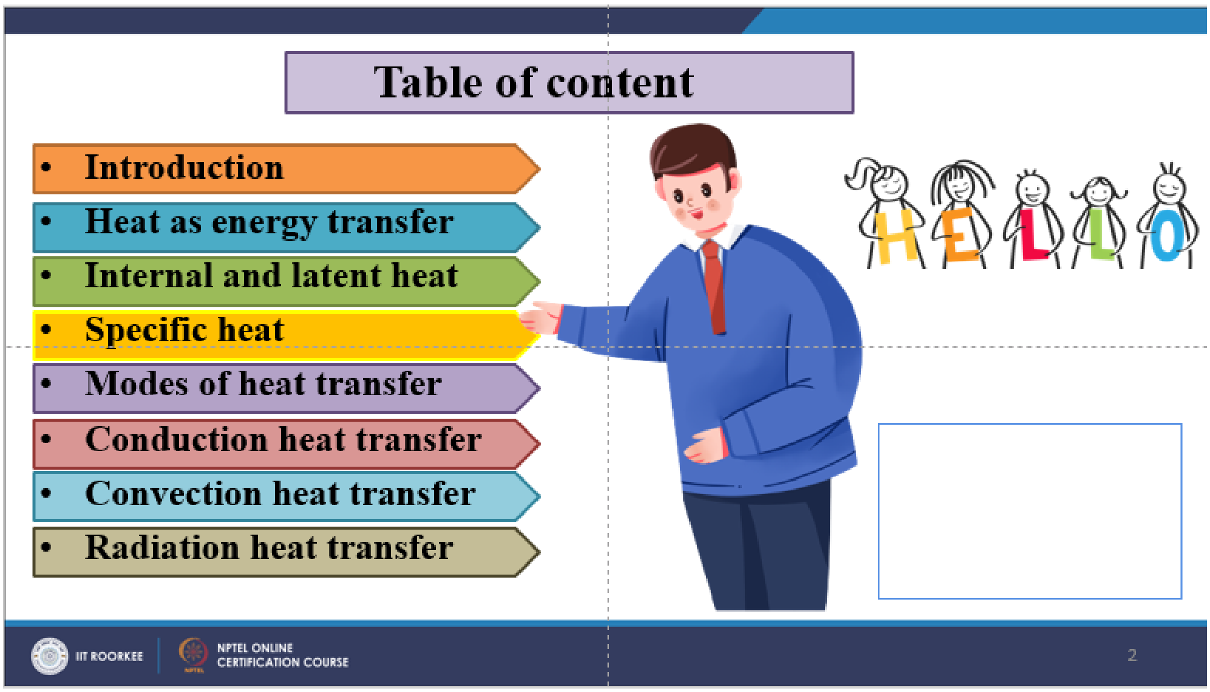
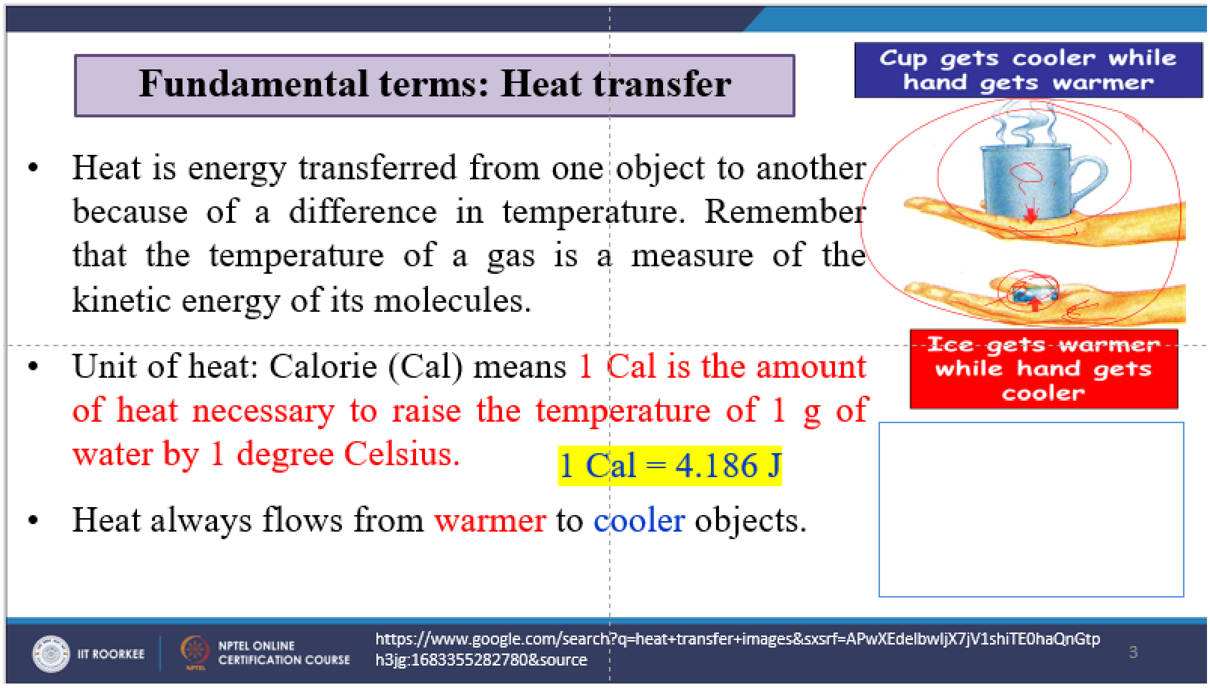
Lecture – 16
Heat Transfer Phenomenon in Polymer Systems: Introduction

Hello friends, welcome to the heat transfer phenomena in the polymeric system. This is the new chapter which we are going to start under the edges of polymer process engineering. So, this is the introductory chapter because heat transfer plays a very vital role in all kinds of processing operations of polymeric systems or polymers. So, its study or its awareness or its knowledge is quite essential for further study of this particular segment of polymer process engineering. Now, here are the topics which we are going to cover in this particular aspect. The introduction will have a small amount of introduction and then heat as a trans-energy transfer, then internal and latent heat.



We will discuss the specific heat and different modes of heat transfer. Some of you may be aware of heat transfer, and the different modes of heat transfer, but for the generic term, it is my duty to have an introduction about the modes of heat transfer then conduction, convection, and radiation heat transfer. So, the fundamental of heat transfer the heat, what is heat? Heat is energy transferred from one object to another because of the difference in temperature. Now, remember that the temperature of a gas is a measure of the kinetic energy of the molecule.

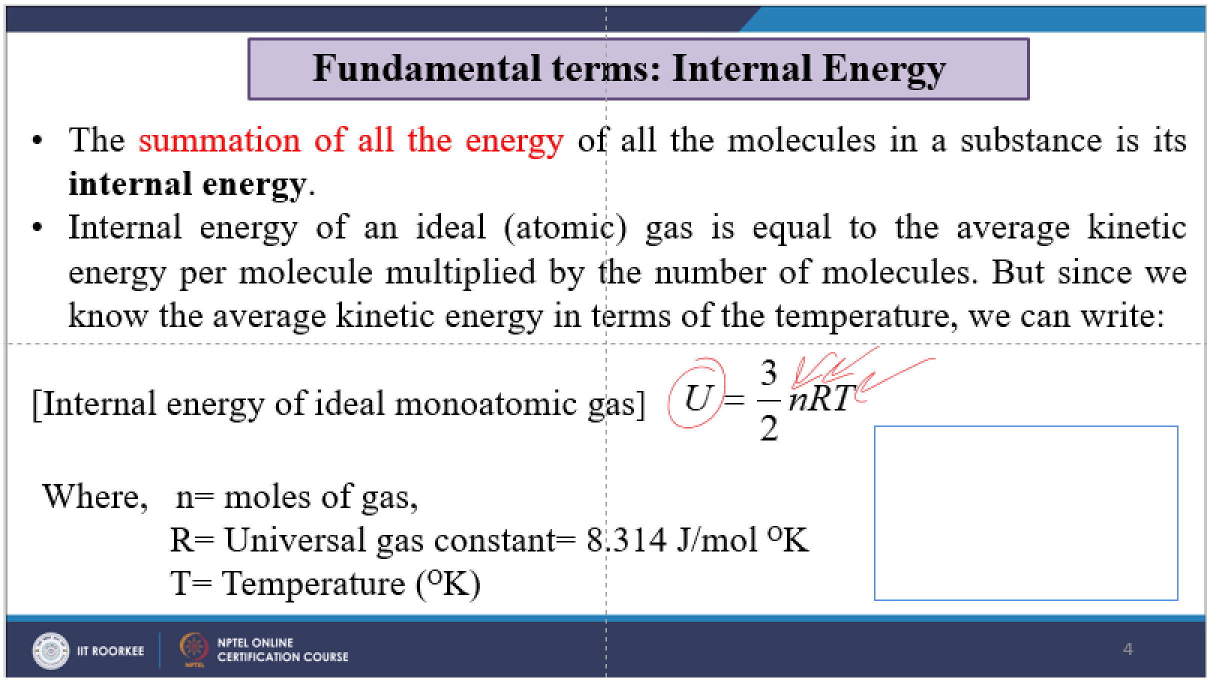


Now, here, you can experience the cup getting cooler while the hand gets warmer. So, there is a significant quantum of energy being transferred to your hand. So, this energy is being extracted from this cup and transferred to your palm. So, this becomes more warmer, and this becomes colder. Now, similarly, the ice gets warmer while your hand gets cooler because your hand is warmer than this ice.

So, ice attracts or extracts the heat from your palm. So, it becomes cooler, and it gets warmer. So, when we talk about this energy or heat, then obviously, in scientific terms, there is a question of what should be the unit. So, the unit of heat is referred to as a calorie. This means a calorie is the amount of heat necessary to raise the temperature of 1 gram of water by 1 degree Celsius.

So, usually, one calorie is referred as 1.4, 1.186 joule. Heat is always from the warmer to cooler objects as we saw in this particular figure. So, the summation of all energy of all molecules in the substance is its internal energy.

This is the new segment of which we are going to start the internal energy because of if you supply the heat to any object, some of the energy is consumed to raise the internal energy and thereafter the molecules are available for the work. So, the internal energy of an ideal or atomic gas is equal to the average kinetic energy per molecule multiplied by the number of molecules. Still, since we know the average kinetic energy in terms of temperature, so, we can write the internal energy of more ideal monoatomic gas U is equal to 3 upon 2 nRT, n is a number of moles of gases, R is the universal gas constant and it is referred as 8.314 joules per mole Kelvin and T is the temperature in Kelvin. Now, let us have a brief outlook on the specific heat. This is the amount of heat required to change the temperature of a material.



$$U = \frac{3}{2}nRT$$

Where, n= moles of gas,

R= Universal gas constant= 8.314 J/mol ^{O}K

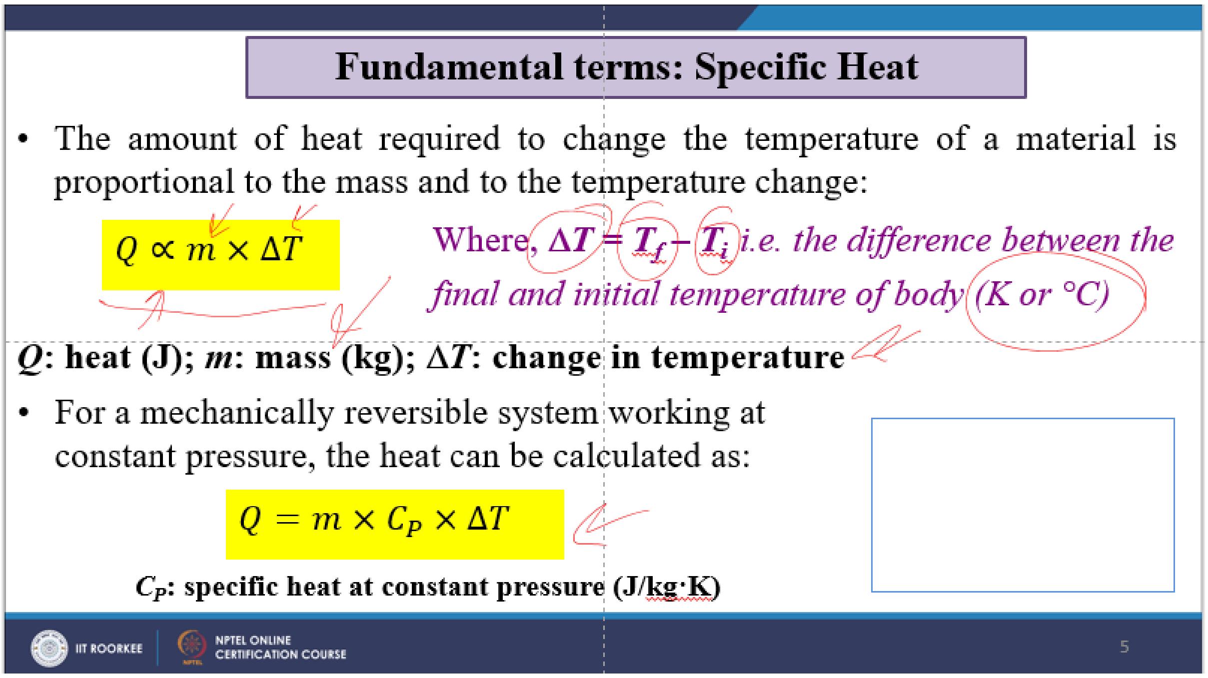
T= Temperature (^{O}K)

This is proportional to the mass and the temperature change. Now, this is Q is proportional to m and delta T where delta T is the final temperature minus the initial temperature. So, that is of anybody at it is represented either in Kelvin or degree Celsius and Q this heat is in joule and m is the mass that is in kg and delta T is the change in temperature. So, for mechanically reversible system working at constant pressure, the heat can be calculated as Q is equal to m C p delta T where C p is the specific heat at constant pressure and the units are joule per kilogram Kelvin. Now, specific heat which is usually represented by C is the characteristic of a material.

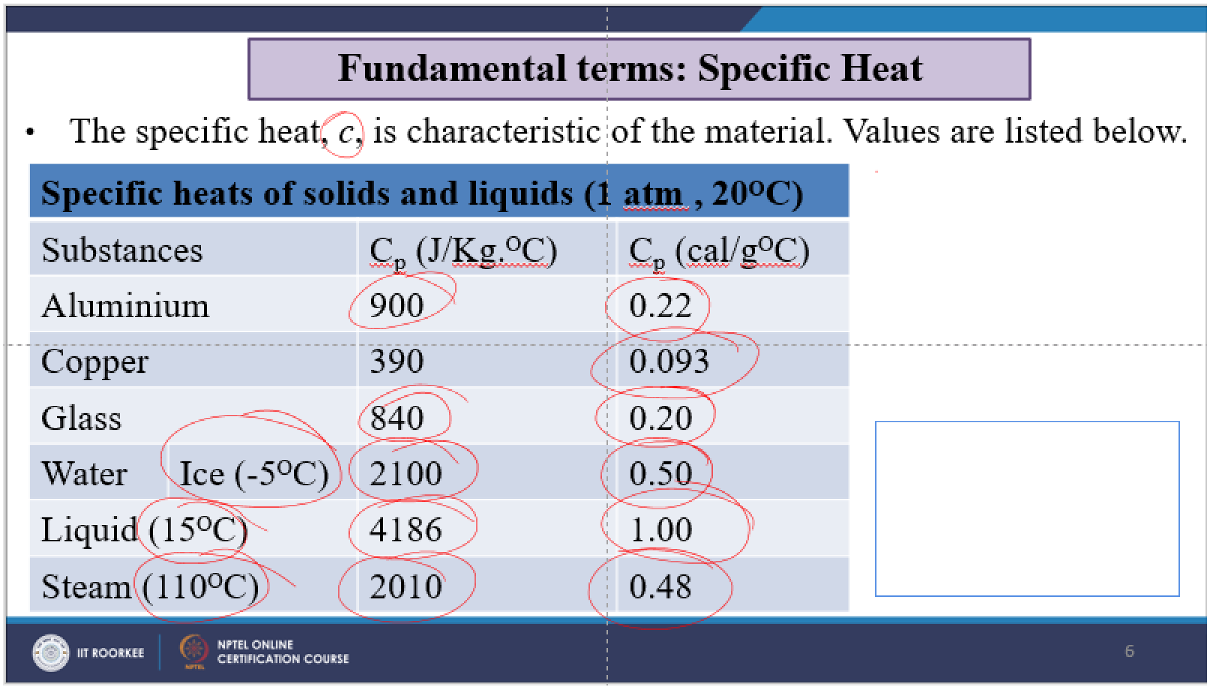
$$Q \propto m \times \Delta T$$

Where, $\Delta T = T_f - T_i$, *i.e. the difference between the final and initial temperature of body (K or °C)*

$$Q = m \times C_P \times \Delta T$$

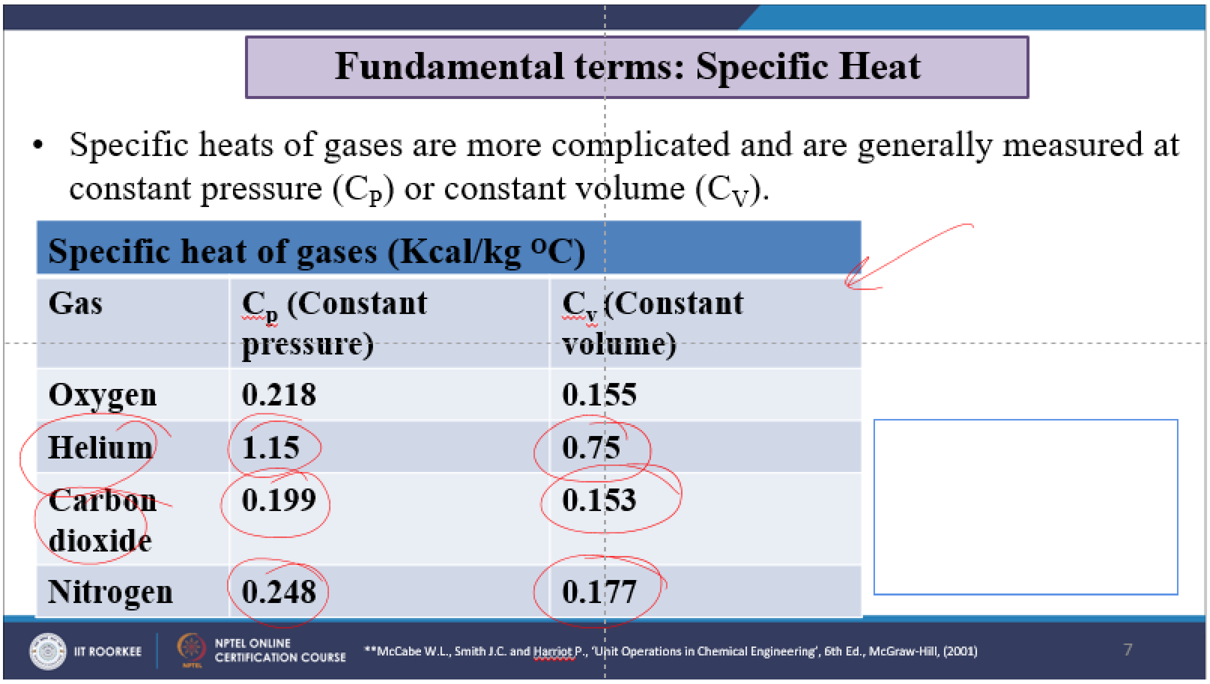


So, different values which are important in due course of study, they are enlisted over here. So, specific heats of solid and liquids for one atom and 20 degree Celsius for different substances, the aluminum 900 joule per kilogram degree Celsius, then or if we wish to represent in say kilogram per gram, sorry calories per gram degree Celsius it is 0.22, then the copper 390 and 0.093 calories per gram Kelvin and the glass having 840 and the C p value in calories per gram degree Celsius is 0.

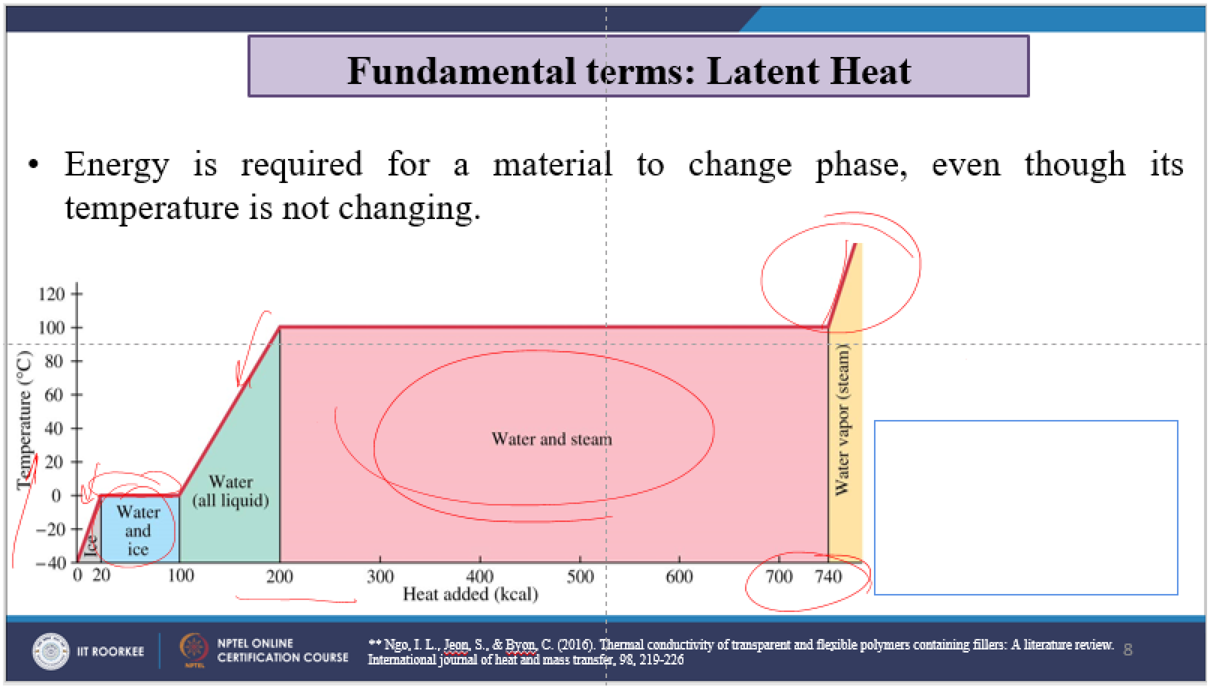


20. Water because water is available in different forms ice, liquid, steam. So, at minus 5 degrees Celsius, it is having the specific heat of 2100 joules per kilogram degree Celsius. If we talk about in terms of a calorie it is 0.5 calorie per gram degree Celsius and if you take the liquid water 15 degrees Celsius, it comes out to be 4186 joule per kilogram degree Celsius and 1 calorie per gram degree Celsius if we talk about in other units. In steam if we talk about 110 degree Celsius, it is 2010 joule per kilogram degree Celsius and 0.48 calories per gram degree Celsius.

So, the specific heat of gases are more complicated and are generally measured as constant pressure or constant volume. So, this table represents the specific heat of the gases in kilocalorie per kilogram degree Celsius for some of the common gases and the specific heat is represented in the constant pressure and the constant volume both. So, oxygen the Cp is 0.218 whereas, the Cv is 0.

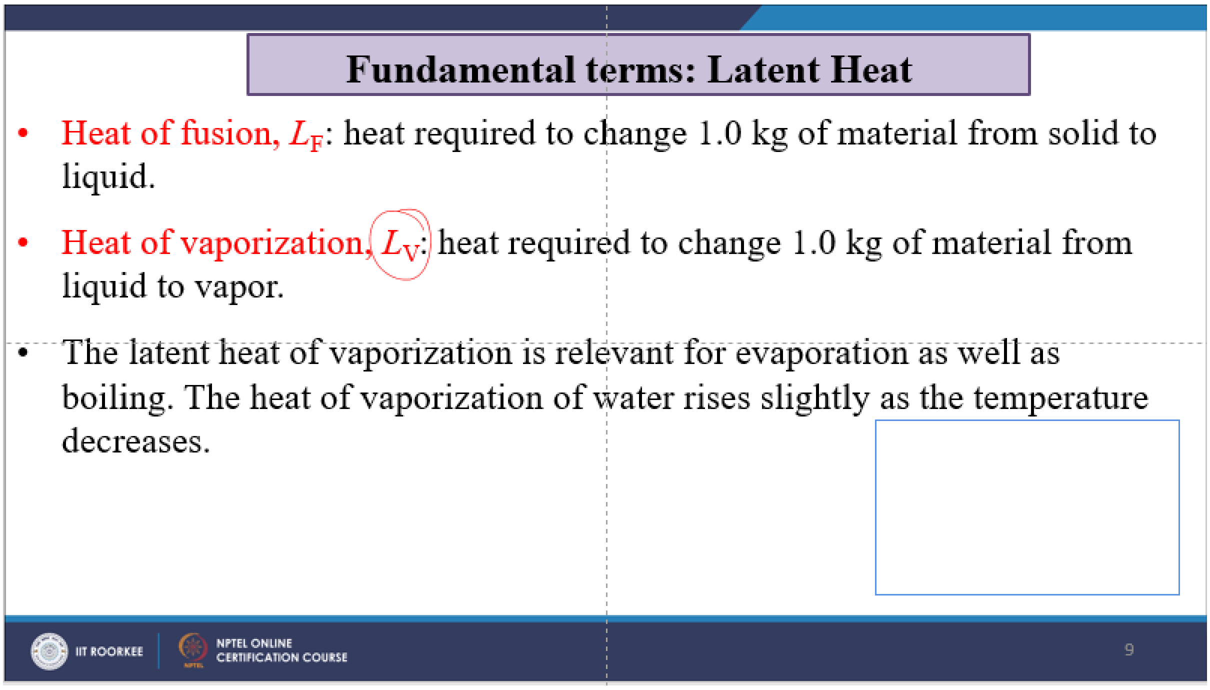


155 and helium 1.15 the Cp and Cv is 0.75 and the carbon dioxide 0.199 and Cv is 0.153 and the nitrogen 0.



248 and 0.177 is the Cv value. Now, latent heat is again very important phenomenon this is the energy required for a material to change phase even though its temperature is not changing. Now, here you see the best example of water here we are having the ice and we raise the temperature by adding the heat. Now, you see that after some time at 0 degree Celsius the temperature is constant but the heat

is more that is water and ice then after 100 kilocalories it converts all the water into the liquid and then if we raise the temperature to 100 degree Celsius you may have water and steam and if you raise further the temperature then the water you may get the water vapours the steam saturated steam and then superheated steam all this by giving more and more amount of heat in kilocalories. Sometimes some of the nomenclatures are of use that heat of fusion it is sometimes referred as LF this is the heat required to change the 1 kilogram of material from solid to liquid.

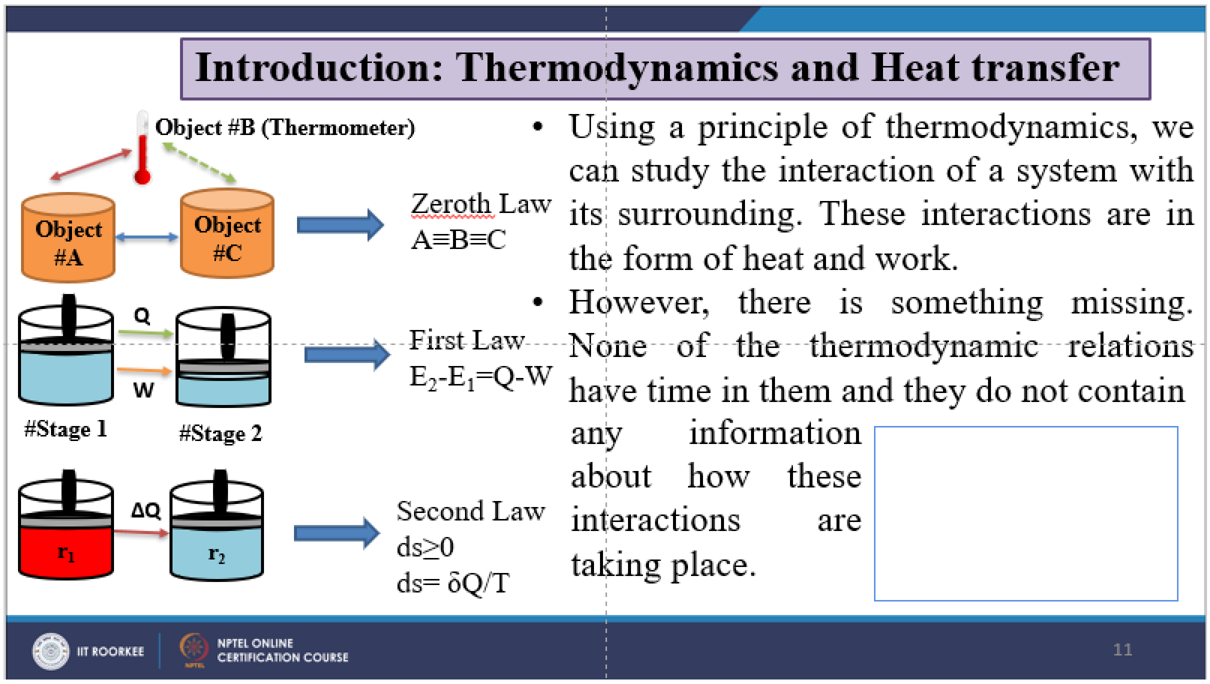


Then heat of vaporization referred as LV the heat required to change 1 kilogram of material from liquid to vapor. The latent heat of vaporization is relevant for evaporation as well as boiling the heat of vaporization of water rises slightly as the temperature decreases. Now, on a molecular level the heat added during the change of state does not go to increase the kinetic energy of individual molecules but rather to break the close bonds between them so the next phase can occur. Now, here you see that latent heat at one atmosphere of a different substances oxygen, nitrogen, ammonia, water, lead, iron etcetera. Now, here you see the melting point like oxygen they are having the melting point of minus 218.

8 degree Celsius and the heat of fusion kilojoule per kilogram 14 and kilocalorie if you convert into the kilocalorie per kilogram. So, it comes out to be 3.3 and the boiling point in is around minus 18.3 degree Celsius and heat of a vaporization is 210 kilojoule per kilogram and 81 kilocalorie per kilogram. Similarly, if you see the water because water is referred as the reference material some or other way.

So, water the melting point is 0 because at one atmosphere we are taking it and the heat of fusion is 333 kilojoule per kilogram and the boiling point is a 100 degree Celsius with the heat of a vaporization of 2260 kilojoule per kilogram or 539 kilocalorie per kilogram. Similarly, if you take iron the iron melting point is 1538 whereas, the heat of fusion is 289 kilojoule per kilogram and kilocalorie per kilogram if you talk about in this particular aspect it comes out to be 69.1 and boiling point of iron is 3023 degree Celsius whereas, the heat of vaporization 6340 kilojoule per kilogram and if you convert it into the kilocalorie it comes out to be 1520 kilocalorie per kilogram. Now, let us talk about the thermodynamics and a heat transfer. Now, using the principle of thermodynamics we can study the interaction of a system with its surrounding.

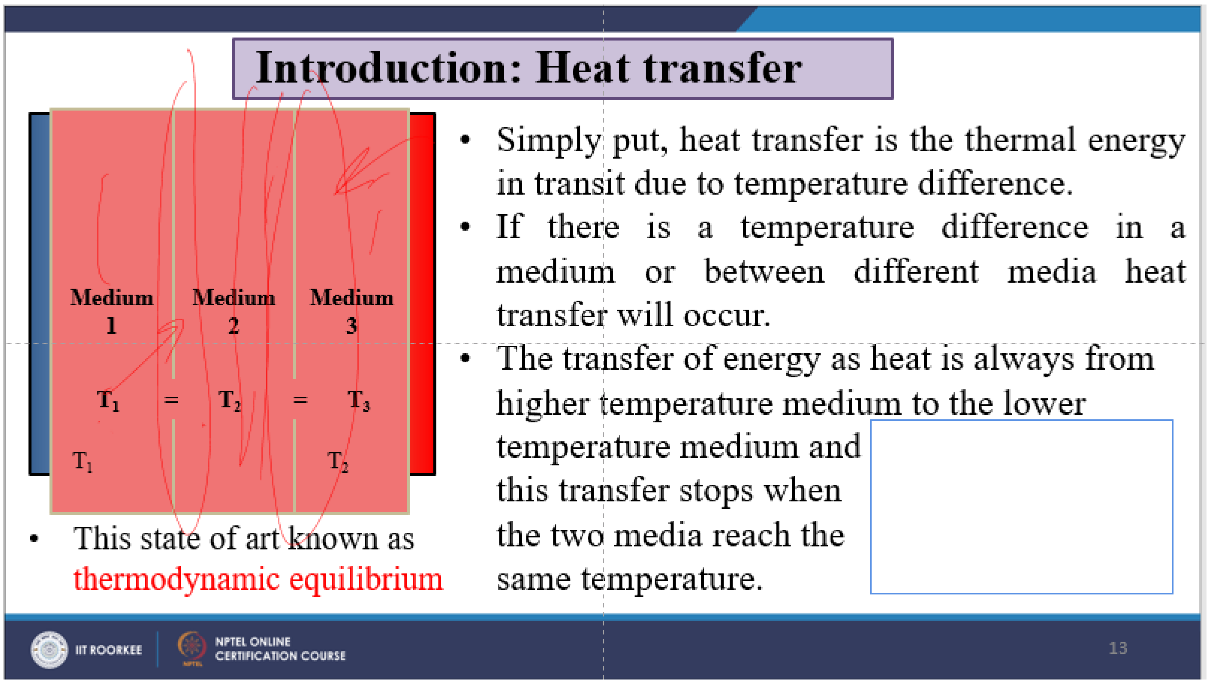
Now, these interactions are in the form of a heat and a work. However, there is a something missing none of the thermodynamic relation have time in them and they do not contain any information about how these interactions are taking place. So, to support these things, there are various laws from the zeroth law to the first law of thermodynamics to the second law of thermodynamics to the third law of thermodynamics. So, the science of thermodynamics it deals with the amount of a heat transfer or work done for the system and that is undergoing a process from one state to the other and it does not care about how long the process takes. So, here you see you are applying the heat to the system and you are extracting the work.



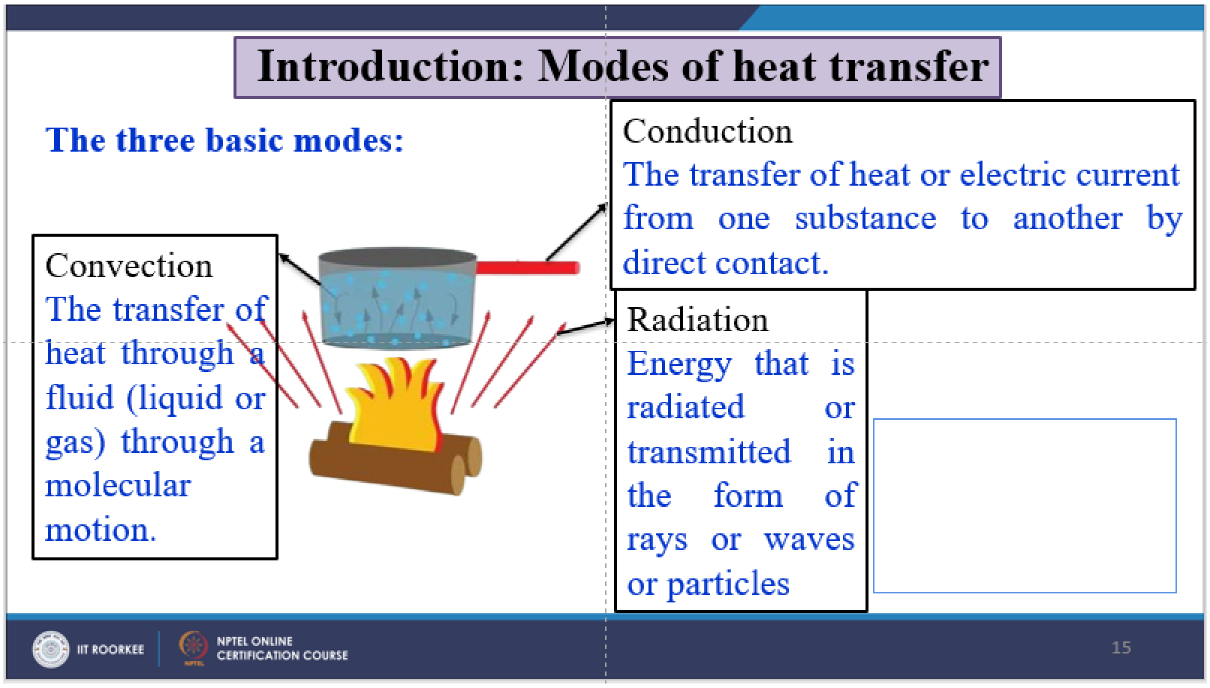
So, from surrounding to this is the system and this is the surrounding. So, anything that comes to the system from surrounding and you are extracting the work to the surrounding, but in engineering we are often interested in the rate of heat transfer and the means with which we can make it happen and this is the focus on this particular lecture. So, let us start it. Let us start with the heat transfer. Now simply put the heat transfer is the thermal energy in transit due to the temperature difference.

If there is a temperature difference in a medium or between the different media heat transfer definitely will occur. The transfer of energy as heat is always from higher temperature medium to the lower temperature medium and this transfer stops when the two media reach at the same temperature. Now this is state of art known as the thermodynamic equilibrium. Now here you see this is the heat surface and this is here both the segments are having the same temperature and that is called the thermodynamic equilibrium. Now simply if you put the heat transfer this is the thermal energy in transit due to the temperature difference if there is a temperature difference in a medium or between the different media heat transfer definitely will occur.

So, the transfer of energy as a heat always from higher temperature medium to the lower temperature. Now here you see that the medium 1, medium 2, medium 3 all these. So, at the interface you will see that T1 is equal to T2 and T2 is equal to T3. This is known as the thermodynamic equilibrium. Now heat transfer is the phenomena which keeps our car engine from overheating.

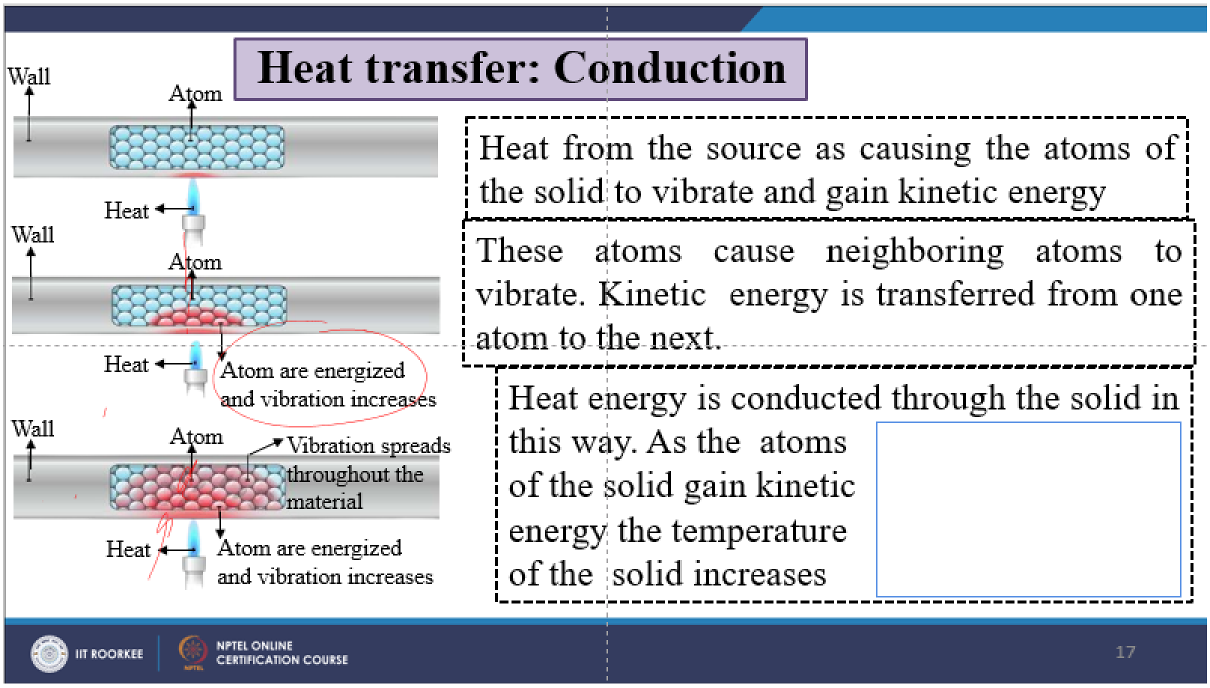


It is what keeps our home warm during the cold winter and cold during the hot summer. Heat transfer helps our food and drinks cool and fresh. It helps power cities and keeps our electronics cool and running. Now this transfer of thermal energy can occur in three different ways. It can happen via conduction, convection and radiation.

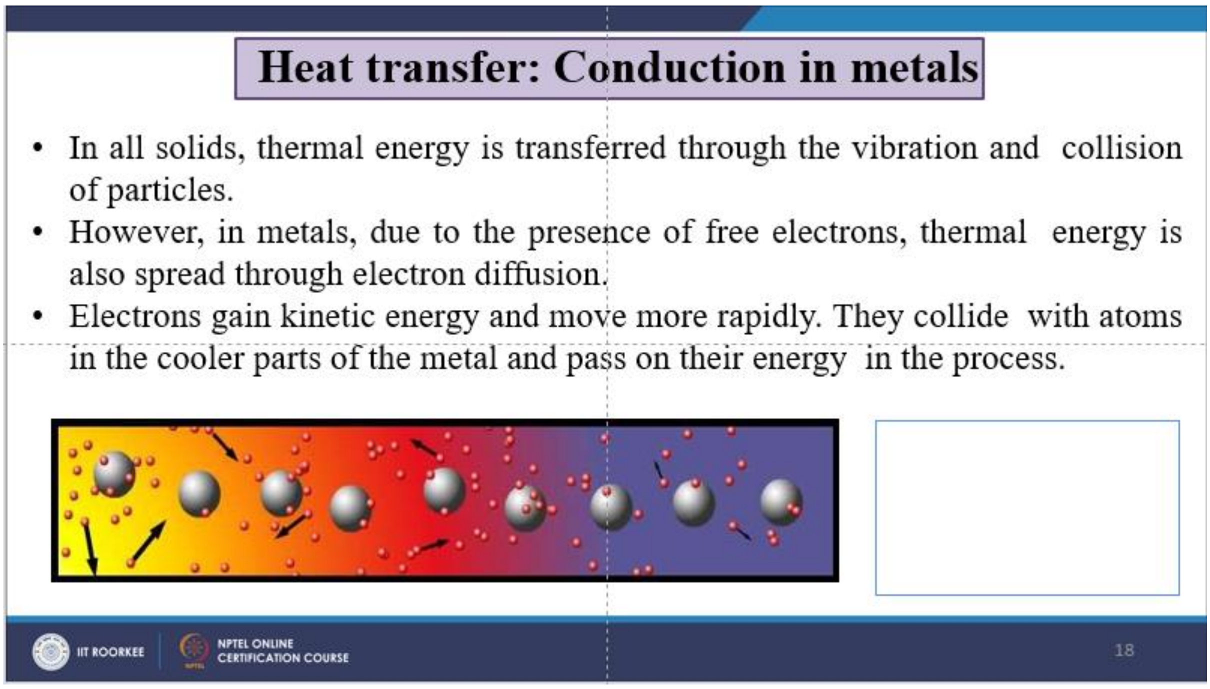


Let us go to the modes of heat transfer. The convection, the transfer of heat through a fluid, liquid or gas through a molecular motion. The conduction, the transfer of heat or electric currents from one substance to another by direct contact and the radiation, the energy that is radiated or transmitted in the form of rays or waves or particles. Now conduction, the conduction is the transfer of thermal energy through a medium without any flow of the medium. The particles are heated and vibrated vigorously.

They collide with the neighbouring particles and transfer their energy to them, and eventually, the particles at the cooler end are also set into vigorous vibration. Like here you see, this is a transfer. The conduction, the heat from the source cause the atoms of the solid to vibrate and gain kinetic energy, and these atoms cause the neighbouring atom to vibrate and kinetic energy is transferred from one atom to the next. The heat energy is conducted through a solid in this way, and as the atom, as the atoms of the solid gains kinetic energy, the temperature of the solid increases. Now, here you see, they are supplying the heat, and it goes to the atom.

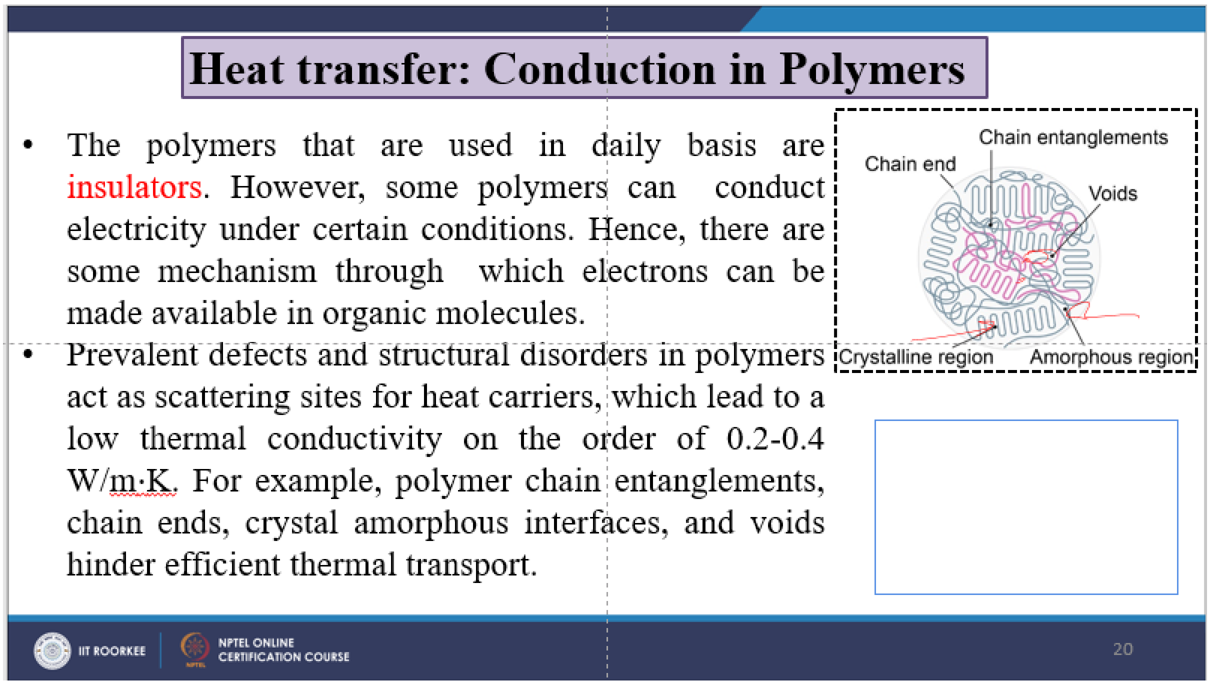


These are energized, and vibration increases and these atoms are energized and it goes to the wall. So, it passes through the wall. Let us talk about the conduction in metal. All solid thermal energy is transferred through the vibration and collision of the particles. However, in metals, due to the presence of free electrons, thermal energy is also spread through electron diffusion.



The electrons gain kinetic energy and move more rapidly. They collide with atoms in a cooler part of the metal and pass on their energy in that particular process. Here you can see, you can you can visualise. Conduction in liquid and gases again very important phenomena. So, the particles in the liquid and gases are spaced farther apart from these solid because solid is more compact in nature and the collision between the particles occur less frequently and the slow transfer of kinetic energy.

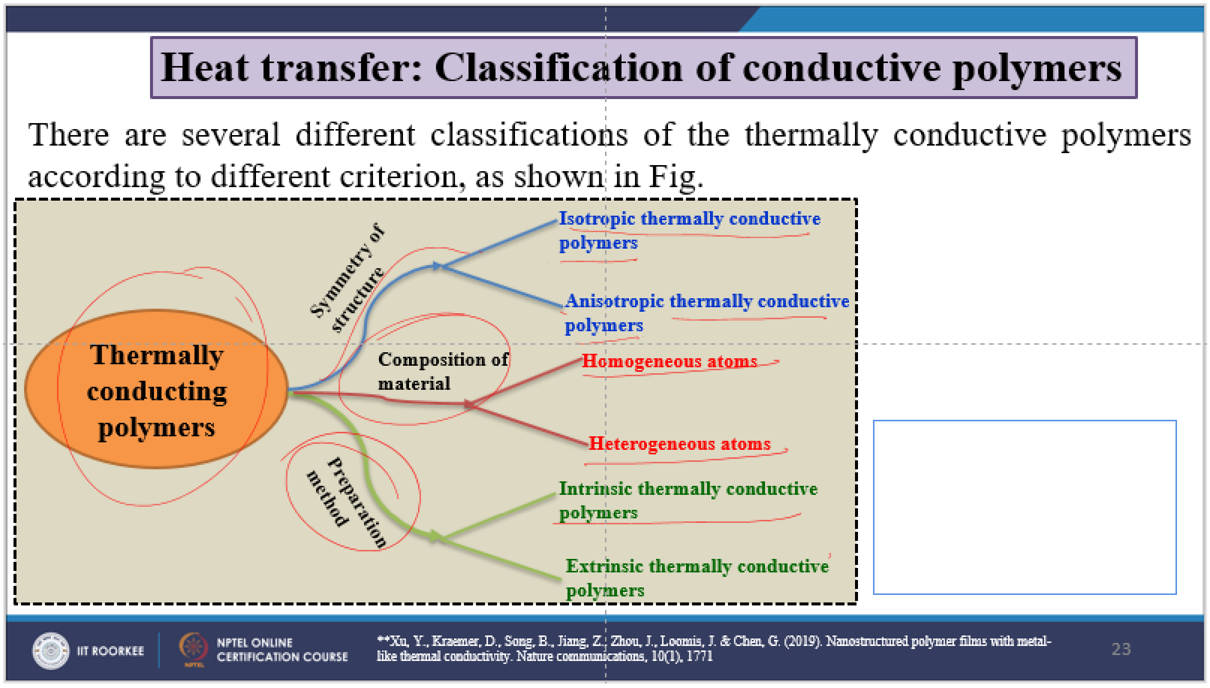
So, you see that here, the ice cube wrapped in the wire gauge and you are supplying the flame and over the period of time it gets melted. Now, let us talk about the conduction in polymers. The polymers that are used in daily basis are insulated sometimes and however, some polymers can conduct electricity under certain conditions. Therefore, there are some mechanisms through which the electrons can be made available in organic molecules. Now, here you see the whenever there are various regions and various aspects of the polymer that you see that in the first chapter we discussed about the polymeric chains.



So, the polymer chains, they are entangled and all together and the chain ends they are openly exposed and some sort may have the crystalline region and some sort they may have amorphous region. Apart from this, there are certain voids. So, if you supply the heat, the chains try to unentangle themselves and they try to align and this is the conduction in the polymers. So, prevalent defects and structural disorder in the polymer, they act as a scattering site for heat carriers which lead to a low thermal conductivity and usually this is in the order of 0.

2 to 0.4 watt per meter Kelvin. For example, the polymer chain entanglement chain ends the crystal amorphous interface and the voids hinder the efficient thermal transport. Now, conduction occurs due to the conjugated carbon chain consist of alternating single and double bond where the highly delocalized, polarized and electron dense pi bonds are responsible for the electrical and optical behavior. So, the fact that common polymers like polyethylene, they are composed of backbones of covalent carbon-carbon bonds and such as semi crystalline polyethylene. Now, these backbone feature as randomly oriented lamellar crystalline or lamellae and they dispersed in amorphous chain network like here you see. Now, atomistic simulations, they have suggested that an individual crystalline polyethylene chain can have a very high possible divergent thermal conductivity.

Now, when we are talking about the conduction in polymers, then we must see that the classification of conductive polymers because they are clubbed under the head of conductive polymers. Now, there are several different classifications of the thermally conductive polymers. Now, according to different criteria which is shown in the figure like thermally conducting polymers, symmetry of a structure again they are subdivided into the isotropic thermally conductive polymers or anisotropic thermally conductive polymers. Then we are having the composition of the material, they are the homogeneous atoms or heterogeneous matter. Then preparation methods based on the preparation method you can classify them like intrinsic thermally conductive polymers, then extrinsic thermally conductive polymers.

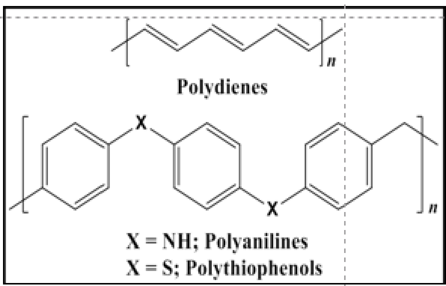


So, all these things are there. Now, let us talk about the conducting polymers preparation methods. So, intrinsically conducting polymers and sometimes they are referred as ICPs, they are organic polymers that conduct electricity and such compounds may have a metallic conductivity or can be a semiconductor. The biggest advantage of conducting polymers is their processability mainly by the dispersion. Here you see that one of the conducting polymers. Now, conducting polymers they have the backbones of the continuous sp2 hybridized carbon center.

Conducting polymers: preparation methods

A) Intrinsically conducting polymers (ICPs) are organic polymers that conduct electricity. Such compounds may have metallic conductivity or can be semiconductors.

- The biggest advantage of conducting polymers is their processability, mainly by dispersion.



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So, one valence electron on each center resides in a p or pz orbital which is orthogonal to the other three sigma bonds and the electron in these delocalized orbitals have high mobility. Now, extrinsically conducting polymers, ECPs, those conducting polymers which owe their conductivity due to the presence of externally added ingredients in them, they are called extrinsically conducting polymers. And they are of two types, one is the conducting element filled polymers CEFP and second one is the blended conducting polymer BCP. Let us take example in high density polyethylene HDP, this is filled with the aluminium nitrite AIN filler and AIN filler can touch and interact with each other to form the AIN-AIN thermally conductive network and channels and finally improve the lambda value of HDPE matrix. Let us talk about the different types of intrinsically conducting polymers.

Conducting polymers: preparation methods

B) Extrinsically conducting polymers (ECP's): Those conducting polymers which owe their conductivity due to the presence of externally added ingredients in them are called extrinsically conducting polymers.

- Extrinsically conducting polymers (ECP's) are of two types.

(1) conducting elements filled polymers (CEFP)

(2) blended conducting polymers (BCP).

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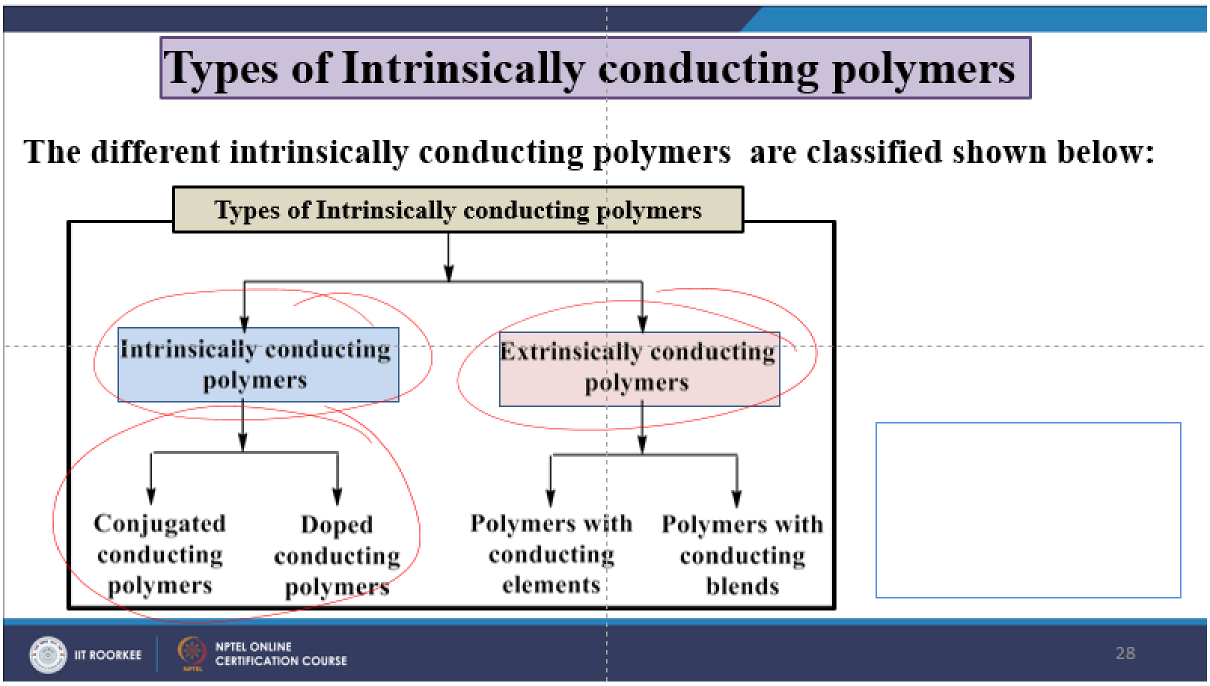
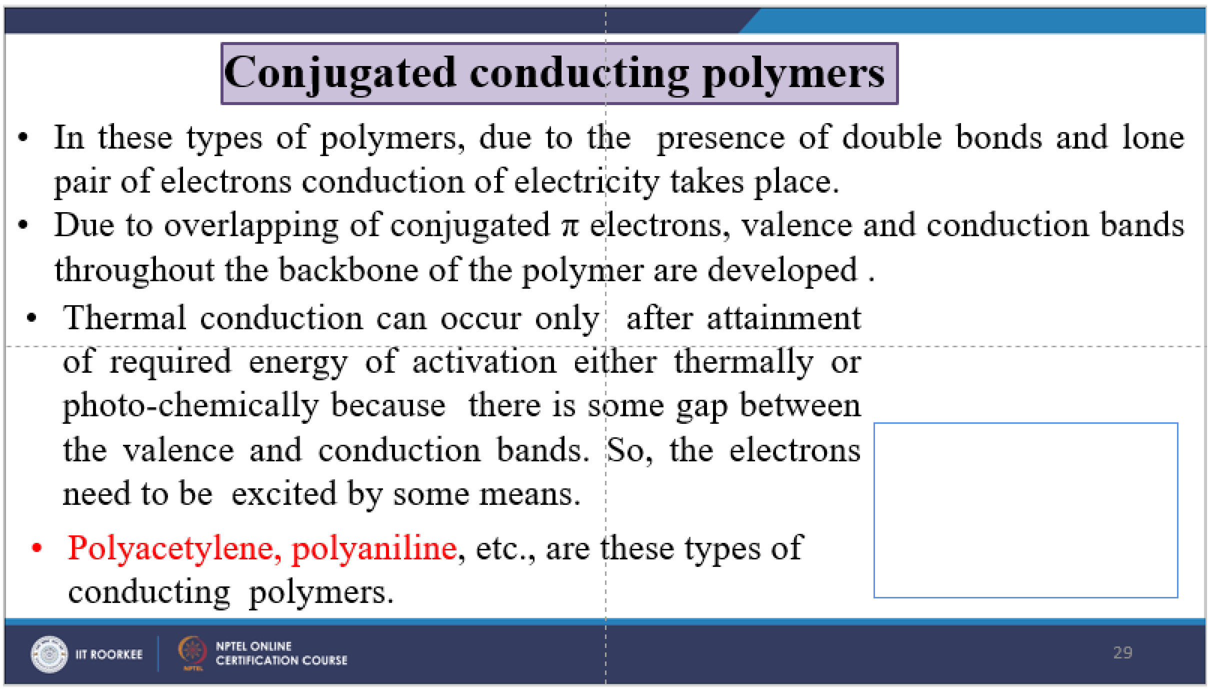
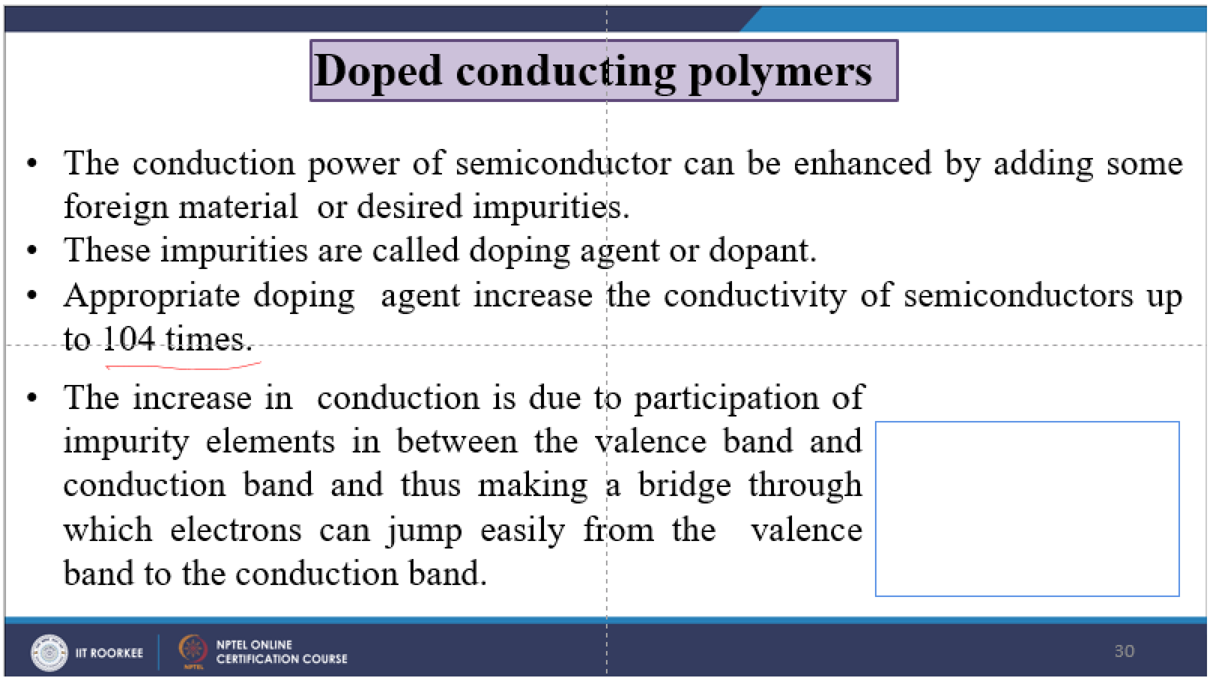
The different intrinsically conducting polymers are classified in two ways. One is the intrinsically conducting polymers and extismanically conducting polymers. Intrinsically conducting polymers, the conjugated conducting polymers and doped conducting polymers, they are the two categories for this set. And again, the extrinsically conducting polymers have two subcategories polymers with conducting elements and polymers with conducting blends.



Let us talk about the conjugated conducting polymers. In these types of polymers, due to the presence of double bond and a lone pair of electron conduction of electricity takes place. Due to overlapping of conjugated pi electrons, valence and conduction band throughout the backbone of the polymers, they are developed. Thermal conduction usually this can occur only after attainment of required energy of activation either thermally or photochemically because there is some gap between the valence and conduction bands. So, the electron needs to be excited by some means this is quite essential. And now polyacetylene and polyaniline etcetera, these are the type different type of the conducting polymers.

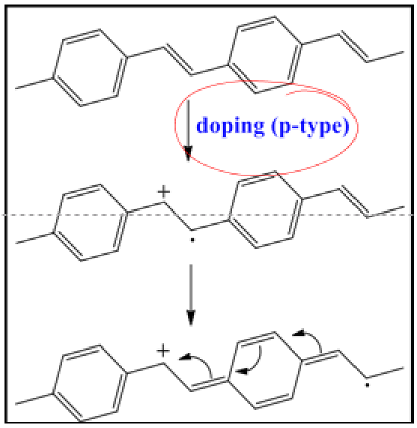


Let us talk about the doped conducting polymers. The conduction power of the semiconductor can be enhanced by adding some foreign material or desired impurities. These impurities are called the doping agent or dopant. The appropriate doping agent increases the conductivity of semiconductor up to 104 times. Now the increase in the conduction is due to participation of impurity elements in between the valence band and the conduction band and thus making a bridge through which the electrons can jump easily from the valence band to the conduction band.



Now doping usually are mainly two types. The p-type doping through the oxidation of material and n-type doping through the reduction of materials. Now let us talk about the doped conducting polymers and p-type doping. Now the p-type doping through oxidation of the material in here you see that this is the p-type doping. Now in this type of a doping some electrons from the conjugated pi bonds are removed through oxidation creating a positive hole called the polaron inside the polymer and the positive hole or polaron can move throughout the polymeric chain and make it conducting polymer. The polymer which have the conjugation in the backbone when treated with the electron deficient series and lewis acid like $FeCl_3$ or I 2 vapor or I 2 or CCl_4 oxidation takes place and a positive charge is created in the molecule.

Doped conducting polymers: p type doping



p-type doping creates positive charge

p-type doping through oxidation of materials: In this type of doping some electrons from the conjugated π bonds are removed through oxidation creating a positive hole called polaron inside the polymer. The positive hole or polaron can move throughout the polymeric chain and make it conducting polymer.

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Now the removal of one electron in the pi backbone of a conjugated polymer forms a radical cation that is called the polaron which on losing another electron forms bi polaron. Now the delocalization of the positive charges causes the electrical conduction of lewis acid which is $FeCl_3$ or $AlCl_3$ they are generally used as a doping agent. Now here you see the polymer you are having the polymer plus any Lewis acid you can get the p-doped polymer or oxidative coupling like polyacetylene CHX plus 3 I 2 it is 2 $CHXI_3$ or polyacetylene CHX plus 2 $FeCl_3$ it gives the CHX and $FeCl_4$ and plus $FeCl_2$. Now let us talk about the n-type doping. Now n-type doping through the reduction of material in this type of doping some electrons are introduced to the conjugated pi bonds through reduction creating a negative hole or charge inside the polymer.

Doped conducting polymers: p type doping example

- The delocalization of positive charges causes electrical conduction. Lewis acids ($FeCl_3$, $AlCl_3$) are generally used as doping agent.

Polymer + Lewis acid ⟶ p-doped polymer (oxidative coupling)

$$(CH)_x + 3I_2 \longrightarrow 2(CH)_x^{+}I_3^{-}$$
Polyacetylene

$$(CH)_x + 2FeCl_3 \longrightarrow (CH)_x^{+}FeCl_4^{-} + FeCl_2$$
Polyacetylene

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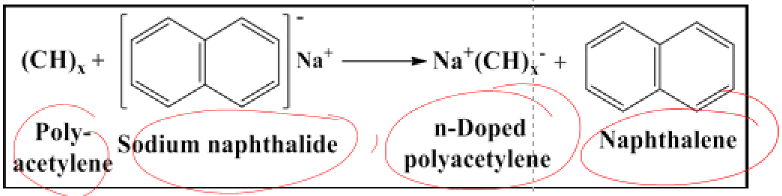
The negative hole of charge can move throughout the polymeric chain and may get to conducting polymer. So, the here we are using the lewis bases like NaC c10H8, Kc10H8 etcetera they are generally used as a doping agent and lewis bases these are the electron rich species are treated with the polymer having conjugation and due to the reduction of the polymer negative charge develops. Actually, see by the addition of one electron polaron and by the addition of the second electron bipolaron they are formed. In bipolaron and due to the de-localization of charge conduction takes place. Like here you see this polyacetylene sodium naphthalide they react with to form the n-doped polyacetylene and naphthalene.

Doped conducting polymers: n type doping example

- Lewis bases, $Na^+C_{10}H_8^-$, $K^+C_{10}H_8^-$, etc., are generally used as doping agents. When Lewis bases (electron rich species) are treated with polymer having conjugation, due to reduction of the polymers, negative charge develops.
- Actually, by the addition of one electron, polaron and by the addition of the second electron, bipolaron are formed. In bipolaron, due to the delocalization of charge, conduction takes place.



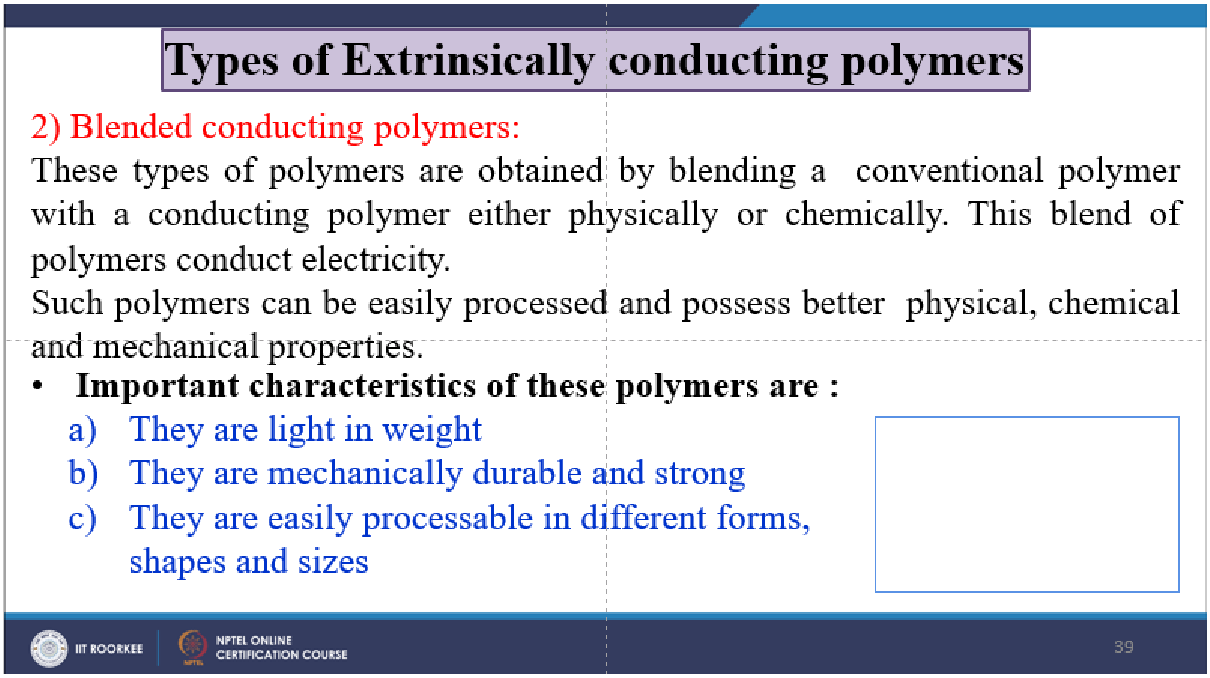
Now let us talk about the types of extrinsically conducting polymers. The conducting elements filled polymers CEFP in this type of conducting element is added to the polymer. Therefore, the polymer acts as a binder to hold the conducting element together in the solid entry. There we are creating the charge in the polymer here we are introducing a foreign body to carry out this to make this system conducting. Because conductivity of these polymer is due to the addition of external ingredients.

Types of Extrinsically conducting polymers

1. Conducting Elements Filled Polymers (CEFP): In this type, a conducting element is added to the polymer. Therefore, the polymer acts as a binder to hold the conducting elements together in solid entity.

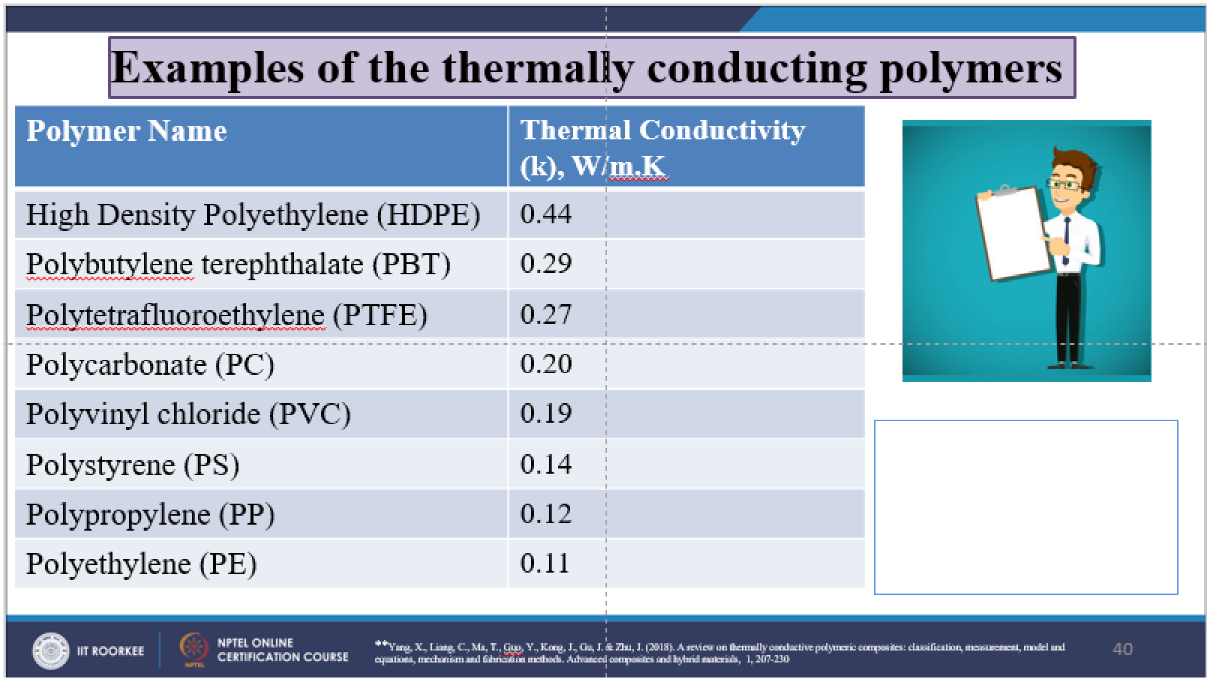
- Thus, conductivity of these polymers is due to the addition of external ingredients.
- Upon addition of conducting element, the polymer will have a property of that conducting element and it will start conducting electricity.

So, upon addition of the conducting element the polymer will have a property of that conducting element and it will start conducting electricity. So, there are various characteristics of CEFP polymers they possess a good bulk conductivity they are cheaper light in weight mechanically durable and strong easily processible in different forms shape and sizes. Now let us talk about the blended conducting polymers. Now these types of polymers are obtained by blending a conventional polymer with a conducting polymer either physically or chemically. The blend of polymer conduct electricity and such polymers can be easily processed and possess better physical chemical and mechanical properties.

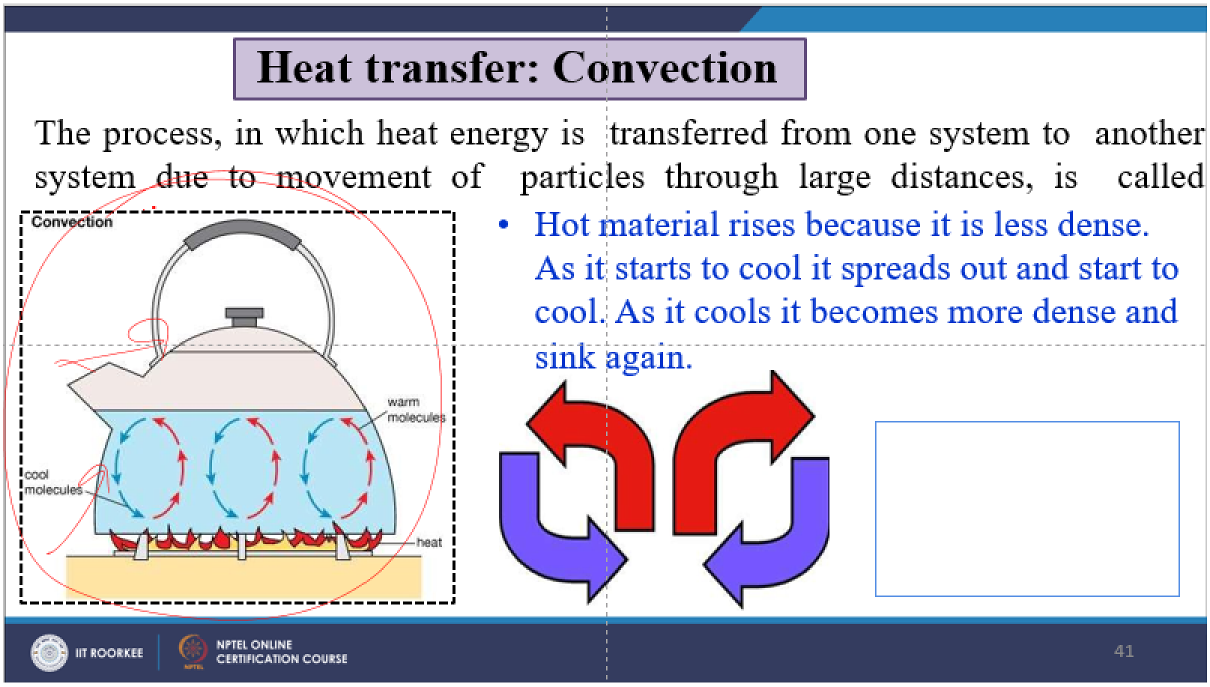


So, there are some of the important characteristics of these polymers they are light in weight mechanically durable and strong easily processible in different form and shapes. Let us take some example of the thermally conducting polymers like high density polyethylene HDPE they are having the thermal conductivity of 0.44 and the polybutylene terephthalate PBT 0.

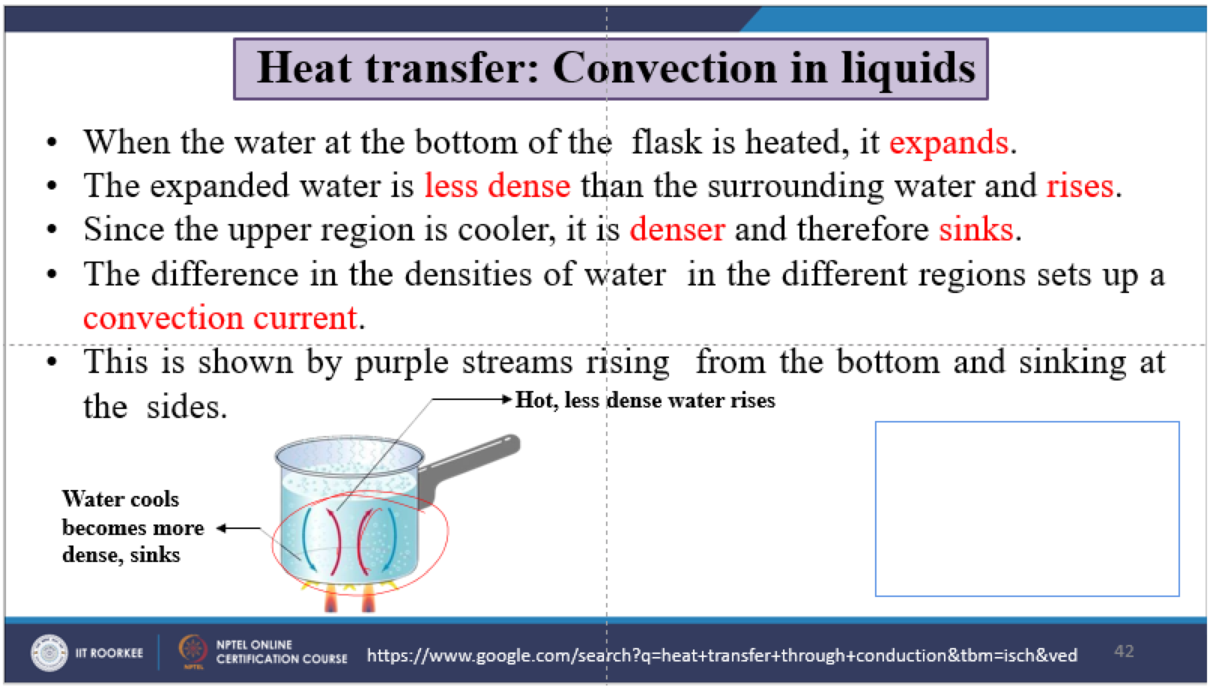
29 polyethylene polytetrafluoroethylene PTFE 0.27 polycarbonate 0.2 polyvinyl chloride PVC 0.



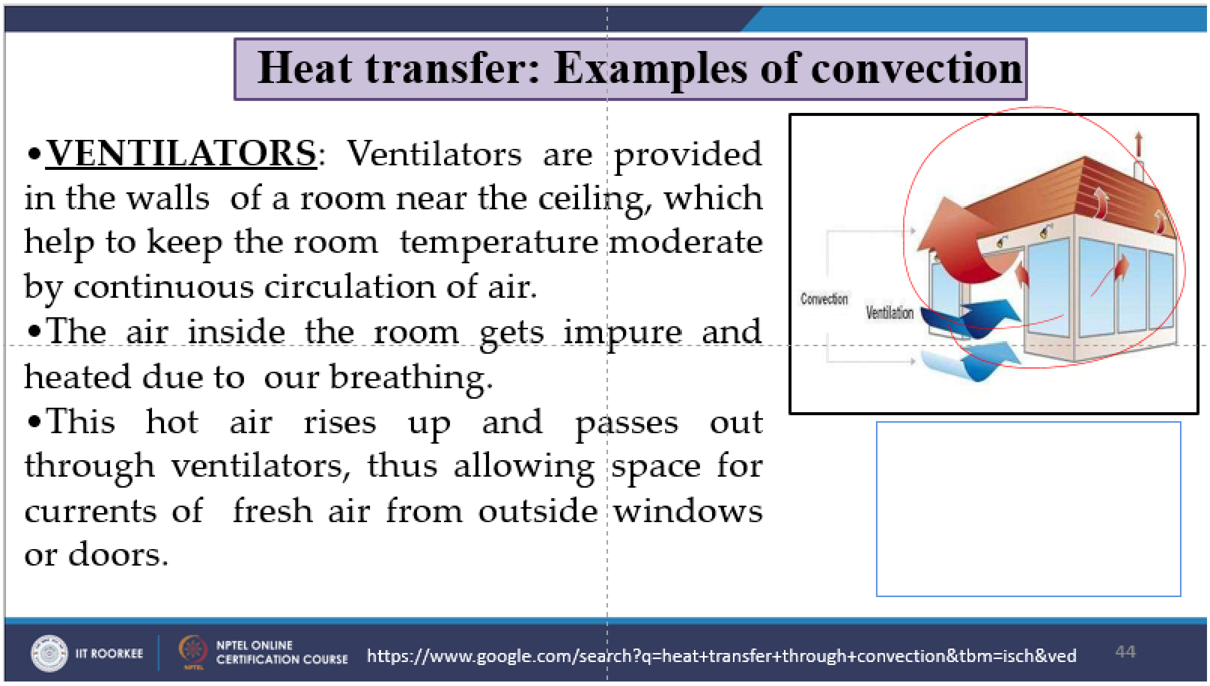
19 polystyrene 0.14 polypropylene 0.12 and polyethylene that is 0.11. So let us talk about the convection this is the process in which the heat energy is transferred from one system to another system due to the movement of the particles where we are not having the movement of the particles but here we are having the movement of the particle through the large distance this is called the convection. So hot material rises because it is less tensile and it starts to cool spread out and start to cool as it cools it becomes more and more denser and sink again.



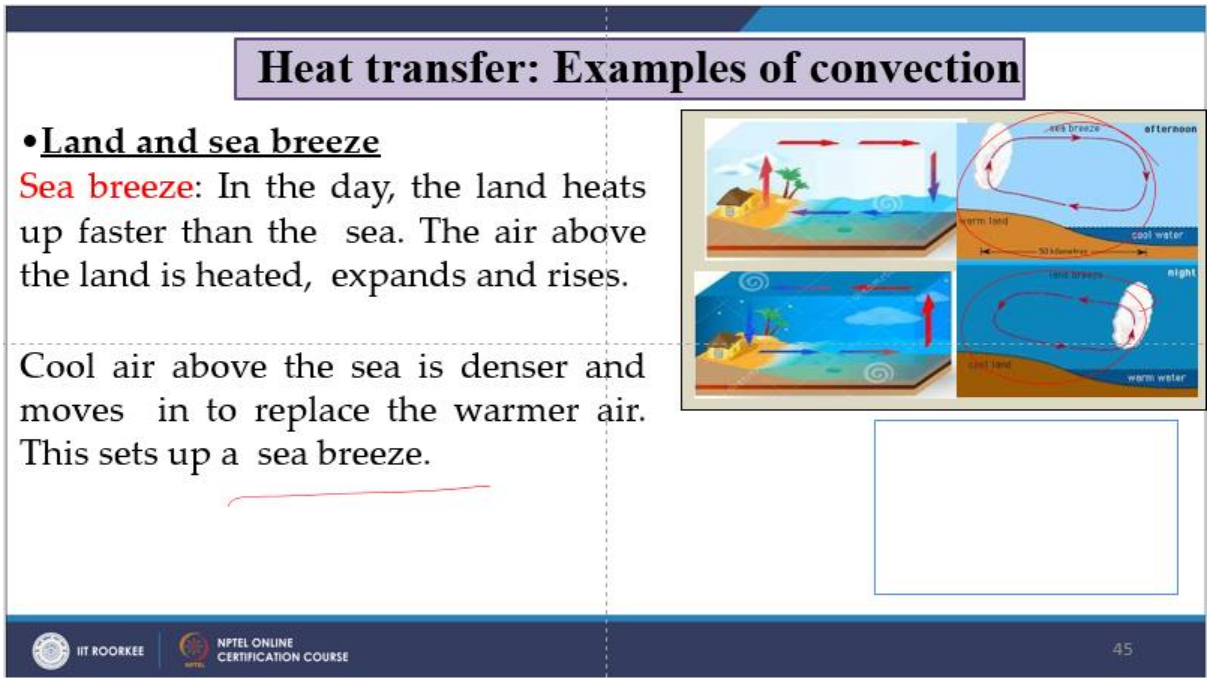
So, this is the convection phenomena. Let us talk about the convection in liquids so when water at the bottom of the flask is heated here it expands the expanded water is less dense than the surrounding of the water and rises since the upper region is cooler here this is a cooler cooler it is denser and therefore sinks the difference in the densities of the water in the different region sets up a convective current. Now this you can see over here this is this is the purple line this is streams rising from the bottom and sinking this side so hot lens dense water rises.



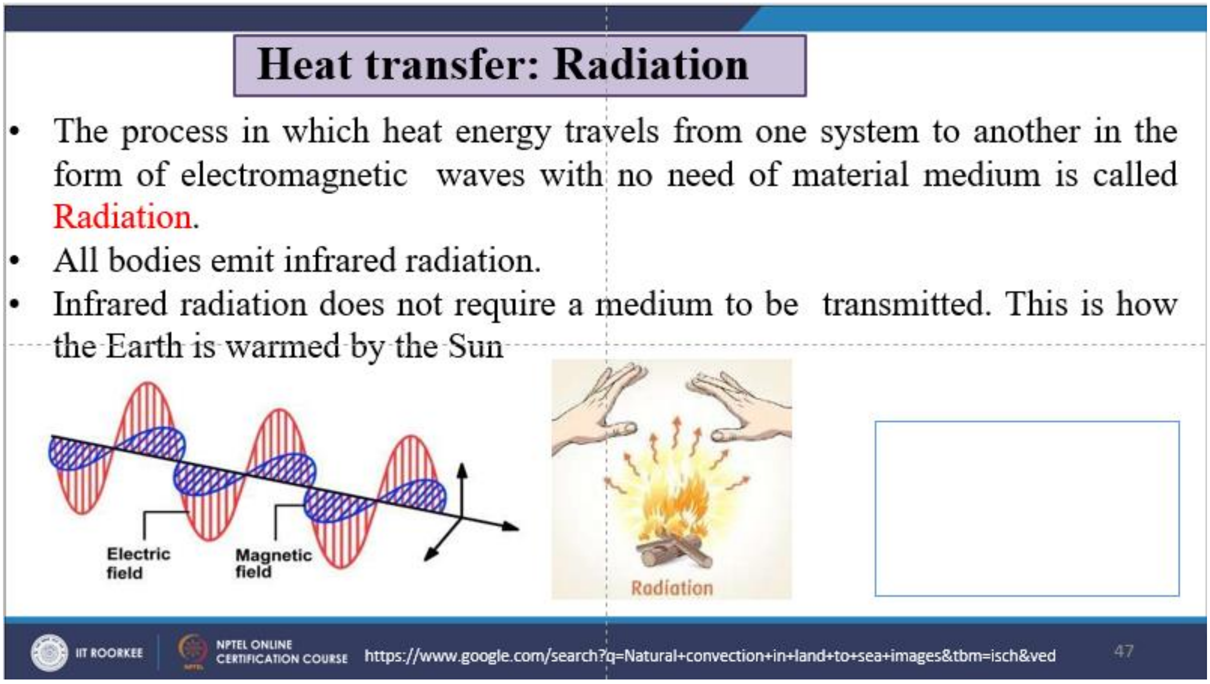
Similarly, if we talk about the convection in gases when the air above the candle usually is heated it expands the expanded air is less dense than the surrounding air and rises out of the chimney here. Since the surrounding air is cooler it is denser therefore it sinks into a chimney and the difference in the densities of the air at the different chimneys set up a convective current. There are some of the examples of convection ventilators. Ventilators are provided in the walls of a room near the ceiling which help to keep the room temperature moderate by continuous circulation of air. The air inside the room gets impure and heated due to our breathing and the hot air rises up and passes out of the ventilators and allowing a space for current to a fresh air from outside.

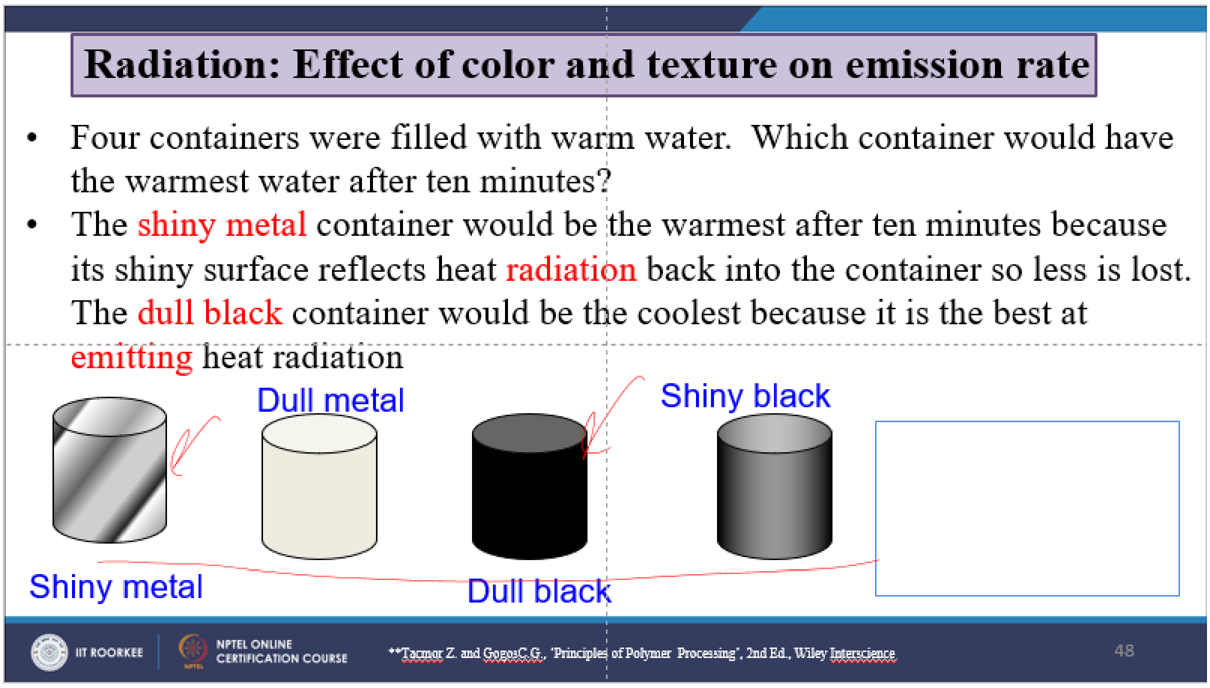


So, it creates a circulating media. Land sea breeze the sea breeze that in the day the land heats up faster than sea the air above land is heated expand and rises and cool air above the sea is denser and moves up to the replace the warmer air and that is a that set up the sea breeze like here you see the sea breeze. The land breeze at night the land cools faster than the sea the air above the land is now cooler and then the air above the sea the convective current is set up in the opposite direction and that is called the land breeze. Now let us talk about the radiation the process in which the heat energy travels from one system to another in the form of electromagnetic waves with no need of any kind of a material medium that is called the radiation. So, all bodies emit infrared radiation and infrared radiation does not require a medium to be transmitted.



This is how the earth is warmed by the sun. Now effect of color and texture sometimes take place in the emission rate. The four containers here you see they are filled with warm water which container would have the warmest water after 10 minutes. The shiny material container would be the warmest after 10 minutes because its shiny surface reflects the heat radiation back into the container so less is the loss. The dull back this one container would be the coolest because it is the best at emitting heat radiation. Now the effect other factors with those who effects the emission or absorption rate one is the surface area.

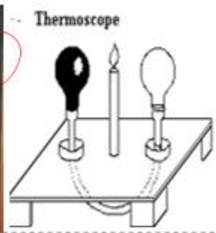




For two objects the identical mass and material, the object with the larger surface area emits or absorbs infrared radiation at a higher rate and the surface temperature. The higher the temperature of an object relative to the surrounding temperature, the higher the rate of emission of infrared radiation. Some of the examples let us take some of the examples the atmosphere would be the basic example the atmosphere is heated by radiation from the sun the atmosphere exhibits convection as hot air near the equator rises, producing winds and finally, there is a conduction between the air molecules and a small amount of air land conduction. A good example would be heating a tin can of water using the Bunsen burner. Initially, the frame produces the radiation which heats the tin can the tin can then transfer the heat to the water through the conduction, and the hot water then rises to the top in the convection process.

Heat transfer examples: Differential air thermoscope

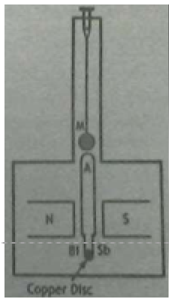
- A thermo scope is a device for detecting and displaying temperature changes.
- It consists of identical glass bulbs A and B which are connected to narrow U-shaped glass tube.
- The tube is filled with sulfuric acid and the space above acid levels in both the arms is filled with air.



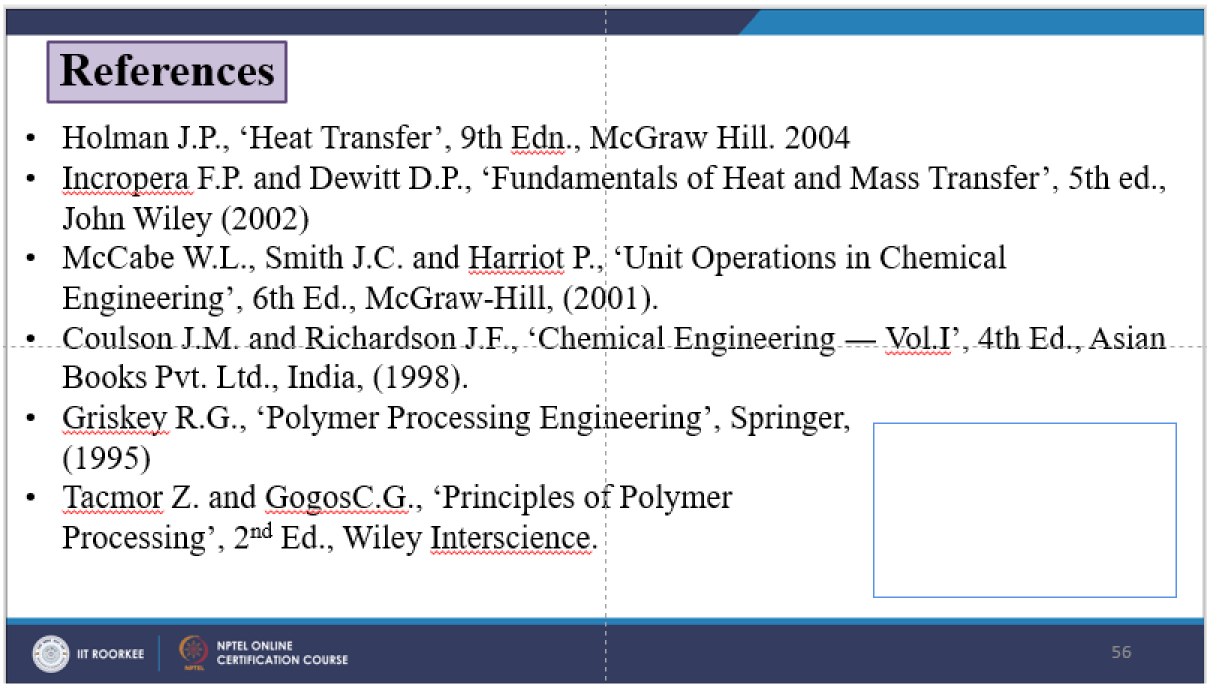
Now differential air thermoscope is usually a device for detecting and displaying temperature changes, and it is essential when we talk about polymer processing where melting, etcetera is important. Now, it consists of identical glass bulbs A and B here you see which are connected to the narrow U-shaped glass tube. The tube is filled with sulphuric acid and space above the acid level and both arms is filled with air. Now bulb A is cooled with the lamp black so that it may completely absorb the heat radiation falling on it when the temperature of the two bulbs is the same, there is no difference in the acid level when the A is bulb A is exposed to heat. It absorbs heat and air in this arm expand resulting in the difference of acid level. Boy's radiometer is the combination of a moving coil galvanometer and a thermocouple it consists of a single loop of silver or copper wire here this is on the lower ends of the wire they are soldered to a copper disc which is coated with a lamp black.

Heat transfer examples: Boy's radiomicrometer

- It is a combination of moving coil galvanometer and a thermocouple. It consists of a single loop of silver or copper wire A.
- The lower ends of the wire are soldered to a copper disc which is coated with lamp black.
- When disc is exposed to heat radiations, a thermo-electric current is produced in the couple made of Bismuth and Antimony and begins to flow in the wire A.
- Hence, we get a current in the galvanometer. The deflection shows the amount of radiation.



So, when the disc is exposed to heat radiation, a thermoelectric current is produced in the couple made of bismuth and antimony and begins to flow in a wire A here. Hence, we get a current in the galvanometer, and the deflection shows the amount of radiation. So dear friends, in this particular segment, we discussed the different types of heat transfer, basically the fundamentals of heat transfer and different modes of heat transfer with the example and the knowledge about this is quite essential for further reading in terms of when we discuss about the heat transfer aspect and heating of all these kinds of the polymeric system.



For your convenience we have enlisted a series of references which can be utilized if you wish to have further reading. Thank you very much.