Concepts of Thermodynamics
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Lecture – 10
Heat and Work

Today, we will start discussing about two very interesting and important concepts in classical thermodynamics, Heat and Work.

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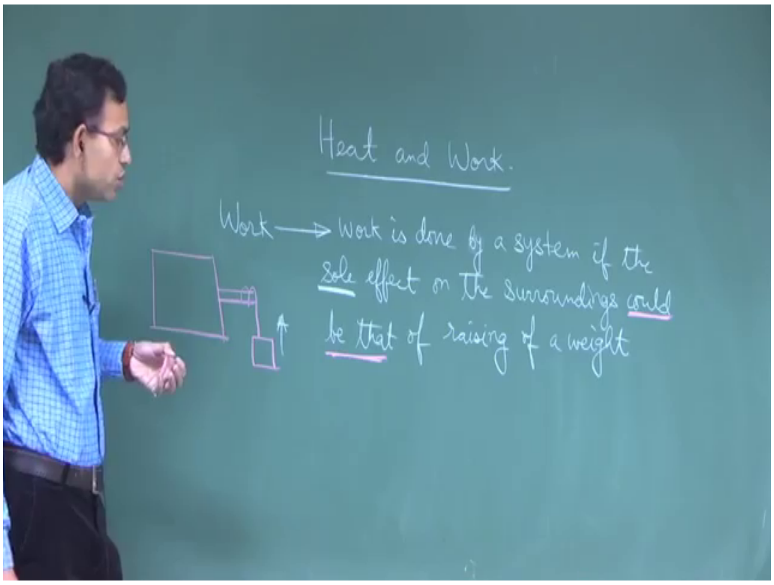

The name thermodynamics traditionally evolved from two important Greek words therm and dynamic. So, one is equivalent to heat and other is equivalent to power. So, thermodynamics is often perceived as a branch of science or engineering that deals with heat and work and their inter conversion. Of course, modern thermodynamics is not just like that, even there could be information flowing in a system and you can have transport associated with transfer of information in an information technology system.

So, thermodynamics in a broad sense is not just heat or work, but the fundamental premises of thermodynamics have all been postulated on the basis of heat and work which has been extended to other systems where the traditional heat transfer or work done may not be taking place, but you may also have equivalent effects such as the transfer of heat and work.

So, we will start with the definition of work. Work is done on a system or work is done by a system if the sole effect on the surroundings could be that of raising of a weight, ok.

So, this is a very tricky statement. You know thermodynamics the statements in thermodynamics the definitions are pretty generic, sometimes very philosophical. So, it is very very important to interpret between lines. So, work is done if the sole effect on the surrounding; so, there is a system and there is a surrounding the system is doing some work if the sole effect could be that of raising of a weight, very important thing is could be that not that it is always that could be that of raising of a weight means equivalent work of raising of a weight could also we work. It is not that raising of a weight is just doing work.

So, this is a template or prototype of doing work. So, you have a system and say it is connected by a rod in which you tie up a string which you rotate this rod with a pulley and then what is happening is as you make this shaft rotate this string is unwound and this goes up. So, once this is happening you can say that there is a raising of a weight. So, what is so typical about raising of a weight? What is so typical about raising of a weight is that there is a gravity which is pulling the weight down and you are overcoming that resistance to make a displacement.

So, if there is a displacement against a resistance then thermodynamic work is done. So, it is very much different from mechanical work. Mechanical work even if there is no resistance if there is a force and there is a displacement the dot product of force and displacement is work. In thermodynamic work, it is the resistance force which is important. So, the work is calculated as resistance force times the displacement not the applied force times the displacement because if there is no resistance, there is no thermodynamic work done.

So, in a little bit of light note I can say that the participants in this course are going through I mean you all of you have started going through the lectures of this and we will have assignments, tutorials, quizzes and exams. See as a teacher I will feel great if I set very tough questions and despite setting the tough questions you are able to answer those questions and get good grades. I think more than a teacher as a student you will be more satisfied because if there is a tough question and you have been able to address the tough question and get a good grade; that means, you have done some work against resistance. So, it is something of real achievement of satisfaction.

On the other hand, if there is no resistance you just sit and enjoy the lectures with cups of coffee without paying an attention and then whatever you do I give you the final best grade for all the students then even if you get the best grade you will not get that kind of satisfaction. So, in human life philosophically we all get the joy of success because there is a resistance to get success. If there is no resistance to get success, there is no joy in getting success. So, similarly in thermodynamic world, there is an achievement in terms of doing work if there is a displacement against a resistance.

So, with this little bit of note I can give you an example in which there is a there is a displacement of the system boundary, but there is no work done.

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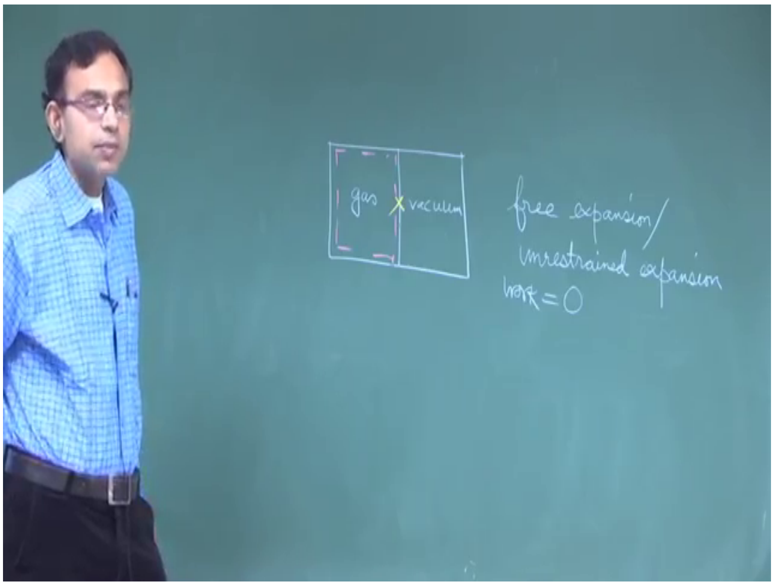

So, let us say that there is a chamber this chamber is partitioned in two half's; on this side there is a gas, on this side there is vacuum. Your system is this gas. Now, suddenly what you do is you puncture this membrane and very quickly this gas fills up this entire volume because there is vacuum, there is no resistance against the expansion of this gas. This is called as free expansion or unrestrained expansion here the work is 0.

So, you can say that the system boundary from here it gets stretched up to this entire volume of the chamber, but because there is no resistance force there is no work done.

So, this illustrates the basic principle of thermodynamic work that I have just mentioned now.

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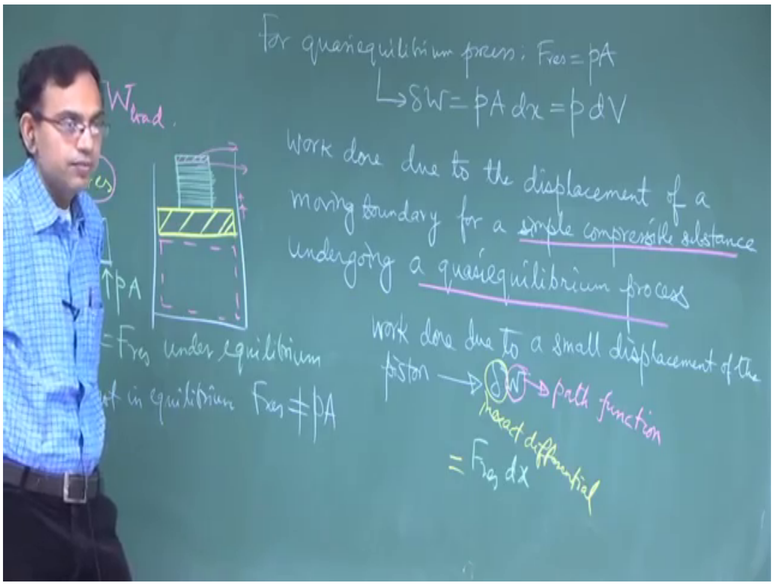

So, work done due to the displacement of a moving boundary for a simple compressible substance undergoing a quasi equilibrium process so, that template is like this; there is a piston. See, piston cylinder arrangement is a very classical template by which we illustrate various concepts in thermodynamics. Let us say there is a piston. This piston is getting displaced and we are interested to find out what is the work done due to the displacement of the system boundary this is the system boundary the system boundary gets displaced because the piston is moving. There are certain keywords in the description of this heading and I will go through the keywords very carefully before getting into the expression for the work done.

The first keyword is simple compressible substance. So, what is a simple compressible substance? In a thermodynamic system other than the effects of change of pressure volume and temperature and related properties you could also have other effects which are important like electric effect, magnetic effect and all those things. Despite having those factors a simple compressible substance is a substance where pressure volume temperature changes or the changes of the related parameters are much more important than the other effects like electrical effect, magnetic effect and so on.

So, what would happen if there are other affects the work done due to electric, magnetic this type of effects has to be also considered while finding out an expression for the work done. So, when we are obtaining an expression for the work done, this means that we are not considering in electrical work, magnetic work these types of things we are only focusing on pressure, volume, temperature change this type of change and it is undergoing a quasi equilibrium process.

That means, what is the model problem model situation in which it can move in a quasi equilibrium process? Let us say you have thin slices of very small loads on this pistol. You remove the top slice, this slice and then it will go up a little bit you remove the next slice it will go up a little bit. In this way if you remove the loads slowly in a very small incremental step this will move also slowly in very small incremental step. With is very slow process all the intermediate states will get sufficient time to achieve thermodynamic equilibrium; that means, when we say that this is a thermodynamic equilibrium state, we mean everywhere the pressure temperature specific volume all are the same.

When it comes to a new configuration we should allow it sufficient time so that everyone in this new configuration it will come to a new common value of pressure temperature specific volume like that. If we want to give it that time then the process has to be very slow, that is the deviation from equilibrium is only infinitesimal that is negligible deviation from equilibrium. So, with this negligible deviation from equilibrium we can say that there is a balance of forces on the piston.

So, there is a pressure from this side there is a resistance force from the other side. What is the F resistance? What is this F resistance? This is m g plus W load this is mass of the piston into g plus the weight of this total weight of this load which is dynamically changing because you are taking one after the other.

So, you have p into A is equal to F resistance under equilibrium. If it is not in equilibrium that is if it is not a quasi equilibrium process if not in equilibrium F resistance is not equal to p into A, ok, there will be a net unbalanced force.

So, what is the work done due to a small displacement of the piston? We write this as delta W. This we do not write as dW. We will later on just after sometime I will let you know that why we do not write it as dW. When we write it as dW it means that it is an exact differential of something; that means, the work done as you go from state 1 to state

2, we will just depend on the states 1 and 2, but not by the process by which you have gone from 1 to 2, but if the work done depends on the process; that means, it is not an exact differential.

So, this is the symbol of inexact differential and the work therefore, because it is differential is inexact differential this is also called as path function; that means, it depends on the thermodynamic process or the thermodynamic path. How it depends we will come into this in a moment. So, this is equal to F resistance into dx, this is consistent with the definition of work because if there is no resistance there is no work done.

For quasi equilibrium process F resistance is equal to p into A, right. So, in that case A dx is dv. So, this is the famous formula for work done which is pdV. I want to talk about a few very important subtle points associated with this very simple expression work done equal to pdV which you have perhaps all of you have learnt from school level, high school level. First of all why this is a path function? So, depending on how pressure changes with volume the work done which is the integral of this will depend, right.

So, it does not it does not just matter on what is state 1 and what is state 2, but also on the path by which you go from state 1 to state 2; that is given by p as a function of V or V as a function of p, that function decides what will be the work done. So, this is number 1. Number 2 is there is no necessity that this has to be a closed system.

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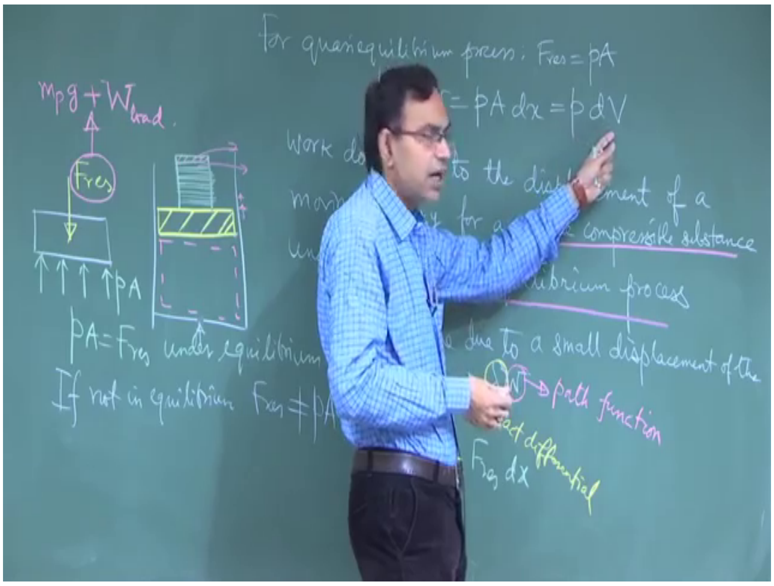

For example, if you have a hole through which you supply air and then this is moving. If it is moving in a quasi equilibrium process, the work focuses only on the system boundary displacement. So, thus whenever there is system boundary displacement in a quasi equilibrium process the work done will be this it does not matter whether it is a closed system or an open system. Many people have a false impression that this is true only for a closed system that is not correct. It is true even for an open system because the definition of work never requires that it has to be a closed system. It is just the resistance force times the displacement. So, to summarize this expression is valid for a simple compressible substance undergoing a quasi equilibrium process. That is all, no more assumption is there associated with it.

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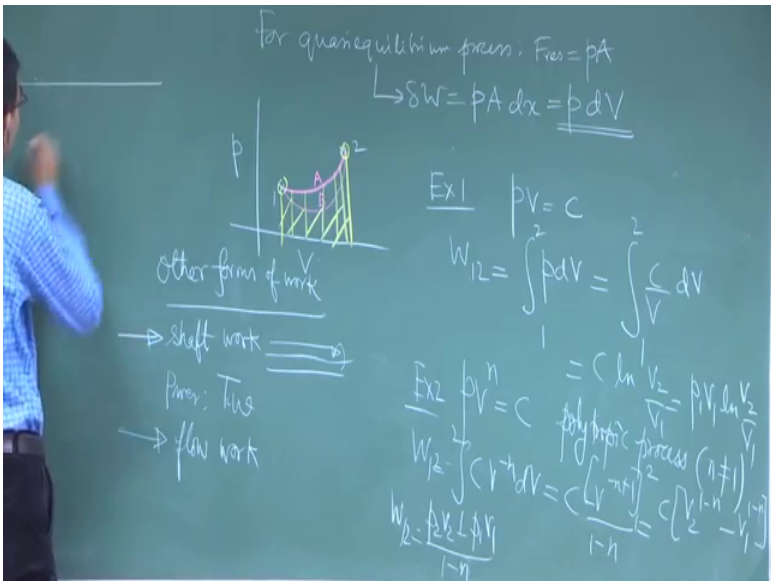

So, we will consider an example how to calculate the total work done two typical examples, but before that I will illustrate graphically why this is called as a path function. So, pV. So, let us say this is state 1, this is state 2. So, while going from state 1 to state 2, you might have a path 1 or path A you might have another path B. The work done is what? The work done is integral of pdV, right. So, that is the area under the curve. So, area under this curve is different from the area under this curve, although the state points is 1 and 2 remain the same. So, that is why we say that it is path function and therefore, delta W and not dW.

So, example – 1 will be say pV equal to constant. This is typical to isothermal process of an ideal gas. So, W 1 2 work done from one to 2 is integral of pdV from 1 to 2. So, p is C by V C ln V 2 by V 1. So, C is nothing, but p 1 V 1 or p 2 V 2. So, this is p 1 V 1 ln V 2 by V 1.

Example 2: pV to the power n equal to constant. This is called as a poly tropic process; that means, many times when you plot the pressure versus volume data you can fit the pressure versus volume data with pV to the power n, where n is not equal to 1. If n is equal to 1 that is what we have already considered. So, do not confuse this with an adiabatic process.

Adiabatic process is a special case of a poly tropic process, but it could also be any other process. So, any process which could be artificially fitted in the form of an equation pV to the power n equal to constant, that is a poly tropic process. So, W 1 2 is equal to pC V to the power minus n dV 1 to 2. So, these C V to the power minus n plus 1 by minus n plus 1.

So, C into V 2 to the power 1 minus n minus V 1 to the power 1 minus n. C into V 2 to the power minus n is p 2 and C into V 1 to the power minus n is p 1. So, we can write W 1 2 is p 2 V 2 minus p 1 V 1 by 1 minus n, ok. This is the work due to displacement of the system boundary.

There could be other forms of work. What are these? Shaft work. So, what is shaft work? So, if there is a shaft that is rotating and it requires a torque T to rotate it then the rate of shaft work is given by the torque into the angular velocity which is the power.

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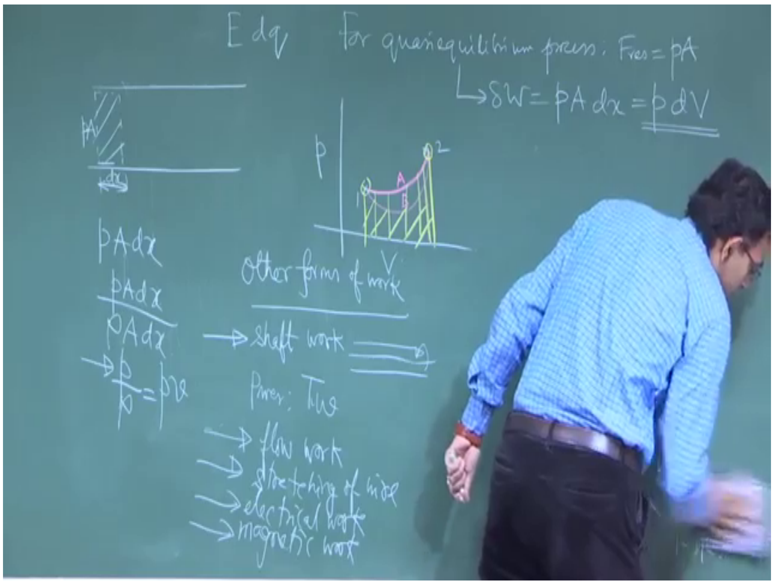

Flow work: What is flow work? Let us say there is a fluid which tries to enter a pipe. So, because the pipe is already jammed with fluid, the fluid has to overcome the pressure and maintain the flow otherwise the flow cannot be maintained. So, if the pressure is p and the area of cross section is A and the element of fluid we consider as dx then the total work due to displacement of one front of the fluid by dx is p A into dx.

So, this much of energy the fluid must have to maintain the flow in presence of pressure otherwise it cannot displace this and make the fluid move, it will be a stagnant fluid. So, this work per unit volume or per unit mass A into dx is the volume that into row is mass. So, that is called p by rho or p into specific volume in thermodynamics.

So, pressure into specific volume is what the energy required to maintain the flow in presence of pressure per unit mass. This is called as flow energy or flow work. So, you have flow work. Then you also have work done due to stretching of a wire, this is due to surface tension. If you stretch a wire you do some work because if you expand an area by stretching a wire you do a work by virtue of putting more energy to the surface. This is due to surface tension.

Then, electrical work: so, if you have an electrical potential E and if you are charging with a charge dq then the work done in this case; plus or minus I will come later on because the sign convention of work and work we have not yet discussed, but if you have potential or a electrical field E and if you have a charged dq the work done associated will be proportional to E into dq.

And, then you could also have magnetic work. So, if you have ions a paramagnetic salt and then you apply a magnetic field to orient the ions in a certain direction, then you do some work. This is called as magnetic work. So, the orientation of ions in a paramagnetic salt can be reorganized by applying a magnetic field and therefore, it associates it with some work.

So, all these forms of work shaft work, flow work, stretching of a wire electrical work, magnetic work these are different forms of work which are beyond what is captured by pdV. So, pdV is not all that you have to keep in mind.

So, next very briefly we will discuss about the sign convention for work because we have work as a algebraic quantity it should either be positive or negative.

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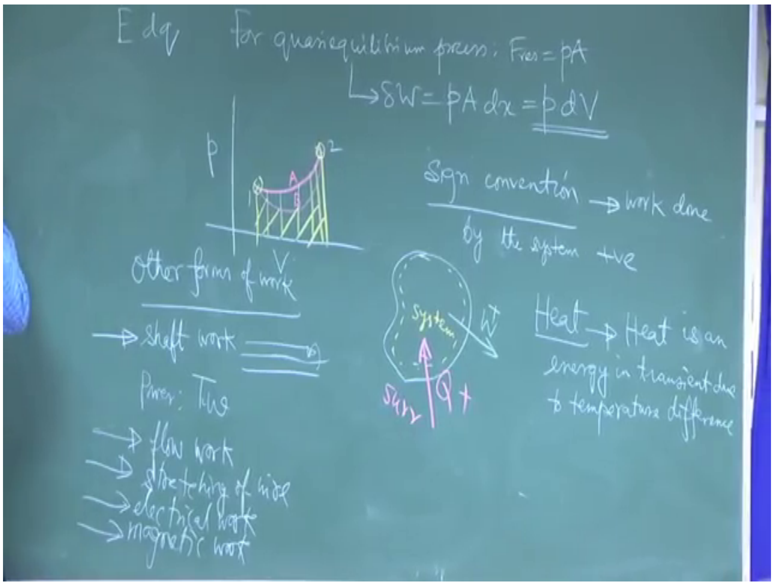

So, our sign convention is that we will follow throughout this course is that work done by the system is positive.

So, if there is a system like this, if it does work, then what will happen? Energy will flow from the system to the surrounding because at the expense of that energy only it will do work. So, this we call as positive work where energy is leaving from system to surrounding. So, this is our system. So, again I am repeating, as per the sign convention we are following in this course, if energy is leaving from system to surrounding we are calling it as positive work. Very briefly we will now talk about heat.

So, what is heat? Heat is an energy in transient due to temperature difference. So, if you have a system which is different from the surrounding temperature then there is a heat transfer either from the system to the surrounding or from the surrounding to the system which is governed by the temperature difference. So, let us say. So, let us take an example when the surrounding is having a greater temperature at than that of the system. So, in that case, a heat flows like this which we call as positive heat transfer. So, positive heat transferred is energy gained by the system and positive work is energy lost by the system, ok.

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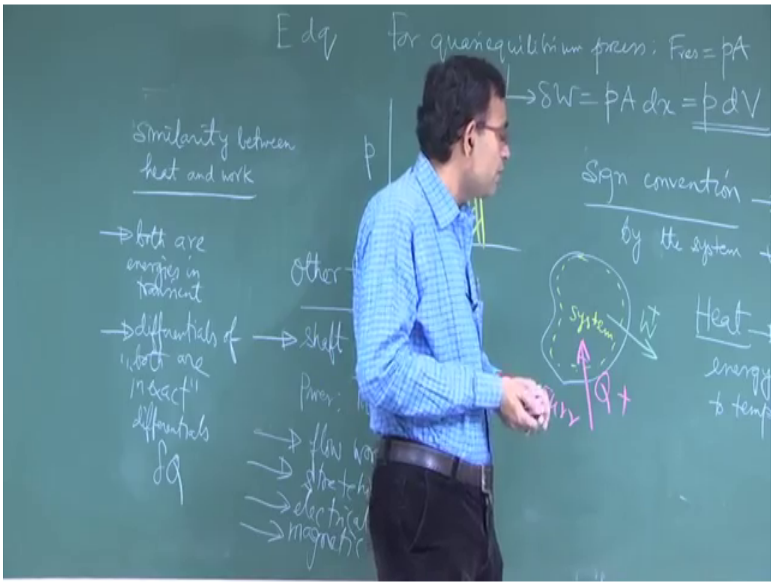

So, heat and work what is there similarity? So, similarity between heat and work; both are energies in transient, ok. So, work is also energy in transient because whenever the system boundary is moving then only work is done. System does not possess any work, it also does not possess any heat. If you have a bucket of water sometimes we say that it has lot of heat, it is a wrong terminology it has a lot of internal energy maybe which we will discuss later on as a terminology, but heat a system cannot process heat. Heat can only be transferred across a system boundary either from the surrounding to the system or system to the surrounding, similar is work. So, both are energies in transient not energy possessed by a system, first thing.

Second, differentials of both are inexact differentials. So, for differential of heat we call delta q naught dq because heat transfer is also depending on what is the thermodynamic path. Thermodynamic path means how pressure changes with volume during the process. So, these are the analogies.

The sign convention is opposite, but there is no sacrosanct thing about it. It is our way of taking the sign convention. If somebody takes the sign convention such that work input is like instead of energy flowing out. Energy flowing in is positive work; that also is ok. There is nothing wrong with it, but all the subsequent equations that we develop for example, first law of thermodynamics and so on, we have to be careful about the sign convention. We will throughout this course the following the sign convention if somebody follows a different sign convention those equations will be altered with algebraic sign. So, that is the only sacrosanct thing about the sign convention of heat and work.

So, to summarize today we have understood what is heat transfer, what is work done and their similarities in terms of notional features like energies in transient and their differentials are path dependent or inexact differentials.

Thank you, very much.