Basics of Mechanical Engineering-3

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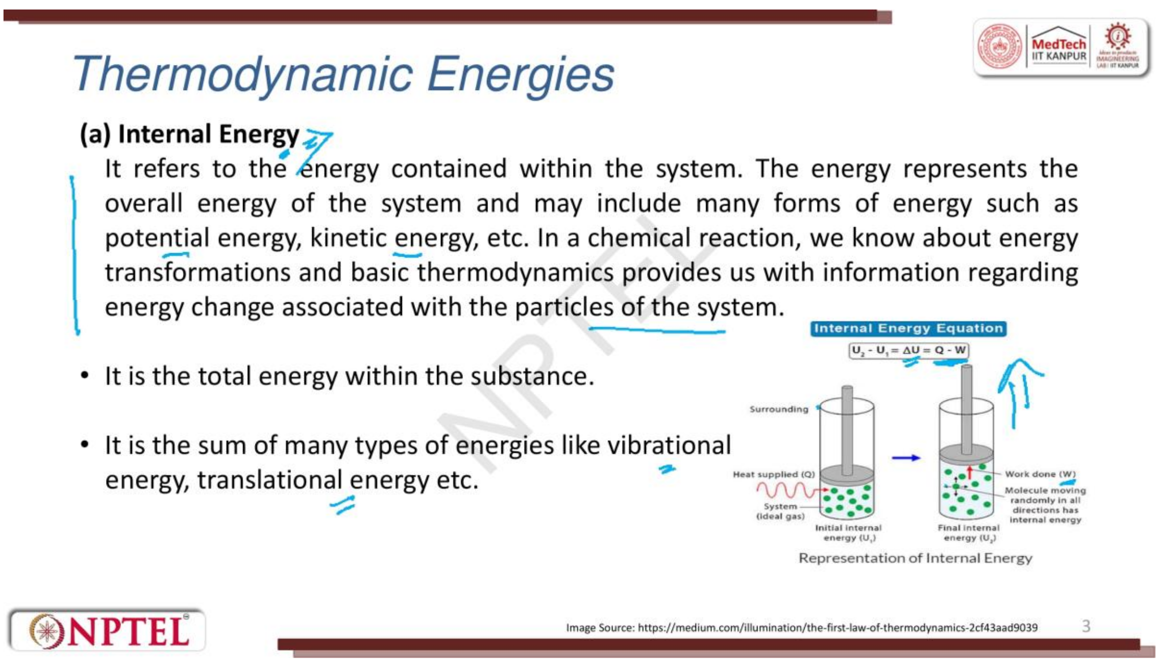
Week 01

Lecture 03: Thermodynamic Energies

Welcome to Part 3 of Introduction to Thermodynamics. This lecture will be the basis for the rest of the course. Part 1 and Part 2 have covered some fundamentals. Now, with Part 3, you will have a summary of all the fundamentals related to the course. Now, let us explore the different types of energy.



So, internal energy. Internal energy refers to the energy contained within the system. I am bubbling with energy to do this job. It's my capability. This is internal energy.

So, it refers to the energy contained within the system. The energy represents the overall energy of the system and may include many forms of energy, such as potential energy, kinetic energy, etc. So, it also includes exothermic and endothermic reactions. In chemical reactions, we learn about energy transformations, and basic thermodynamics provides information regarding the energy changes associated with the particles of the system. So, internal energy is the energy contained within the system.

So, for example, you have a cylinder and a piston. So, this is the surrounding outside. So, you apply heat. When you apply heat, the system—ideal gas, whatever is there—starts expanding. Energy gets into it, and it starts expanding.

The moment it starts expanding, you can see the piston moving in the upward direction. So, now here, if you see the surrounding, you have a glass jar, then ideal gas is filled. So, here the internal energy is U1. So, when you heat it, it becomes the final internal energy U2. So, W is the work done, which is trying to push the piston up.

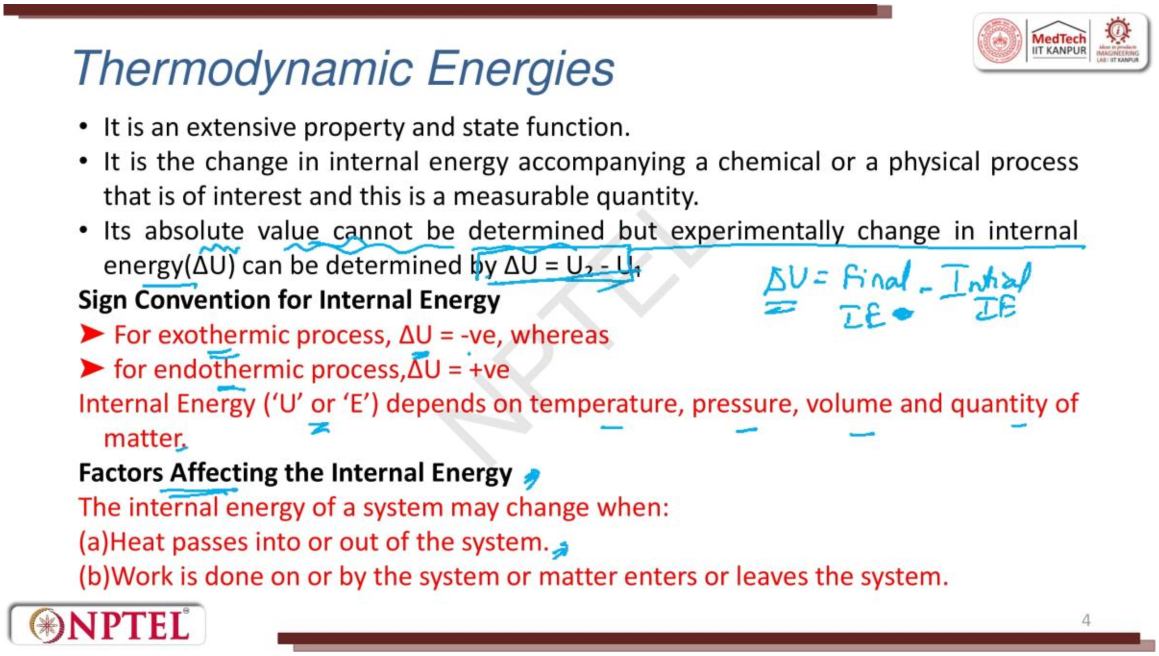
So, what is the work done? So, the difference—the final minus initial—is nothing but the difference in internal energy, which is nothing but Q minus the work done. So, the work done is W. So, when you try to heat it, the molecules move randomly in the direction and have internal energy. So, it moves left and right, up and down, and then slowly the piston is pushed upward. So, internal energy is the amount of energy contained within the system.

The energy represents the overall energy of the system, which includes potential energy and kinetic energy. It is the total energy within the system. That is internal energy. It is the sum of many types of energies, like vibrational energy and translational energy. So, all these things contribute to internal energy.

It is very important. Internal energy. What is the energy present within the system that enables the job to be done? For example, think of an IC engine. In an IC engine, what happens?

You have a cylinder, a petrol engine. You have a cylinder. Now, you compress and push the air-fuel mixture inside. You have a spark plug. This spark plug ignites.

So, there is an explosion. So, there is heat being generated. The moment heat is generated, the piston goes up. The moment the piston goes up, it is connected with a link, which in turn is connected to the engine, and now the vehicle moves. So, that is what we are trying to discuss here. So, that is Q - W.



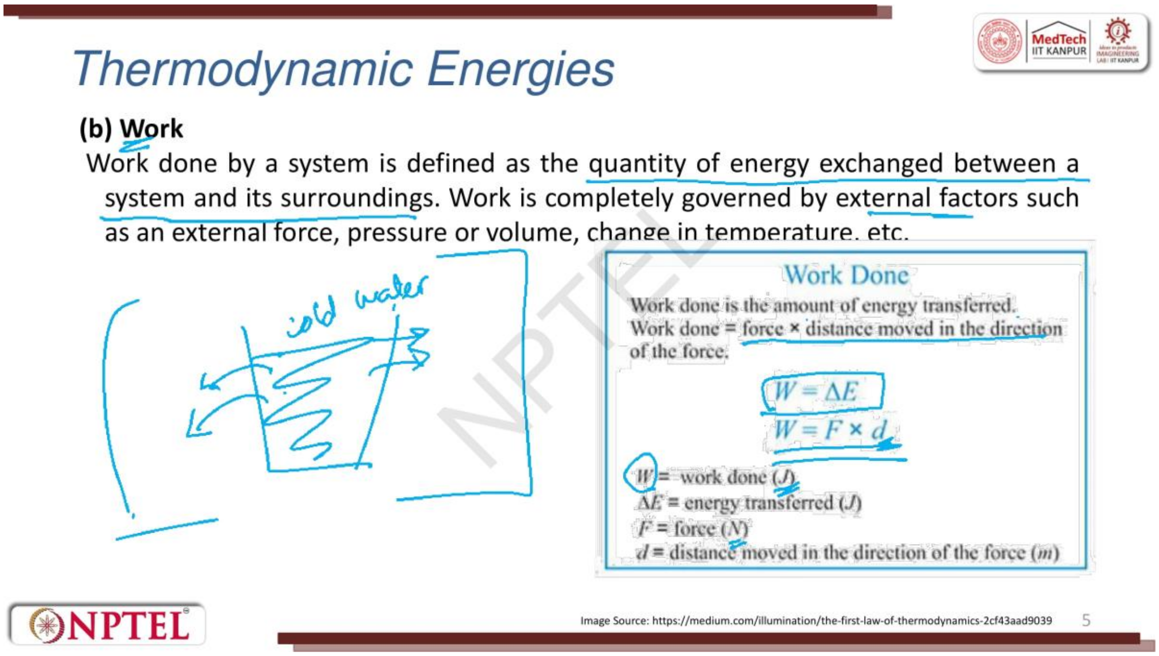
So, it is an extensive property and a state function. It is the change in internal energy accompanying a chemical or physical process that is of interest, and this is a measurable quantity. Its absolute value cannot be determined, but the experimental change in internal energy can be determined as this. So, its absolute value cannot be determined. Please underline: its absolute value cannot be determined.

But experimentally, the change in internal energy can be determined by this equation. Is that clear? The absolute value cannot be determined, but experimentally, you can get it done. So, the sign convention for the internal energy: exothermic, endothermic. Exothermic is when the reaction happens, it releases heat.

That is exothermic. It ejects heat out. When you say endothermic, it absorbs heat. So, if it is exothermic, we always say ΔU. $\Delta U = U2 - U1$. So, if ΔU is negative, then it is called as exothermic. If ΔU is positive, then it is called as endothermic.

For example, when you try to have the toffees and then after having this toffee, when you suck air, you feel the coolness in your mouth. So, that is nothing but endothermic reaction. The internal energy U or E, it is directly depending on temperature, pressure, volume and quantity of matter. So, if the temperature is high, U changes. If the pressure which is applied is high, E changes, volume changes.

Then, quantity of matter also changes the internal energy. The factors which are affecting the internal energy is the heat passes in and out of the system, tries to change.



The work is done on or by the system or a matter enters or leaves the system is a factor which affects the internal energy. So friends, I have introduced path function. First I introduced state function, then I talked about path function. Then in path function it is very clear, initial final state alone it does not depend, but also it depends on the path of the process which is followed.

Then, we got into Thermodynamic Energies. The first energy what we saw was internal energy. Internal energy is the capability of a system to do something, right? It refers to the energy contained within the system. So, here you can have potential energy, kinetic energy, vibration energy, translation energy, many things, right? So, when we try to talk about these energies, we also try to talk about how do you measure these energies, right?

So, this is what is given in the statement its absolute value cannot be determine. But experimentally change in internal energy A can be determined by A x U. So, it is basically U = U2 - U1 by A. So, you can try to figure out what is it right. Then, I introduced exothermic and endothermic. Exothermic is heat is getting rejected, so it has a value negative which is observed which is positive. And the last point is how does this internal energy change, which is quite natural, right?

When the rod is heated, it radiates, right? When the pan is heated, it radiates, right? When the pan is heated and you put milk, there is a chemical reaction. So, heat passes into or out of the system, then work done in or out of the system. So, now the next energy is Work.

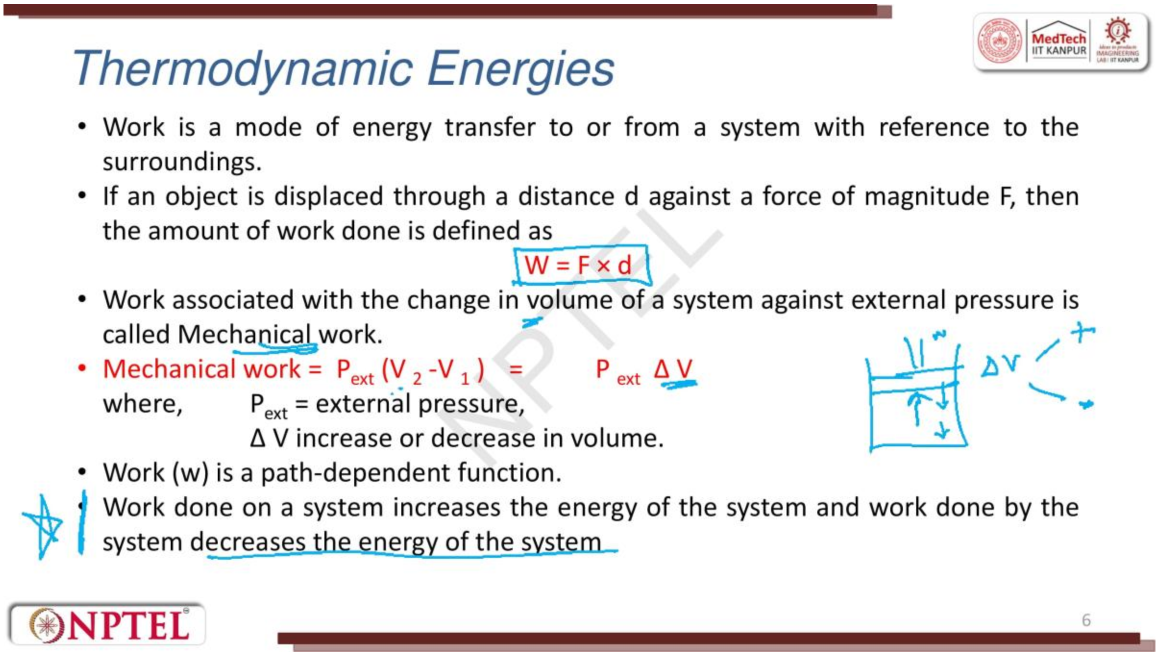
Work done by the system is defined as the quantity of energy exchanged between a system and its surroundings. If I release heat outside, that is work done. When I bring cold air inside, work is done. Work done by a system is defined as the quantity of energy exchanged between a system and its surroundings. If you want an example, this is a glass tumbler filled with cold water.

Now, when the exchange happens between the system and the surroundings, It is nothing but work. The work is completely governed by external factors. Suppose I place it inside a refrigerator and keep this glass; what will happen? The performance changes.

That is what I said. The work is completely governed by external factors such as external force, pressure, volume, change in temperature, etc. So, work done is nothing but the quantity of energy exchanged between the system and its surroundings. So, if you look into it, the units of work done are always joules, and if it is joules per second, then it becomes watts. So, the energy you apply to your house—when you install an energy meter and draw electricity into your house—we always measure the work done there, right?

The work done is nothing but the amount of energy transferred, which is nothing but force multiplied by distance, the distance moved in the direction of the force. So, W is nothing but ΔE. What is E? E is the internal energy. So, W can be defined as force multiplied by the distance moved in the direction of the force, $W = Fd$. The unit for force, the unit for work, is always joules.

So, ΔE, the energy transferred, is also in joules. The force is in Newtons, d is the distance, which can be in meters, millimeters, or microns; it is a linear scale. So, through this, what you are able to do is figure out how to calculate the work done, right? The work done is equal to ΔE.



Work is a mode of energy transfer to or from a system with reference to the surroundings. This is always compared to the surroundings.

If an object is displaced through a distance d against a force of magnitude F, then the amount of work done will be written as W = F x d. The work associated with the change in volume, if you go back to the piston example, you will see V1, V2, the change in volume, ΔV. The work associated with the change in volume of a system against the external pressure is called mechanical work. Suppose there is a piston with a dead weight; now you heat it, and the volume expands. So, ΔV is the change in the volume of the system against the external pressure. What is the pressure here? Here, it is nothing but the load, right, the piston load.

So, that is mechanical work. So, mechanical work = P_{ext} (V2 - V1) = P_{ext} ΔV. So, P exit is the external pressure, ΔV is the increase or decrease in the volume. You can have it vice versa; if you have a cylinder and then you have a piston which is very heavy in load. So, what happens?

Even though you try to expand, this piston's weight will be very high, it will try to slip down. So, what happens is the final volume ΔV can be positive, which means it can be V1 - V2 or it can be V2 - V1. So, you can try to have the positive value or negative value. So, that depends on ΔV, okay. So, the increase or decrease in the volume is possible.

The work is a path-dependent function. For example, when you apply a very heavy load, right, let us take a sponge inside a glass and have a piston. Now, you try to press it from the top. The volume is reduced. So, I am trying to give you an example such that you will appreciate volume can increase or volume can reduce.

So, it basically depends upon the energy that is there inside. The work is a path-dependent function. Work done on a system increases the energy of the system, and work done by the system decreases the energy of the system. Note it down. This is a very, very important term.

Work done on the system. Work done on the system increases the energy of the system. The work done by the system decreases the energy of the system. So, friends, you can sit down and try to make at least three examples for both these things. So, that can be a home assignment for you, so that you go back and refer or think further.

The work done on the system increases the energy by compressing. The work done by the system decreases the energy of the system. So, decreasing the energy means expansion, whatever you are doing.

Thermodynamic Works

WORK	GENERALIZED FORCE	EFFECT	EXPRESSION
Displacement Work (PV Work)	Difference in pressure	Change in volume (dV)	dW = P. dV
Mechanical Work	Difference in force	Change in position (dl)	dW = F. dl
Surface Energy Work	Surface tension (σ)	Change in surface area (dA)	dW = σ. dA
Electrical Work	Potential difference(V)	Change in amount of charge (dq)	dW = V. dq

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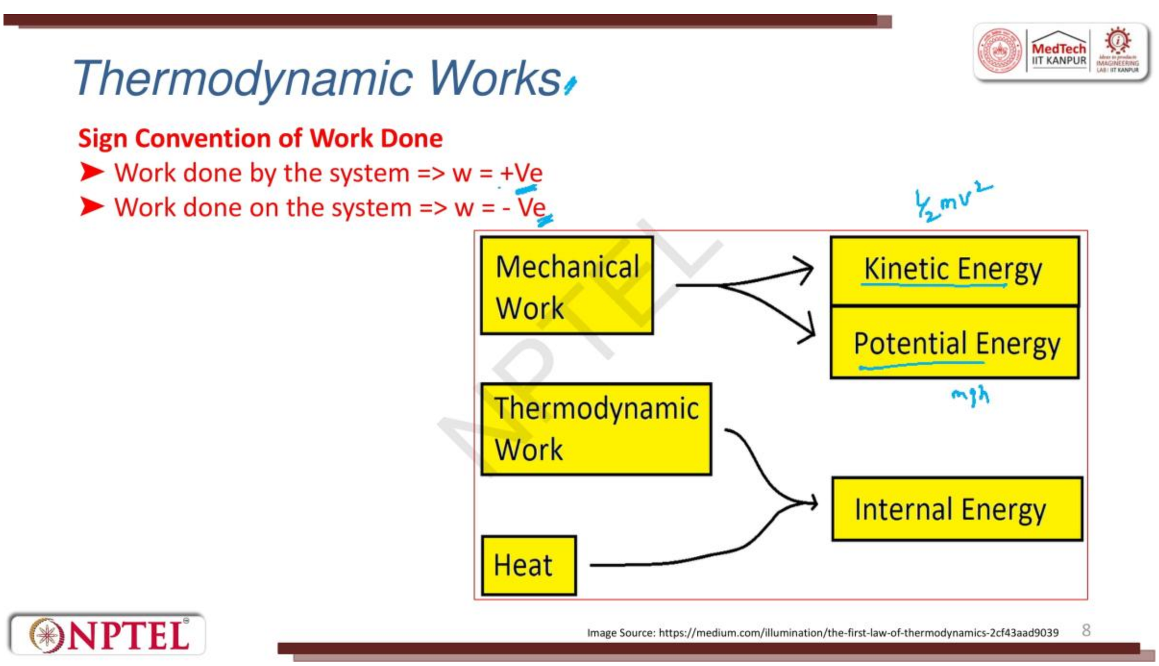
So, let us see the thermodynamic work. So, one is work: generalized force, effect, and expression. So, this will try to give you a formula-based understanding. Displacement work, which is the generalized force, is the difference in pressure. The effect is whether there is a change in volume, that is dV. So, the expression is going to be dW = P. dV. When we talk about mechanical work, it is the difference in force. So, here the change in position will be there, dl.

So, mechanical work will be dW = F. dl. The surface energy work is nothing but surface tension. So, the change in the surface area is dA. So, the work done will be dW = σ. dA. For example, you try to take a cup and keep it in the open atmosphere.

Now, what you do is take the same tumbler, glass, or paper cup and immerse it 20 feet down into water. You see the amount of pressure exerted on the surface. Now, it shrinks. Now, you go 100 meters down. It becomes a very small cup.

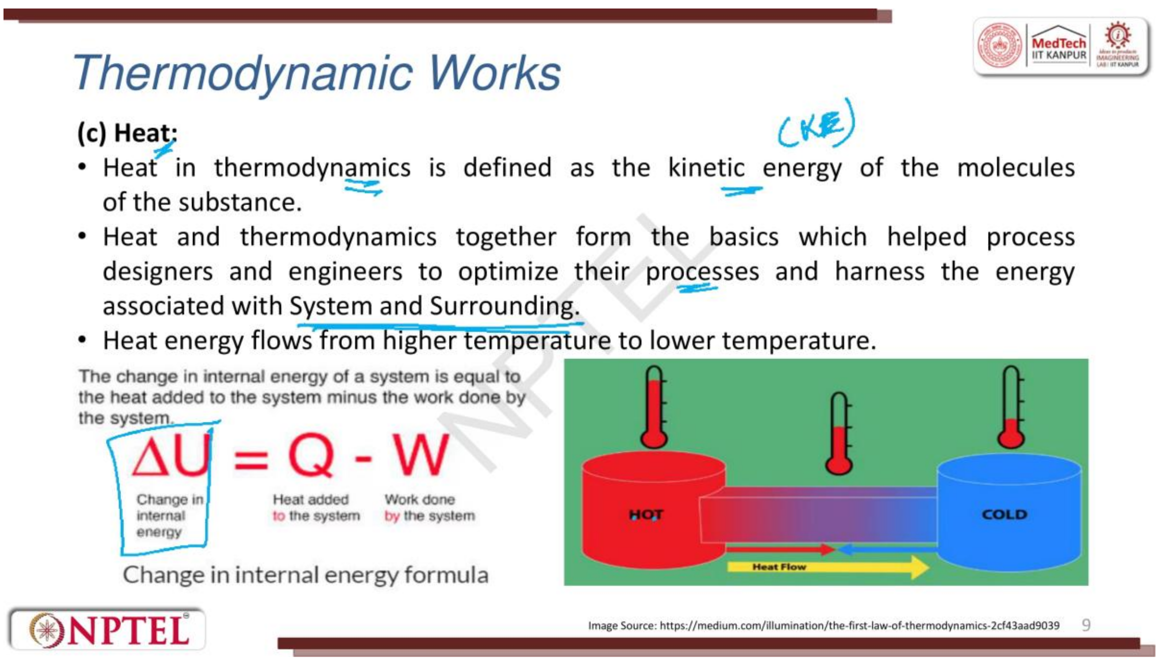
So, that is nothing but surface energy work. So, surface tension is σ. So, σ. dA. Now, electrical work is nothing but the potential difference voltage V, which is the change in the amount of charge dq. So, it is nothing but dW is equal to your potential difference.

Potential difference is nothing but voltage V2 - V1, higher voltage minus lower voltage—that is dW = V. dq. So, if you look at it, these are the expressions, and these are the work done, which is there in the diagram, which we have discussed till now.



So, in thermodynamics, work done has two conventions which we have to follow. The first convention is going to be: work done by the system, W, will be positive. When the work is done on the system, it will be negative.

Mechanical work has two energies: one is kinetic energy, and the other one is potential energy—kinetic and potential energy. So, potential energy is mgh. If you want to look at it from the design perspective, it is nothing but half mv squared. So, the thermodynamic work and heat put together affect the internal energy. Thermodynamic work, what we are seeing here—thermodynamic work and heat put together—gets into the internal energy of a system. So, the third work—thermodynamic work—the first thermodynamic work we saw was internal energy. We saw internal energy. Then, we saw what is work. Then, work we had seen the formulas.

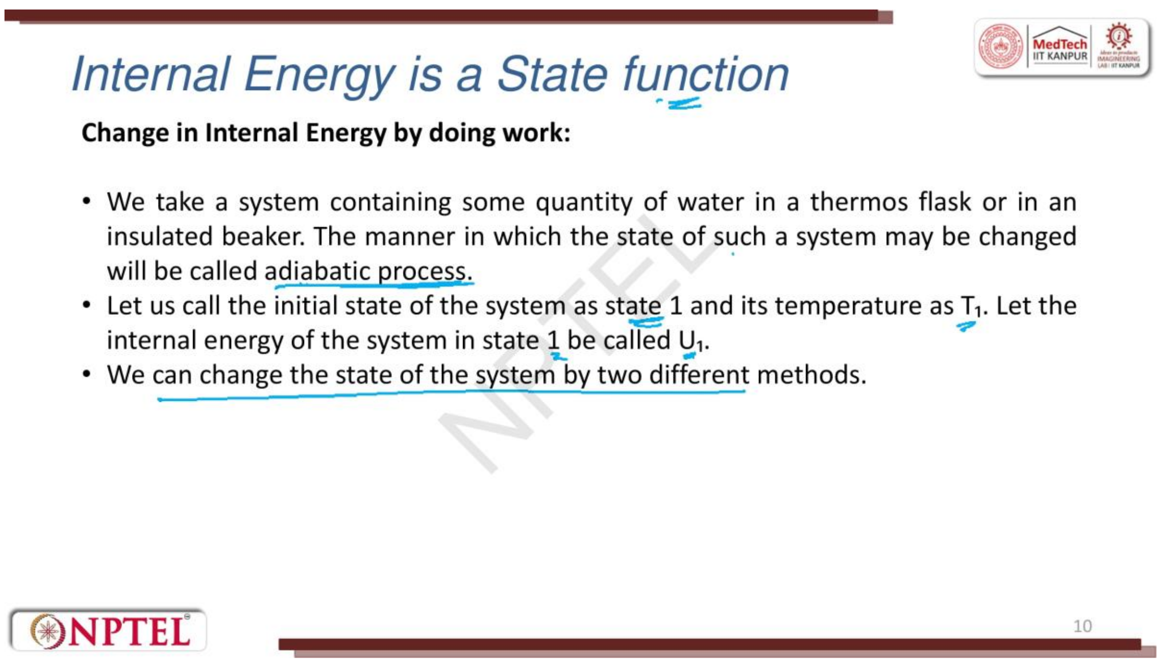


Now, we are going to see the third one is nothing but Heat. What is Heat? Heat in the thermodynamics is defined as a kinetic energy of the molecules of a substance. Heat in thermodynamics is defined as the KE (kinetic energy) of the substance. Heat and thermodynamics together forms the basis which help processes designer and engineer to optimize their process and harness the energy associated with the system and surrounding. Very, very important term. Heat and thermodynamics. We have studied what is thermodynamics.

Heat and thermodynamics together, thermodynamics work and heat together, right, forms the basis which helps to process designer and engineer to optimize their processes and harness the energy. The heat energy flow always flows from a higher temperature to a lower temperature. The change in internal energy

$\Delta U = Q - W$

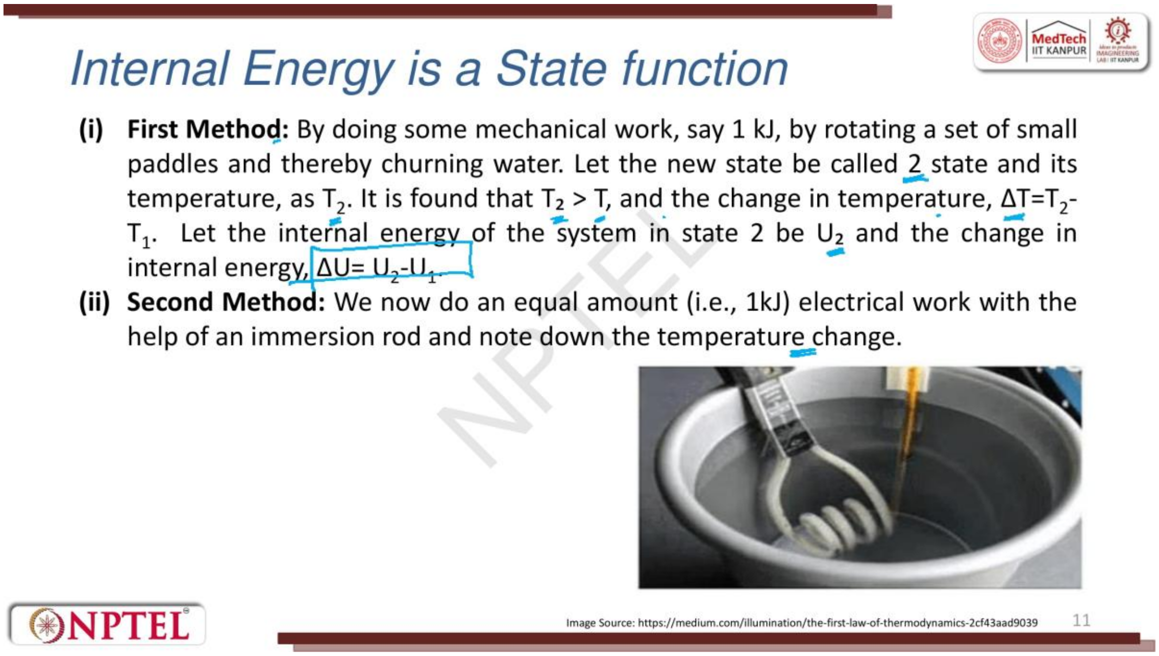
Q is heat added to the system, W is work done by the system. The change in the internal energy of a system is equal to the heat added to the system minus the work done by the system. So, we have already understood what is work. What is heat you have understood. So, the internal energy change is given by this. So, heat is the third thermodynamic work.



So, internal energy is a state function. Change in internal energy by doing work. We take a system containing some quantity of water in a thermos flask or in an insulated beaker.

The manner in which the state of such a system may be changed will be called an adiabatic process. You will see what an adiabatic process is in the course of time. We take a system containing some quantity of water, pour this water into a thermos flask, right? The manner in which the state of such a system may be changed will be called an adiabatic process. Let us call the initial state of the system as state 1 and its temperature T1.

Let the internal energy of the system in state 1 be the energy U1. We can change the state of the system by two methods.

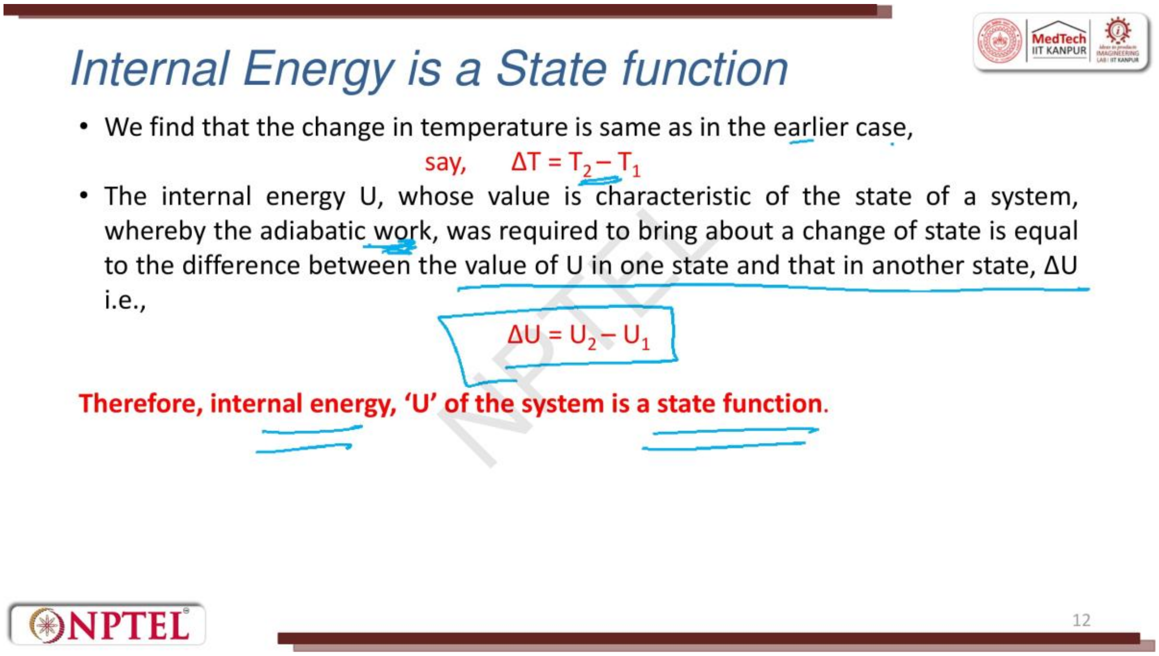


The first method is going to be by doing some mechanical work, say 1 kilojoule, by rotating a set of small paddles and thereby churning the water. So, what we are trying to say, you see here. So, we are trying to understand the adiabatic rate, the manner in which the state of such a system may be changed will be called an adiabatic process.

So, now what we are trying to do is? We are trying to make two different methods. The change of the state of the system. The first method is, you take a beaker of water. And then what you do is? You put a fan there, a stirrer there and then you rotate, right. By rotating a set of small paddle, thereby churning the water. You do not, the water temperature, whatever it is, you are churning it.

For example, you try to take morning milk, in that you put a bone waiter and then use a stirrer. You keep stirring it, right. Let the new state be called as 2 state and its temperature be called as T2, right. It was found T2 > T1 and the change in temperature is dT = T2 - T1. Let the internal energy of the system in state 2 be called as U2 and the change in the internal energy will be called as dU = U2 - U1.

This is one way. The second method is, we now do a equal amount of electrical work with the immersion of a immersion rod and note the temperature change. So, you try to push an immersion rod, and then you try to heat the immersion rod. So, now the temperature of the water goes higher.



So, we find that the change in the temperature is the same as the earlier case, T2 - T1. The internal energy, whose value is characteristic of the state of a system, whereby the adiabatic work required to bring about the change in the state is equal to the difference in the value of U from one state to another. So, we are now trying to explain the adiabatic work. When the internal energy—so two things, right? One is you put a temperature, you stir it. Why are we insulating it?

So that the heat does not go out. You just stir it. So, that is what mechanical work is done, and that is what thermal work is done. So, the internal energy U, whose value is characteristic of the state of a system, whereby the adiabatic work required to bring about a change of state is equal to the difference between U in one state and in another state. So, dU = U2 - U1.

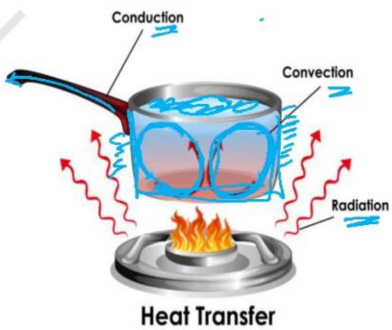
Therefore, the internal energy U of a system is a state function. Now, what are we trying to do? We are, time and again, trying to say that internal energy is a state function. If you go back and see, where did we discuss all these state functions? So, this is a state function we defined. State variables or thermodynamic parameters depend only upon the initial and the final state of the system, right.

Internal Energy is a State function

Change in Internal Energy by transfer of Heat:

The energy that flows across the boundary of a system during a change in its state of difference in temperature between system and surroundings and flows from higher to lower temperature.

- We can bring about the same change in temperature by transfer of heat through thermally conducting walls which allows the heat to pass in and out of the walls.
- Let's take water at temperature, T_1 in a container made up of copper as it forms thermally conducting walls.



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Internal Energy is a State function

Enclose it in a huge heat reservoir at temperature, T_2.

The heat absorbed by the system (water), Q can be measured in terms of temperature difference, $T_2 - T_1$.

In this case change in internal energy, $\Delta U = Q$, when no work is done at constant volume.

So, the change in internal energy by transfer of heat. When we try to keep a vessel and when we try to heat it with a burner, there are three types of heat transfer can happen, which is radiation, convection and conduction. So, that is why, if you see all the pans which you are may using in kitchen, they will always have a poor conductor handle which will be made out of polymer, bakelite or ceramic, some material like that. So, if you have the same material of pan as well as the handle, then when you try to heat the pan, the handle also gets heated.

So, sometimes people make a wrong choice of material selection by just looking at the aesthetics, but you have to choose a non-insulating material when you are trying to do a heat one. So, convection and radiation. So, we will see all the three in detail. Change in internal energy by transfer of heat. The energy that flows across the boundary of a system, the energy which flows across the boundary of the system, during a change in its state of difference in temperature between the system and the surrounding and flow from higher temperature to lower temperature is called as a change in internal energy by heat transfer.

When you bring about the same change in the temperature by transfer of heat through thermal conduction valves which allows the heat to pass through it in and out of the valve. So, that is conduction. Let us take a water at a temperature T1 in a container made out of copper as it forms thermal conduction walls. So, this is thermal conduction walls. If you want to replace it, you can also put glass.

So, there will be no conduction. So, you can put an ice here, and then ice cream you can put and then put a wall here which is of glass. So, there will be no conduction, right. But here we want heat to go inside. So, we put a container of copper, right.

So, enclose it in a huge heat reservoir at a temperature T2. The heat absorbed by the system (water) is Q can be measured as T2 - T1. In this case, the change in the internal energy dQ = U where no work is done at constant volume. Keep that in mind. No work is done in constant volume.

Before getting into, I have explained about conduction. I will also explain about radiation. Anything which rejects out of this boundary from heat, that is radiation. Conduction through a solid and heat from here goes there. What is convection?

Convection is nothing but when I start heating it, what happens is the hot water, whatever is there, slowly starts heating up and then becomes slightly lighter, and it keeps going up. So, then the cold water, because it is a closed volume, gets pushed down to the empty space. I am giving an analogy, but there is no empty space. So, here, what will happen?

The hot water will become lighter and go up, and in turn, wherever it moves up, the cold water will come. Now, you see, there is a swirling action.

There is a swirling action. By doing so, what will happen is the water which is hot at the bottom will try to slowly transfer the energy. Then, at the top, you will also try to have the heat. So, this process of rotation and movement is nothing but convection. So, friends, in this particular chapter, we had a fundamental understanding, and it is a fundamental chapter.

So, here, first we saw what thermodynamics is, and then we saw the laws of thermodynamics: 0, 1, 2, 3. Then, we saw the state and explanation of the zeroth law, first, second, and third laws. Then, there was a classification we saw: microscopic and macroscopic approaches. Then, the kinetic molecular theory of the gaseous state. We saw that.

Then, Assumption and Porcelain. Then, Features of Pressure of a Gas we saw. Then, Kinetic Interpretation of Temperature of a Gas. Then, three different systems: Open Loop System, Closed Loop System, and Isolated System. Then, Intensive and Extensive Thermodynamic Properties.

Then, we saw the State Path Functions. Then, we saw Thermodynamic Energy, Internal Energy, Work, and Heat. And finally, we saw how we can say the Internal Energy is a State Function, and we saw the derivation. So, in this particular chapter, we have used all these books as references to make this chapter. Now, before I close, I would like to give you some small assignments.

Try to look at the AC in your house and then try to define the state function, path function, and process for this example. Take another example: try to make kulfi or ice cream, I would say, right? The stick ice, right? So, in stick ice, what happens is they try to maintain. So, what they generally do is, they have a bigger container, put ice in this container, a lot of ice in this container. Then they have a cold mold here, which is an insulating mold.

They pour whatever liquid is here, and then they place a stick. And then what do they do? They keep rotating this fellow so that the liquid gets solidified, and then you get it. For an ice cream that is generated like this, what is the state function, path, and process? What is the final delta E that is there? Next, let us take an example of a pan, okay. Inside a pan, it is filled with water. Then, in that pan, I am trying to place another container, and in this container, I am trying to boil an egg. So, this is another container. This container is filled with water again, right? And here, the container is closed. It is floating or kept on top of the water in the other container.

And then the system heats. So, this is a conducting body. This is also a conducting body. So now, I heat it from the bottom. Now, try to find out what the state function, path, and process are, along with delta E, and try to keep a very realistic temperature. For example, at what temperature does water freeze? You know that temperature.

So, ice is also there, so try to be more realistic. If you are able to solve these three problems and put your concepts very clearly, then it will make this course easier to pick up speed in the coming lectures. So, with those few words, thank you very much. We will continue in the next lecture with more details about thermodynamic loss.

Thank you.