Basics of Mechanical Engineering-3

Prof. J. Ramkumar

Prof. Amandeep Singh Oberoi

Department of Mechanical Engineering

Indian Institute of Technology, Kanpur

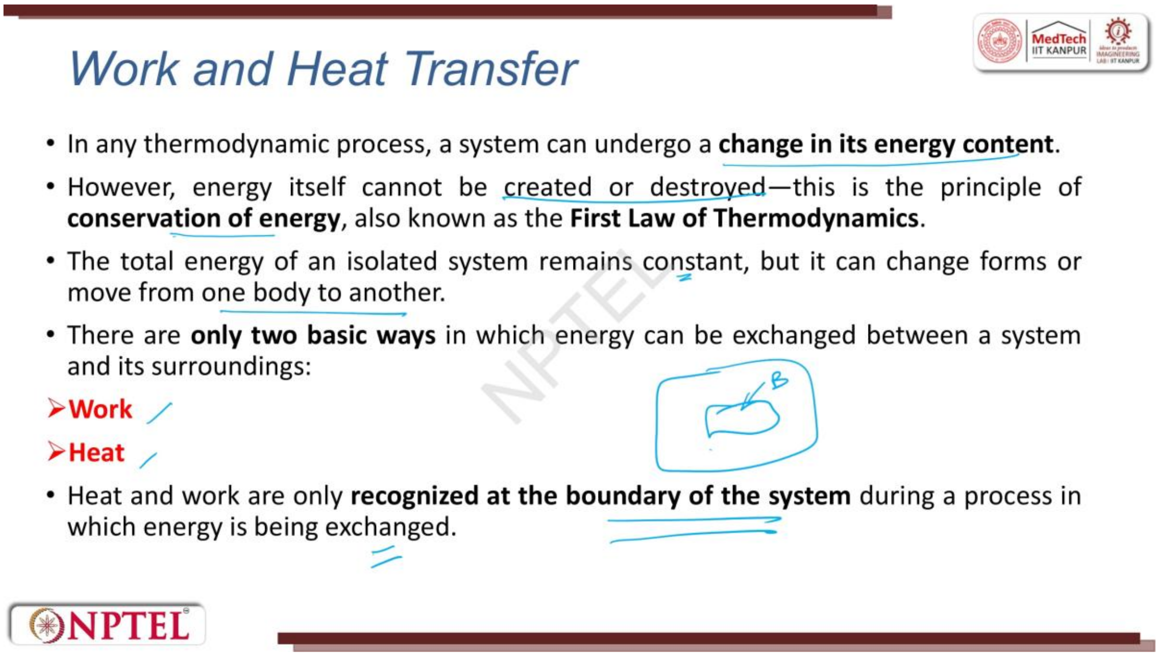
Week 02

Lecture 06: Basic Laws of Thermodynamics (Part 1 of 5)

Friends, let us move to the next lecture. In this lecture, we will explore the Basic Laws of Thermodynamics. So, when you talk about thermodynamics, there is only heat, work, and energy. So, it keeps revolving around the same thing. Maybe you will examine a cycle, or you will study a law, or you will explore some applications.

So, fundamentally, it revolves around it because we have understood state properties, paths, path functions, then we examined cycles, and then we studied PV diagrams and TS diagrams. So, that is all there is to it. So, it just revolves around it, but with a little more understanding at every level.

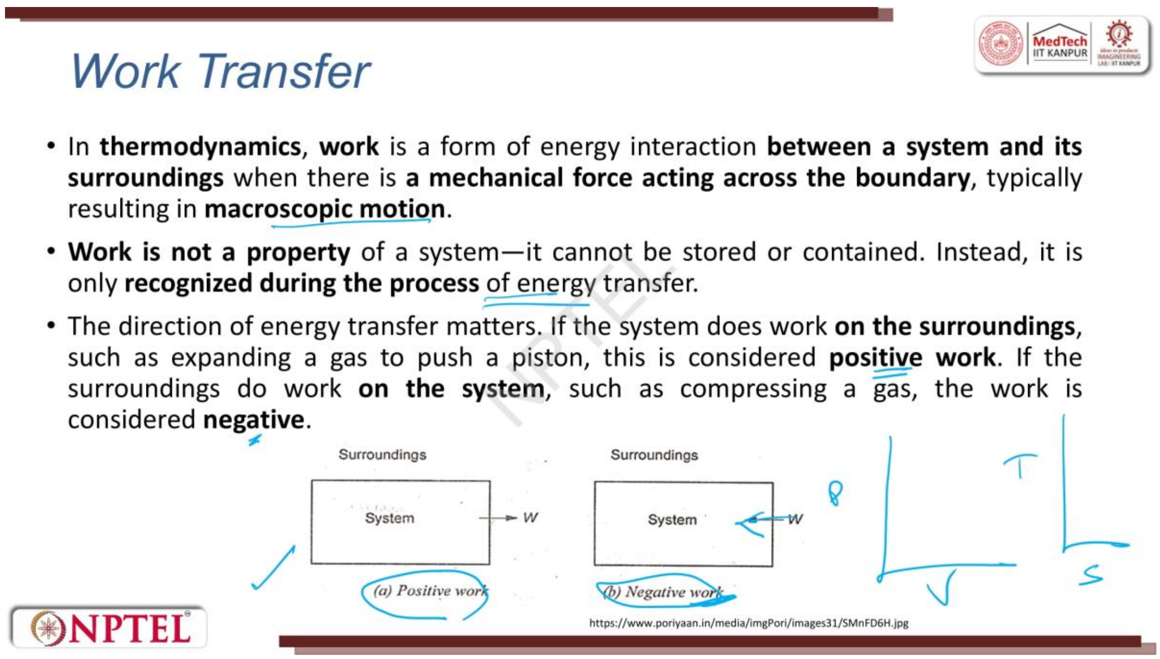
So, in this lecture, we will delve a little deeper into work and heat transfer. First, we will examine work transfer, followed by heat transfer, and then latent heat transfer. If time permits, we will try to solve some problems during the lecture or in the tutorials.



In any thermodynamic process, a system can undergo a change in its energy content. However, energy itself, as you know very well, can neither be created nor destroyed. It can only be converted from one form to another. So, this is the principle of conservation of energy, which is otherwise called the first law of thermodynamics.

The total energy of an isolated system remains constant, but it can change form or move from one body to another. For example, I have a hot body. I am touching it with a cold body. There can be a difference in temperature. They will try to find the gradient and, with respect to time, it tries to normalize, right?

Both become the same temperature. So, there are only two basic ways in which energy can be exchanged between a system and its surroundings. It can be either work or it can be heat. Heat and work are only recognized at the boundaries of the system. Boundaries of the system, surrounding, system, boundary—this is the boundary. Recognized at the boundary of the system during a process in which energy is exchanged. It can be ice kept here, surrounded by ambient temperature, so you can see at the boundary what is happening.



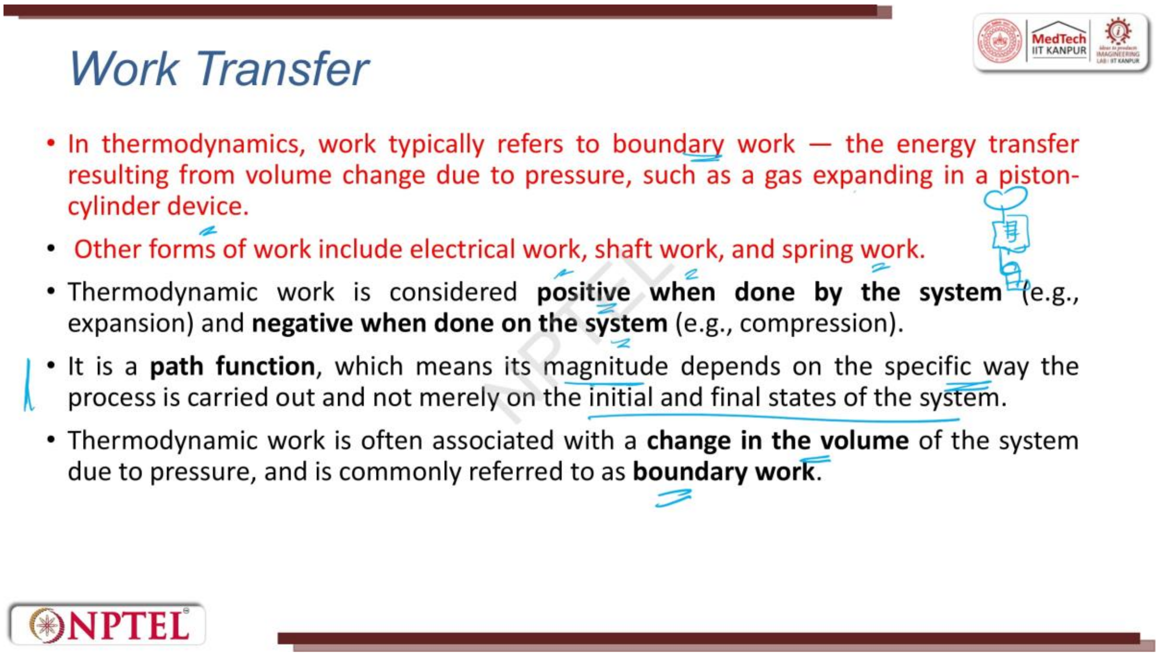
Work transfer. In thermodynamics, work is a form of energy interaction between a system and its surroundings. When there is a mechanical force acting across the boundary, typically resulting in macroscopic motion. Friends, work is not a property of a system. It cannot be stored or contained.

Instead, it can only recognized during the process of energy transfer. Now, you should be very clearly distinction. You will see energy can neither be created nor be destroyed. This is a principle of conservation of energy. Now, let us look at work.

Work is not a property of a system. It cannot be stored or contained. Instead, it can only be recognized during the process of energy transfer. The direction of energy transfer matter. The direction, in which the energy transfer happens. If the system does work on the surrounding, such as expanding a gas to push piston, It is considered as positive work. When the system does something and throws it into the surrounding, so it is said as positive work.

If the system does work on the surrounding, AC unit does something and give a comfort to the surrounding. So, the system does work on the surrounding such as expanding a gas to push a piston. It is considered as positive work. If the surrounding to do work on the system, and it is on the system such as compressing a gas, the work is said to be considered as negative work. Now, friends, you can go back and see your PV diagram or your TS diagram.

You can see where positive work happens and where negative work happens.

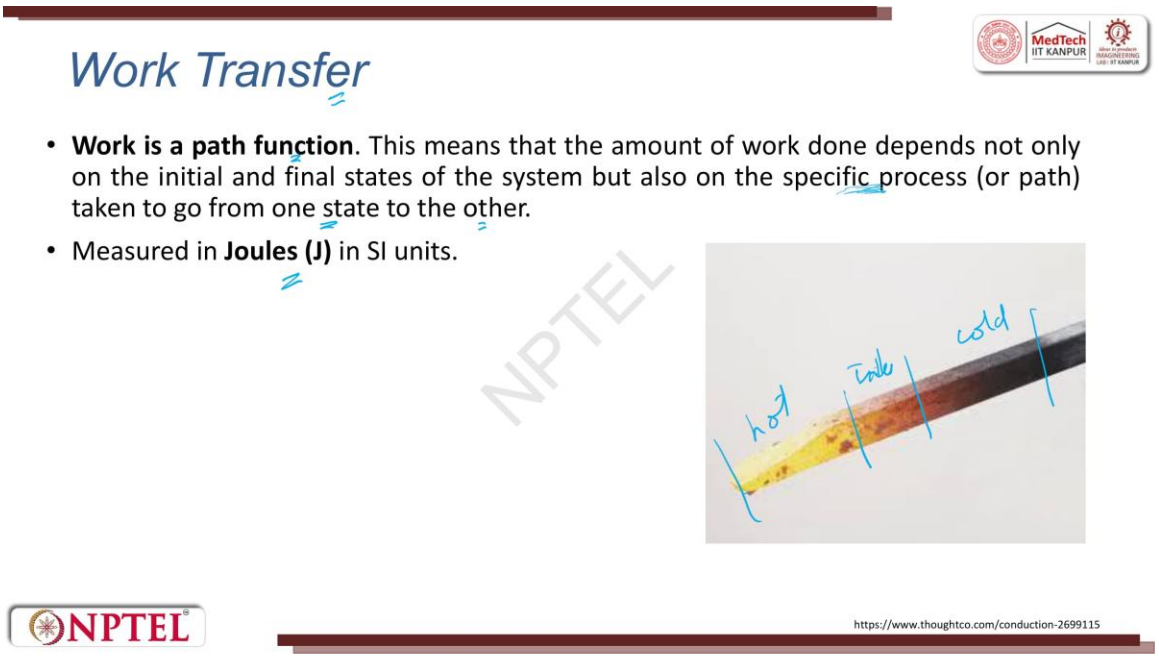


In thermodynamics, work typically refers to boundary work. The energy transfer results from volume change due to pressure, such as gas expanding in a piston. The energy transfer results from volume change due to pressure. You compress gas, heat gas, and it expands, such as gas expanding in a piston-cylinder device.

Other forms of work include electrical work, shaft work, and spring work. Spring work is what I was trying to talk about yesterday with the spring balance. You have this thing and then you have a hook. So, you have a hook where you put the weight, right? There is a graduation, and this graduation reduces. So, other forms of work include electrical work, shaft work, and spring work.

Thermodynamic work is considered positive when done by a system and negative when done on the system. So, I have compared expansion and compression. It is a path function, which means its magnitude depends on the specific way the process is carried out and not merely on the initial and final states. Please note down this point. It is a path function.

Work transfer is a path function, which means its magnitude depends on the specific way the process is carried out and not merely on the initial and final stages of the system. Thermodynamic work is often associated with the change in volume of the system due to pressure, and it is commonly referred to as boundary work. So, it is predominantly compression or expansion. Thermodynamic work is often associated with a change in volume of a system due to pressure. Work transfer.



Work is a path function. This means that the amount of work done depends not only on the initial and final stages of the system but also on the specific process or path taken to go from one state to another. Work is always measured in joules. So, you have a hot rod. So, you can see this portion is hot, this portion is in transition, and this portion is cold.

I will say intermediate. And this is hot. Right. So, this means that the amount of work done depends not only on the initial and final stages of the system but also on the specific process or path taken to go from one state to another, which is also defined as work in a path function.

Work Transfer

Infinitesimal Work (Differential Form):

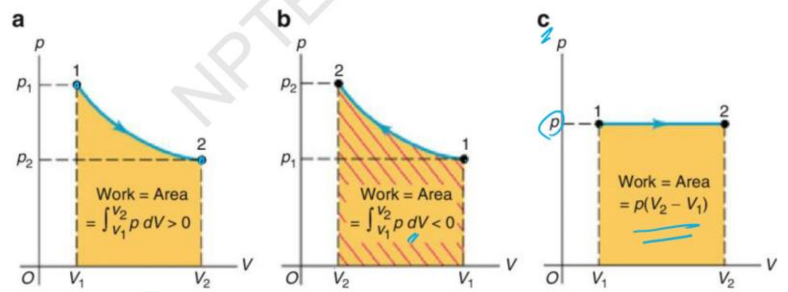
When a system undergoes a small change in volume *dV*, and the pressure at the boundary is P_{ext} (external pressure), the infinitesimal amount of work δW done by the system is:

$$\delta W = P_{ext} \cdot dV$$

This form assumes the process is **quasi-static**, i.e., it proceeds infinitely slowly so that the system remains in equilibrium at every stage.

Work Transfer

- **If V2>V1** (expansion):
  - W>0 The system **does positive work** on the surroundings.
- **If V2<V1** (compression):
  - W<0 The surroundings **do work** on the system.



https://studfile.net/html/2706/320/html_fFdTQevyfo.Vjul/htmlconvd-2PkDtk_html_18fb7e25c3bbf5ab.png

When it is infinitely small work or in differential form. When a system undergoes a very small change in volume which is dV and the pressure at the boundary is P_{ext}, the infinitesimal amount of work

$$\delta W = P_{ext} \cdot dV$$

So, dW is the change in work done, external pressure P_{ext} and dV is the change in volume. This form assumes that the process is quasi-static. Static is permanent, quasi-static is in between, right?

And dynamic is the other extremity. This form assumes the process is quasi-static. That is, it proceeds infinitely slow so that the system remains in equilibrium at every stage. When a system remains in equilibrium at every stage, it is called as quasi-static. It proceeds infinitely slow so that the system remains in equilibrium at every stage.

So, slow moving is quasi-static. So, this is infinite simile work. The other one is integrated form. Integrated form is for a finite volume change, when the volume is very small right, when the finite volume change happens. To calculate the total work done over a change in volume from V1 to V2, we integrate W which is volume from V1 to V2 times P_{ext} into dV.

So, now, you see the difference. When it is very small, the delta work is equal to P exit $\delta W = P_{ext} \cdot dV$ When it is a finite change in volume, W equals integration from V1 to V2 of P exit into dV. To calculate the total work done over a volume change from V1 to V2, we integrate the differential volume. This equation represents the area under the PV curve. What is a PV curve?

We studied it. A PV curve can be like this. Something like this, right? You can take a PV curve. I'm just giving a very, very idealistic case or just an example. So, the area under the curve in a PV diagram.

So, this is called the integrated form for a finite volume change. So, this is what you can see here. So, when the work is done on the gas. The work is done by the gas, right? So, if it is work done on the gas, dV is less than 0.

When dV is greater than 0, you see this. So, minus P dV is equal to W when work is greater than 0. When work is less than 0, we get this form. Where did this negative come from? If you refer to my previous lecture, you will see where this negative came from.

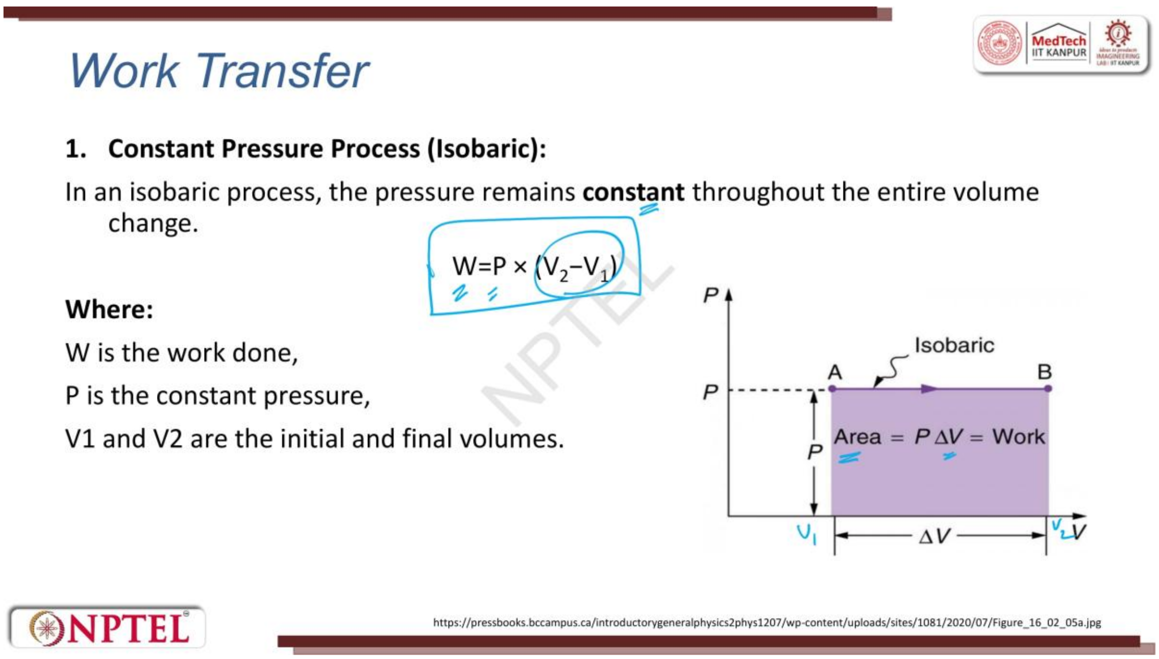
So, this diagram clearly shows what is the work done on the gas and what is the work done by the gas. When is dV less than 0, and when is dV greater than 0?

If V2 is greater than V1, it is expansion. So, the work will be greater than 0. The system does positive work on the surroundings.

When V2 is less than V1, it is compression. So, the work done will be less than 0. The surroundings do work on the system. So, when I try to go back and look into that integrated form, P1 to P2, right? So, this is P versus V. So, P1 and P2 are the initial and final pressures.

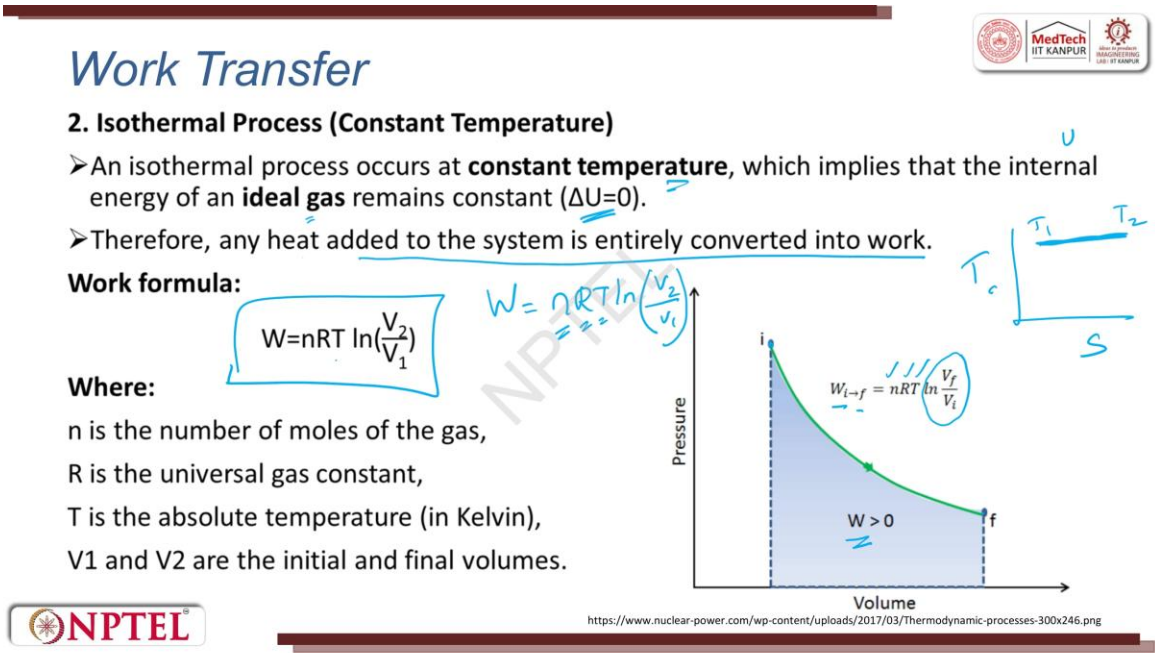
So, if the pressure is very high and it is trying to expand with respect to volume, the pressure falls down, and the volume expands. So, it is called expansion. So, the work is equal to the area integral from V1 to V2: P times dV, which is greater than 0. When it goes into compression, from V1 to V2, the pressure changes from P1 to P2, so the work done is equal to the area, and you get V1 to V2, P with a small delta V, which is always less than 0. So, if you want to represent it in C, we can try to see that P, you try to draw V1 to V2. So, at constant pressure, it expands by volume, the pressure is constant, then the work is equal to the area, which can be represented as P times V2 minus V1.

So, when we try to have a constant pressure, right? So, the work transfer. So, it is interesting. We saw V2 greater than V1, V2 less than V1, right?



Then, we are now trying to see a constant pressure process. What is a constant pressure process? You might know it is isobaric. In an isobaric process, the pressure remains constant throughout the entire volume change. W = P x (V2 - V1), where work done is W, pressure is constant, and V1 - V2 is initial to final or final minus initial. So, when we try to plot a PV diagram.

So, V on the x-axis is delta V, which is a change. So, we can try to take V1 and V2. So, delta V is the change from V1 to V2, and then the pressure, which is maintained constant from A to B. So, the area is going to be P times delta V, which is equal to the work. Delta V is V2 minus V1. So, this is what it is: V2 minus V1.

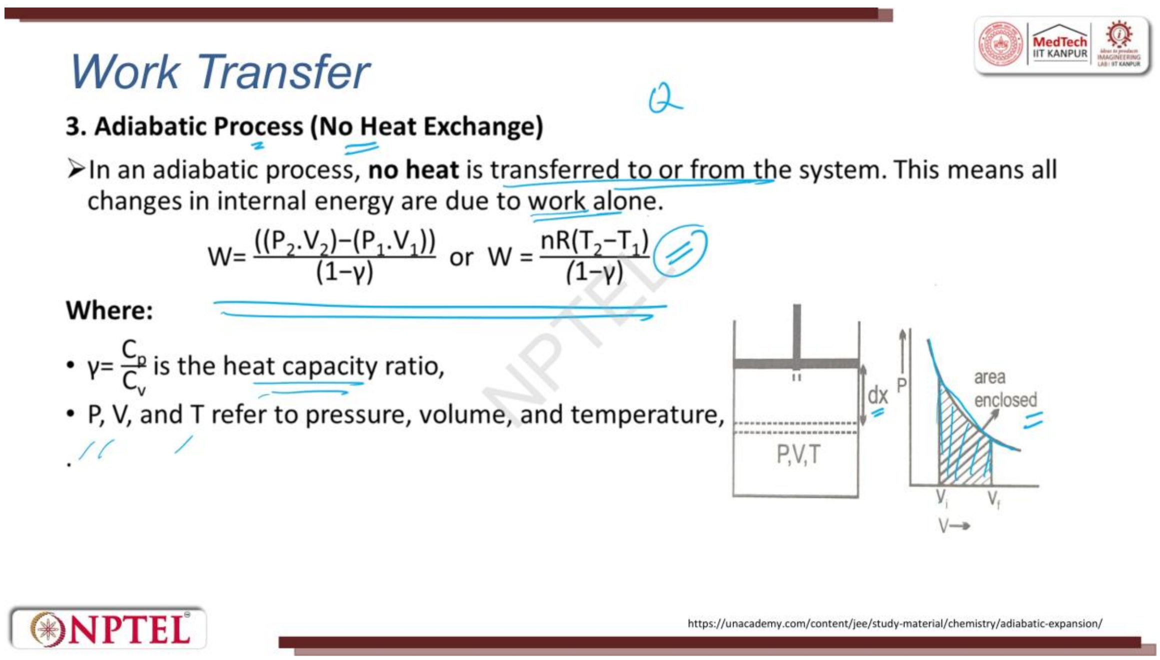


Then we have an isothermal process. What is an isothermal process? The temperature is constant. So, how can I represent a constant temperature in a PV diagram? You cannot. So, what you do is you have a TS diagram.

In this diagram, the temperature will be constant. It can be T1 to T2, right? In a TS diagram, where S is entropy and T is temperature. In a PV diagram, when it is drawn for an isothermal process with a constant temperature, we represent it like this. So, an isothermal process occurs at a constant temperature, which implies that the internal energy of an ideal gas remains constant.

Delta U is constant. Internal energy is represented as U. Therefore, any heat added to the system is entirely converted into work. The heat which is added to the system is entirely converted into work. So, the formula for this is going to be $W=nRT\ln(\frac{V_2}{V_1})$

What is n? n is the number of moles of the gas, where R is the universal gas constant, T is the absolute temperature, and V2, V1 are the volumes. So, now you see for an isothermal process, how do you represent the work formula? If you go back, you see for isobaric, how do you represent the work formula? Right. So, when you look at the pressure versus volume diagram, when you are trying to move from initial to final, then nRT, which is mole constant temperature, into natural logarithm of Vf by Vi. So, it is this. So, this is the area under the curve where the work is greater than 0.



Now, let us try to take an adiabatic process and see the work transfer. In adiabatic, there is no heat exchange. You remember the adiabatic cube, right?

In an adiabatic process, no heat is transferred to or from the system. So, there are only two things. You push into the system or take from the system. So, there is no heat transfer. This means all changes in internal energy are due to work.

If you look at the previous one, you can see that the heat added to the system is entirely converted into work. If you see here, all changes in internal energy are due to work alone. So, here it can be represented as

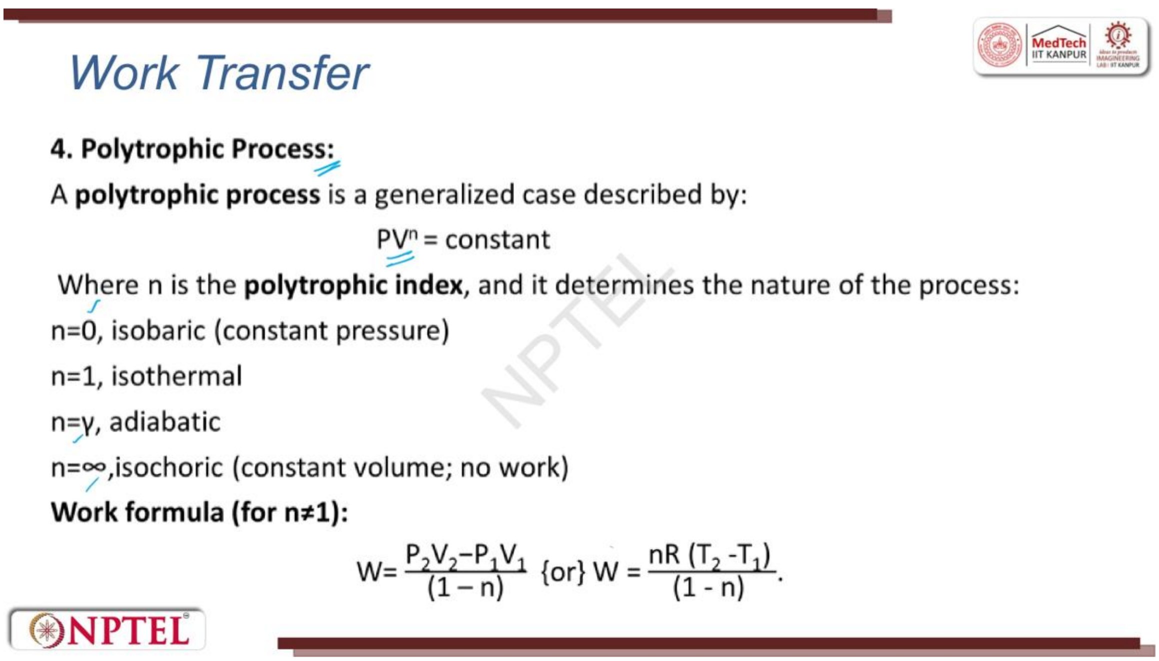
$$W = \frac{((P_2.V_2)-(P_1.V_1))}{(1-\gamma)} \text{ or } W = \frac{nR(T_2-T_1)}{(1-\gamma)}$$

This, $\gamma = \frac{C_p}{C_v}$ which is the heat capacity ratio. Where P, V, and T are pressure, volume, and temperature.

So, this is P1, V1, T1. There is a delta exchange, right? So, it becomes P2, V2, T2, right? When temperature is constant, then T2 becomes T, as both T values are equal. So, when it goes from P1, V1, T1, when it expands by delta X, this is what it is.

And when we try to plot it with a PV diagram, we see there is a curve. When it is expanded, moves from here to here, there is expansion which is happening. So, this area which falls below this curve is called as area enclosed. So, here, the work transfer is represented by this way. So, for adiabatic process, we have seen, for isothermal process we have seen and for a constant pressure also we have seen.

So friends, you have three processes. For a constant pressure process, how do you calculate the work? For isothermal process, how do you calculate the work? And for adiabatic process, how do you calculate the work?



Now, let us try to understand for a polytrophic process. Polytropic process is generalized case described by PV^n = constant, where n becomes 0 when you put isobaric, when n becomes 1 if you put isothermal, when n = γ is adiabatic, when n = infinite is a constant volume process which is called as isochronic process. So, the work formula for n which is not equal to 1. So, when it is not equal to 1, it can be 0, it can be γ, it can be infinite. So, then it is represented as

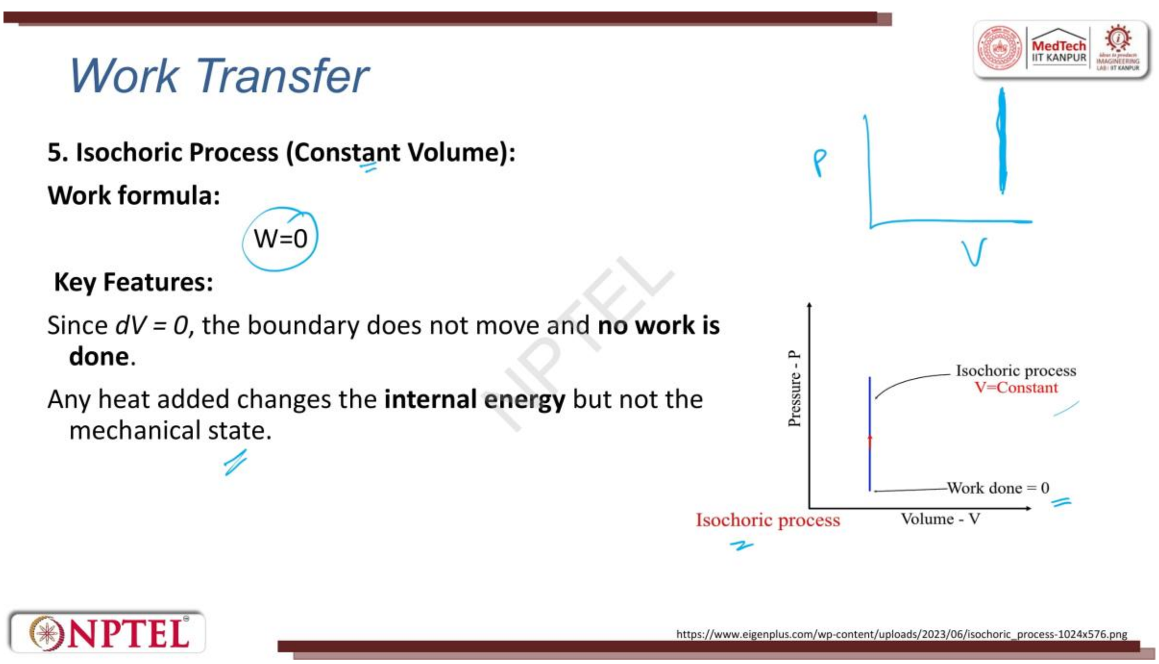
$$W = \frac{P_2V_2 - P_1V_1}{(1-n)}$$

What is n? n is these values which you take and if you go in the previous n, it talks about the number of moles of the gas, right?

So, here if n is not equal to 1, then we represent it like this, or we would like to redefine this properly, move left and right and all. So,

$$W = \frac{nR\,(T_2 - T_1)}{(1 - n)}.$$

It is almost the same. You see here. How did we get it? So, this is for a polytropic process.



In an isochoric process, when the work volume PV equals the PV diagram and the volume is constant, it goes like this. So, there is no change in pressure; volume is constant. Whatever you do, volume is constant. So, in an isochoric process, the constant volume process, the work formula is W equal to 0.

So, since dV = 0, the boundary does not move and no work is done. So, any heat added changes the internal energy but not the mechanical state. So, it is pressure versus volume, so it is a constant volume process; this is how you draw it. So, in an isochoric process, the work done will be equal to 0. So, if you look into it, everywhere the work done you can try to find out, so this is the area enclosed, right. So, in an isochoric process, the work done will be 0; no work is done.

Work Transfer

Process Type	Condition	Work Expression	Real Example
Isobaric	Constant pressure	$W = P(V_2 - V_1)$	Boiling water at atmospheric pressure
Isothermal	Constant temperature	$W = nRT \ln\left(\frac{V_2}{V_1}\right)$	Gas expansion with heat exchange
Adiabatic	No heat exchange	$W = \frac{P_2V_2 - P_1V_1}{1 - \gamma}$	Rapid air compression in engines
Polytropic	PV^n = constant	$W = \frac{P_2V_2 - P_1V_1}{1 - n}$	Compressors, real gas systems
Isochoric	Constant volume	$W = 0$	Gas in sealed rigid container

So, this is a table of comparison for various processes, conditions, expressions, and real-time examples. So, in an isobaric process, which is a constant-pressure process, the formula for work done is $W = P(V_2 - V_1)$ So, it is used in boiling water at atmospheric pressure. You keep a pan, pour water in it, and heat it from the bottom, right?

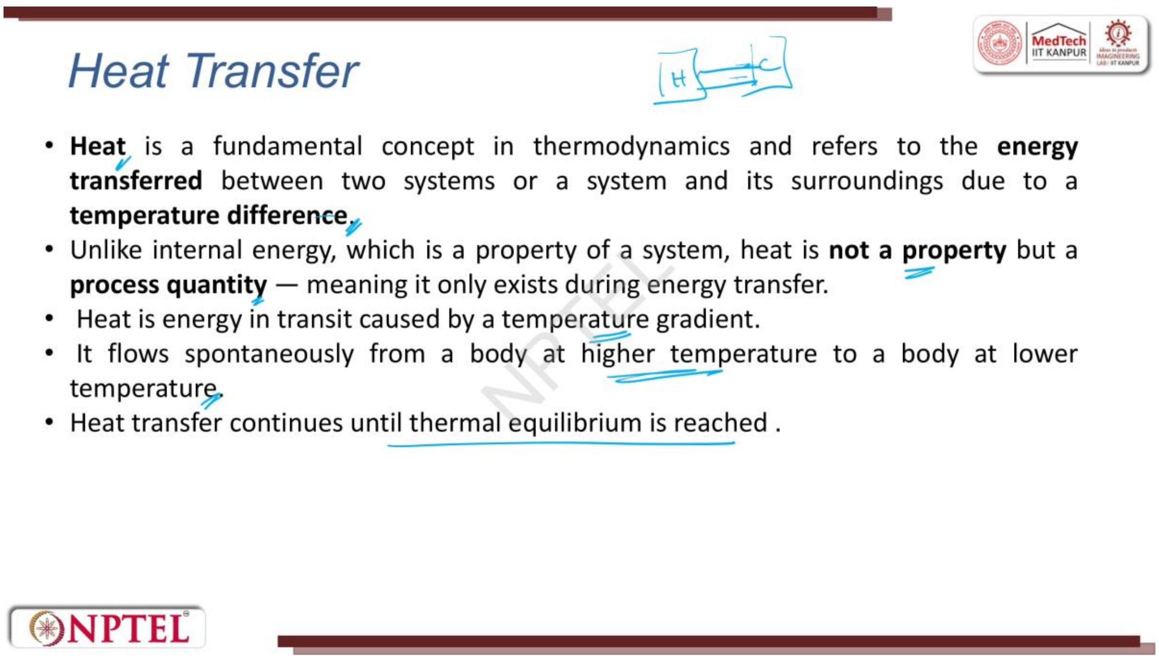
The boiling water at atmospheric pressure, so V2 - V1. An isothermal process, which is a constant-temperature process, has $W = nRT \ln\left(\frac{V_2}{V_1}\right)$ So, here, the temperature is maintained constant. So, gas expansion with heat exchange follows this isothermal process. When we talk about an adiabatic process, there is no heat exchange.

So, the formula is $W = \frac{P_2V_2 - P_1V_1}{1 - \gamma}$ So, it is used in rapid air compression in engines. When you compress engines, like IC engines, rapid air compression happens.

Polytropic is PV^n = constant where this gamma is replaced by an N. So, it is used in compressor, real gas systems, we always use polytropic process. Process type is polytropic. Condition is this, expression is this and real time example. When it is isochronic process, it is constant volume. So, where W is equal to 0, so the gas in sealed rigid container if it is there is a typical example for isochronic process.

Isochronic process you saw here, the work, there is no work done by the system. So, here any heat added changes the internal energy but not the mechanical state. So, till now what we saw was only work transfer. So, I told you in the beginning itself. Here, if you see there are only two basic states.

One is work transfer. The other one is heat transfer. We have studied about the work transfer. Now, let us move to Heat Transfer.

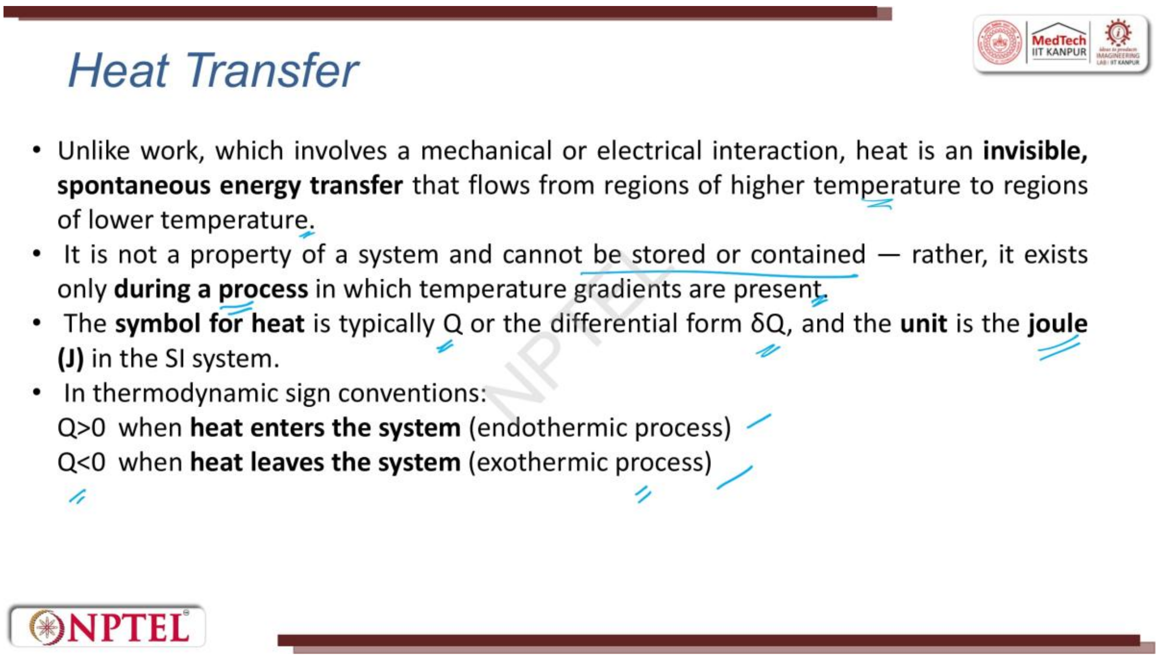


Heat is a fundamental concept in thermodynamics and referred to energy transfer between two systems or a system and its surrounding due to its temperature differences.

Heat is a fundamental concept, right? So, the energy transfers between one system and another when they are close by or between a system and its surroundings. Unlike internal energy, which is a property of a system, heat is not a property but a process quantity. Friends, please try to understand the difference between a property of a system and a process quantity. Heat is energy in transit caused by a temperature gradient.

When there is a hot body and a cold body, there is a connection. Then, we will try to see that heat is energy in transit caused by a temperature gradient. It flows spontaneously from a body at a higher temperature to a body at a lower temperature—hot to cold. The heat transfer continues until thermal equilibrium is reached. Once thermal equilibrium is reached, then everything stays the same; nothing more happens. So, heat is a thermodynamic concept.

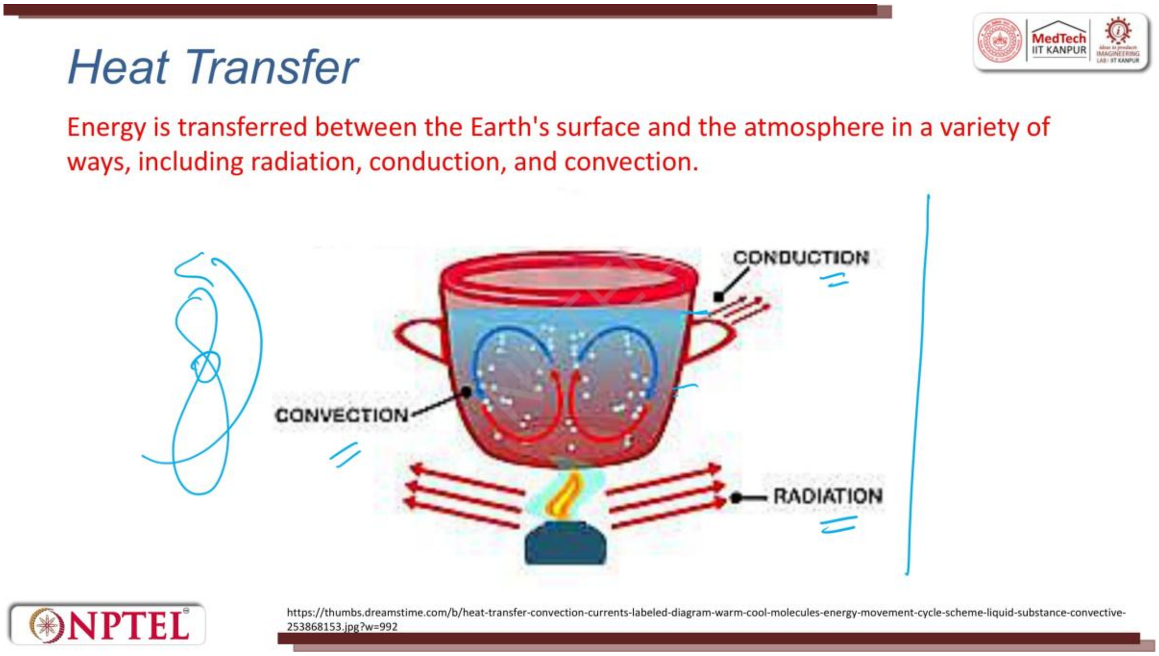
It is an energy transfer between a system and its surroundings. It is due to a temperature difference. So, it is a process quantity. These are important terminologies that you should know.



Unlike work, which involves mechanical or electrical interaction, heat is an invisible, spontaneous energy transfer that flows from a region of higher temperature to one of lower temperature.

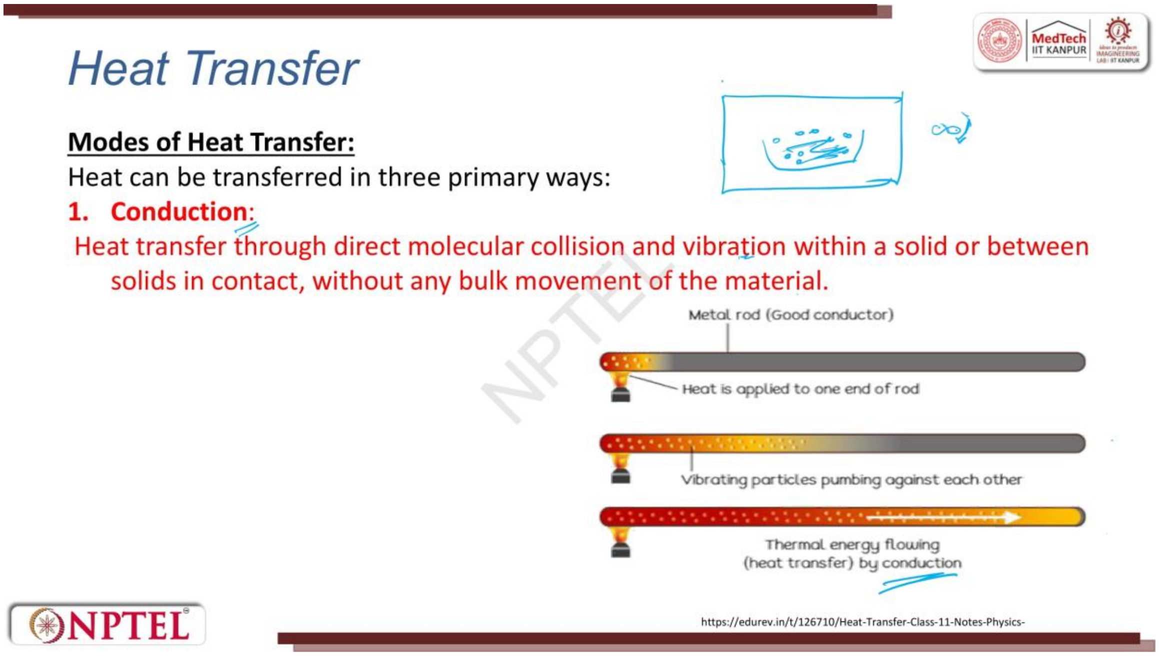
Friends, look at the difference between work. Unlike work, which involves mechanical or electrical interaction, heat is invisible. You cannot see the heat—it is an invisible, spontaneous energy transfer, like radiation, that flows from a region of higher temperature to lower temperature. It is not a property of a system and cannot be stored or contained; rather, it exists only during a process in which temperature gradients are present. The symbol for heat is Q, typically; the differential form is delta Q, and the unit will always be joules. In thermodynamic sign convention, when Q is greater than 0—when heat enters the system—it is an endothermic process.

When Q is less than 0, the heat leaves the system, which is an exothermic process. So, endothermic, exothermic. Exothermic means heat is rejected. Heat leaves the system. Heat enters the system. Endothermic. So, there are two sign conventions.



When we talk about heat transfer, the energy is transferred between the Earth's surface and the atmosphere in a variety of ways, including radiation, conduction, and convection. Convection can also be forced convection. So here, you keep a pan filled with water and heat it from the bottom.

So, from the heat, there is radiation. Because of this heat, there is conduction, because when you touch the top side, there is heat present, which is conduction. And when the handles become hot, it is conduction, and what happens inside this circle is convection. So, convection happens because there is a difference in temperature. This difference in temperature tries to create a swirling action. So, that is called convection.

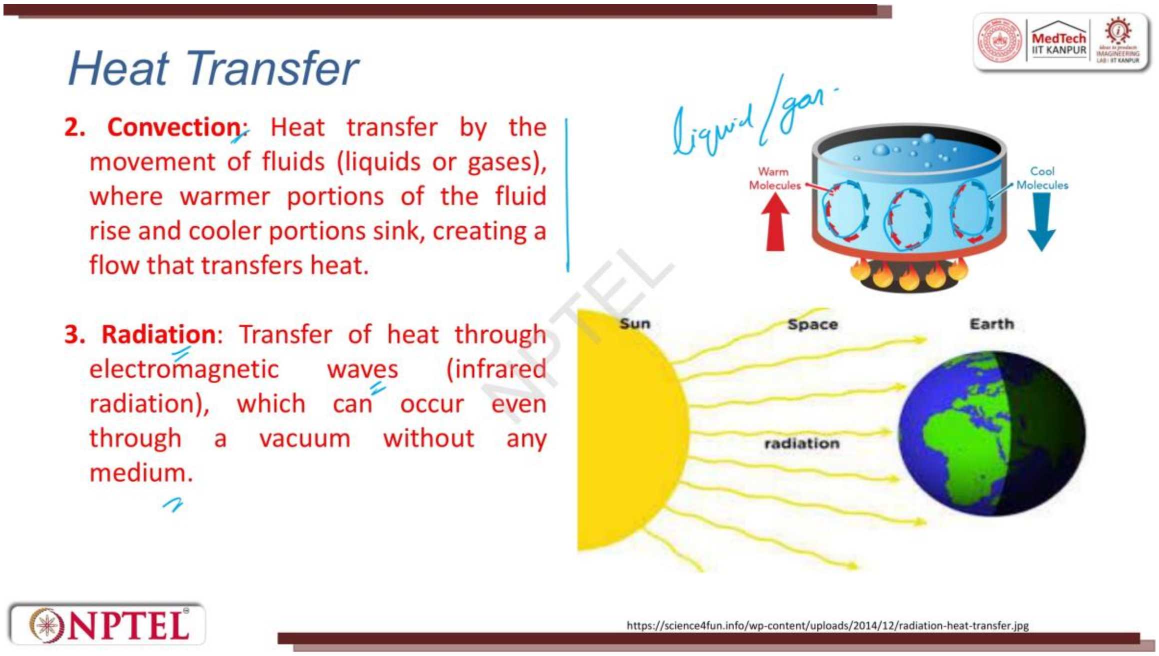


The modes of heat transfer include three different types. So, heat can be transferred in three primary ways. One is conduction. The heat transfer through direct molecular collision and vibration within a solid or between solids in contact, without any bulk movement of the material, is called conduction. Right. Without any bulk movement.

So, if you observe this vibration, it is interesting. When you look at a microwave oven in use, when you switch it on and have a vessel filled with water and some rice particles or something, right. So, now what is happening is, as the microwave interacts with the water, the water molecules, which are dipoles, respond. These dipole molecules rattle and vibrate. When they rattle and vibrate, they create friction. Friction is converted into heat, and that is how it works.

So, why am I trying to tell you this story? It is because vibration in molecular collision and vibration is quite common when heat is present. So, there are bonds, and they will hold onto each other. There is a lot of heat, and now this fellow will have a small instability; they will start vibrating. So, that is what it is. So, you have a metal rod, which is a good conductor. The heat is applied from one end.

So, now, they vibrate. So, because of the vibration of the particles, the heat moves from one point to the other. So, the vibrating particles bump against each other, right? Bumping against each other or vibrating with a bond which is restricted, they vibrate. So, then what happens? The energy flows from the hot end to the cold end; that is conduction.



What is radiation? The transfer of heat through electromagnetic waves, infrared radiation, which can occur even through a vacuum without any medium, is radiation. So, radiation does not need a medium. It can happen through a vacuum also. So, the sun radiates heat on the earth; that is radiation. The transfer of heat through electromagnetic waves.

So, from here also, if you see electromagnetic waves, heat. Transfer of heat through electromagnetic waves, which can occur even through a vacuum without any medium, is radiation. The most interesting part is convection. Convection is nothing but heat transfer by the movement of fluid. The fluid can be liquid; the fluid can be gas.

Where the warmer portion of the fluid rises, the colder portion sinks down. Thus, creating a flow reaction—there is a flow. There is a flow. So, cold molecules come down; hot molecules go up. So, it does not go just like that.

So, when it moves, it moves like a wall. Right. And this can be larger or smaller. So, the heat transfer by the movement of media. So, suppose you have a room inside a room; you put a fan.

Right. And you have a very hot heat radiation that is coming. Assume a cold winter day. On a cold winter day, there is a radiator kept inside your room, and it radiates. Then, you want to uniformly distribute the radiation inside the room.

So, what you do is turn on a fan. That tries to move the hot air and push it toward the cold air. The cold air gets circulated and comes back. That is convection.

Heat Transfer

Specific Heat:

- **Specific heat** is a fundamental property of matter that describes a substance's ability to absorb heat.
- It is defined as the **amount of heat required to raise the temperature of one unit mass of a substance by one degree Celsius (or one Kelvin)** without a change in phase.
- This concept is essential in thermodynamics because it determines how different materials respond to the addition or removal of heat and plays a critical role in thermal energy calculations, heating and cooling processes, and the design of thermal systems.
- It is the amount of heat required to raise the temperature of unit mass of a substance by unit degree.

Heat Transfer

For Solids and Liquids

$$c_p = c_v = c$$

For Gases

c_p – specific heat capacity at constant pressure

c_v – specific heat capacity at constant volume

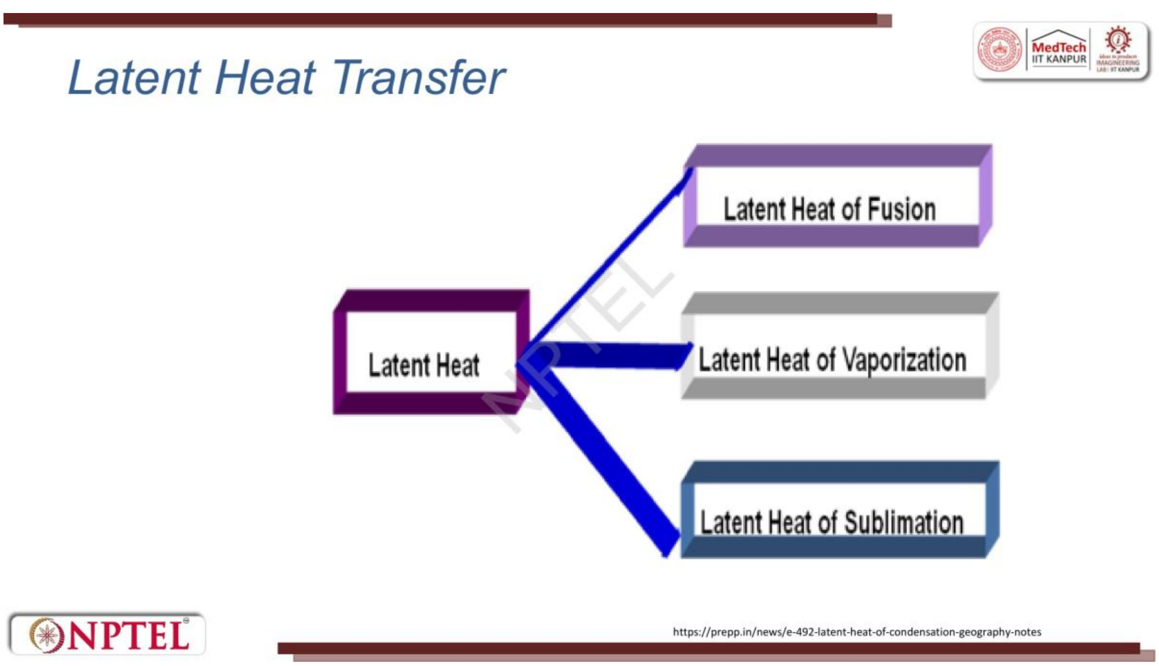
Latent Heat:

- It is the amount of heat transferred to cause a phase change.
- Units: Joules (J) or sometimes kJ/kg for specific latent heat.
- Represents the energy needed to **break or form molecular bonds**

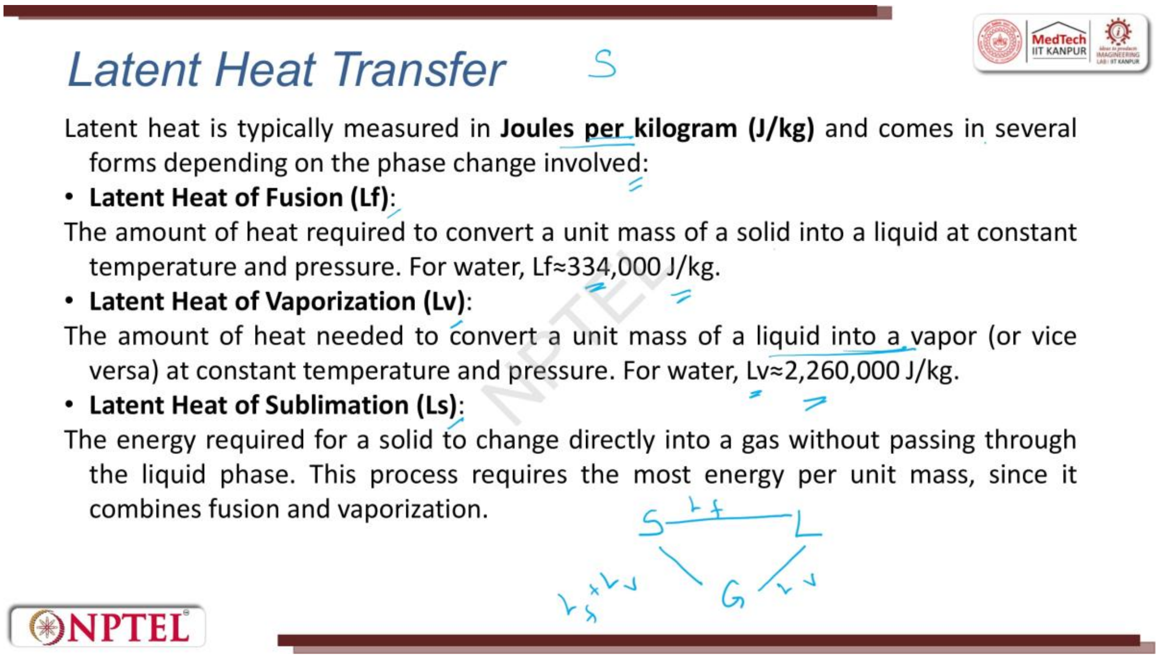
So, the most important terminology in heat is always specific heat. It is a fundamental property of matter that describes a substance's ability to absorb heat. If the specific heat is high, it can absorb more heat; an object or material with high specific heat. It is defined as the amount of heat required to raise the temperature of 1 unit mass of a substance by 1 degree Celsius or 1 Kelvin without any phase change, called specific heat. So, heat divided by unit degree. The concept is essential in thermodynamics because it determines how different materials respond to the addition or removal of heat and plays a critical role in thermal energy calculations, heating and cooling processes, and the design of thermal systems. So, the amount of heat required to raise the temperature of a unit mass of a substance by 1 degree is specific heat.

The specific heat is Cp. For a solid and a liquid, Cp = Cv = C, whereas for a gas, Cp is the specific heat capacity at constant pressure, and Cv is the specific heat capacity at constant volume, right? Cp, Cv. For a solid or liquid, Cp = Cv = C. So, there is another term called latent heat. It is the amount of heat transferred to cause a phase change.

The amount of heat required to raise the temperature of a unit mass of a substance by 1 degree without a change in phase is specific heat. It is the amount of heat transferred to cause a phase change, which is latent heat. The unit is joules. Sometimes, it is kilojoules per kg for specific latent heat. This represents the energy needed to break or form molecular bonds. So, latent heat is very much required to break or form molecular bonds. If you want to machine a polymer, we will always try to break the molecular bonds, right? So, latent heat is very important.



So, latent heat transfer can again have three classifications, like you see here: Cp, Cv, specific heat capacity at constant pressure, and specific heat capacity at constant volume. So, latent heat is latent heat of fusion, latent heat of vaporization, and latent heat of sublimation.

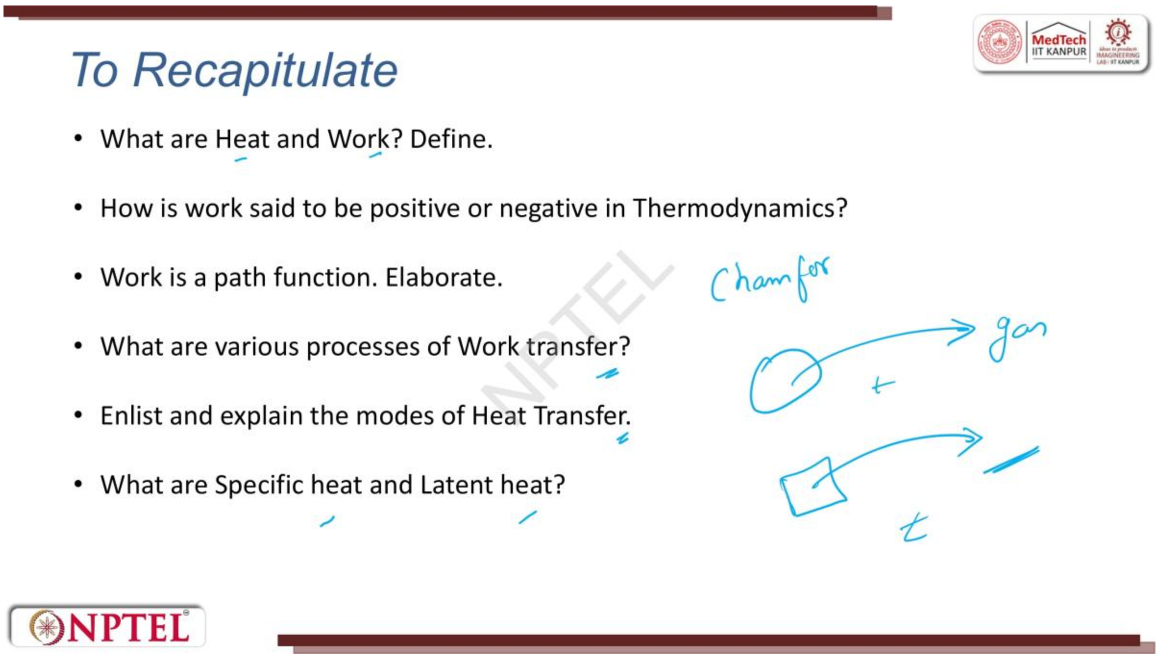


Latent Heat Transfer. The latent heat transfer, as I told you, has three categories: Lf, Lv, Ls. So, the latent heat is represented as joules per kg, and it comes in several forms depending on the phase change involved. So, the heat of fusion is the amount of heat required to convert a unit mass of a solid to a liquid, which is the latent heat of fusion. When we do casting, when we melt ice, or when the ice at the North Pole melts, it is the latent heat of fusion. The amount of heat required to convert a unit mass of a solid into a liquid at a constant temperature and pressure is given.

So, the latent heat of fusion for water is 334,000 joules per kg. When we talk about latent heat of vaporization, it is the amount of heat required to convert a unit mass from a liquid into a vapor. From solid into liquid, it is heat of fusion. From liquid into vapor, it is called latent heat of vaporization or vice versa at a constant temperature and pressure. For water, the latent heat of vaporization (Lv) is 2,260,000 joules per kg.

Watch out the numbers. Then, latent heat of sublimation is the energy required for a solid to directly convert into a gas without passing through a liquid phase. The process requires the most energy per unit mass, since it combines latent heat of fusion and vaporization. So, it is very simple: you have a solid phase, a liquid phase, and a gaseous phase. Solid to liquid is Lf; liquid to gas is Lv.

From here to here, it is Lf + Lv. That's all. So, latent heat of fusion, latent heat of vaporization, and latent heat of sublimation.



So, friends, in this lecture, we tried to see the basic difference between heat, work, and temperature. We saw the definition. We saw when the work is said to be positive.

When is the work said negative in thermodynamics. We saw work is a path function. We saw various types of work transfer. We saw various types of heat transfer. Then we try to see specific heat and Latin heat.

Okay. So, now, let us try to have some examples or exercise for ourself. Take camphor. So, solid camphor and it gets converted into gas. Try to see what time it takes to get converted from a solid to gas, or you can try to take naphthalene ball, very small, have a large surface area, very small volume.

You see what is the time it takes to get transferred. Then, you try to take ice and then try to see a normal ice at room temperature. How much time does it take to get converted into gas into a liquid cup, complete liquid? Right. Now, with this time factor you have note. So, now you go back to your Latin heat of fusion, Latin heat of vaporization, Latin heat of sublimation, and try to understand time against this, so that you try to have a feel for it. And again, if you note down I have reported it with huge values with respect to kgs.

So, whatever you have taken. Maybe few grams from that if you try to transfer and find out what is the latent heat of fusion and that will be nice exercise for you. So, we also saw in this convection radiation which we discussed in last lecture also and we did some I gave you some examples. In the same example, can we try to have a fan which rotates at certain rpm? Okay, let us do that exercise once again. You take 1 liter pan and fill it up with water.

Try to heat it. Try to reduce the water to half of it. Note down that time. Now, you try to allow it to come to room temperature. Next, what you do is for the same setup, when you reduce from 1 to half, then you try to blow air on top of it.

Now, see, how much time does it require to come to room temperature. Now, what are you trying to do? You are forcing some media and trying to improve the convection and see what is the influence of forced air on it. The third one what we will do is, we try to take the same one liter to bring it to half a liter, and then try to keep this pan inside one more beaker of water where in which there the temperature of the water is 25 degrees. See, how much time will it take to come down to room temperature inside the vessel.

So, when you do this exercise, you will try to understand what the influence of the surroundings is on your convection, conduction, and radiation.

References

1) Patrick Chassaing. 2023, Fundamentals of Fluid Mechanics: For Scientists and Engineers, Springer.
2) Younus A. Çengel, Michael A. Boles, Mehmet Kanoğlu, 2023, Thermodynamics: An Engineering Approach, McGraw Hill Education.
3) Frank M White, 2017, Fluid mechanics, McGraw Hill Education
4) R. Fletcher, 2000, Practical methods of optimization, Wiley
5) John D. Anderson, *Computational Fluid Dynamics: The Basics with Applications*, McGraw Hill Education, 1995.
6) Frank P. Incropera, David P. DeWitt, Theodore L. Bergman, Adrienne S. Lavine, *Fundamentals of Heat and Mass Transfer*, Wiley, 2017.
7) M. J. Moran, H. N. Shapiro, D. D. Boettner, M. B. Bailey, *Fundamentals of Engineering Thermodynamics*, Wiley, 2020.

So, while preparing this lecture, we have used a lot of references. So, these are the references which were predominantly used. With that, I would like to conclude this lecture.

Thank you so much.