Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Engineering Thermodynamics

Lecture – 13
First Law of Thermodynamics for Cyclic Process

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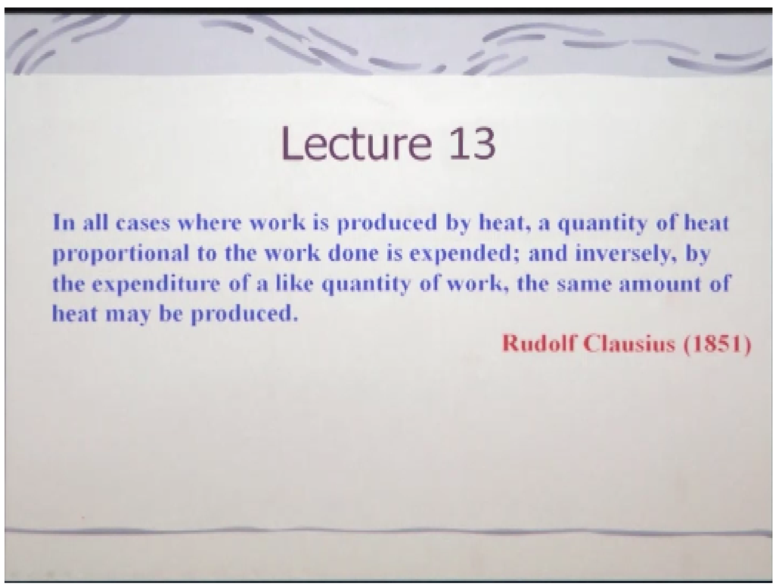

Let us start this lecture with a thought process from Rudolf Clausius who gave the through process in 1951, who says in all cases where work is produced by heat a quantity of heat proportional to work done is expanded, and inversely by the expenditure of light quantity of all same amount of heat may be produced, so if we look at what is the statement and what it will be we will be discussing today in this class however let us recall as usual what we learned in the last lecture.

If you recapitulate that we started with the ideal gas law which was very familiar with you and later on we moved to Vander waals equation of state which can be applied for the real gases we have also seen that that law is good enough for not only the gases but also for the liquid, but however it would not predict well for the vapor and liquid mixtures.

Later on we saw three equation of state which can be applied for real gases but there might be several of them, but we have only looked at the one is the what we call Benedict equation and other is the red leech and Kong equation and another is Ruben and wave equations kind of thing we have seen those are basically me empirical relationships which are not having any theoretical basis and later on we also discuss about virial equation which is having basis of theoretical you know background and unfortunately those coefficients like virial coefficients like you can have higher order terms also but the experimentally only the second order terms one can you know find out the coefficients.

But later on therefore it can be similar to an you know very simple form but however it may not be applied for all the cases that is the limitation of course there is more need to be work to be done for that obtaining the virial coefficients for various gases and various what you call materials and also this thing beside this another thing we did we looked at compressibility factors by using compressibility factor in equation of state you can take care of the real gases, and we have seen that a generalized compressibility chat, and which you know most of the gases rather large number of gases can be or the large number of substances not only gaseous substances can be plotted in single plot.

And we also learnt how to use that you know compressibility factor and chart for evaluating the properties but today we will be doing little different that as I told in the very beginning we will be looking at what you call various relationship various quantities namely the heat and work and energy right.

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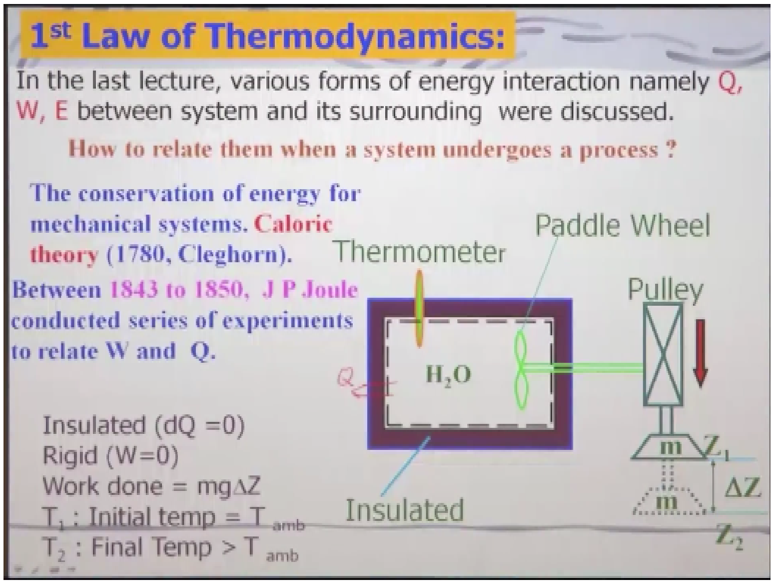

Through which a system interacts with his surrounding but what are the relations between these things what we are going to discuss today because whenever a system undergoes a process right, during it is interaction with surrounding then there will be some change in the energy and that change can be you know energy interaction can take place either by the heat or by the work, now what is the relationship that can connect all these quantities that we are going to see, but I will just give you a little bit to historical perspective.

If you look at till 1780 when the Cleghorn gave theory known as caloric theory before that it was known that about the conservation of energy for mechanical system but however people were not having much idea about what is heat right so and clear Cleghorn is the first person to give a theory which is caloric theory according to this the heat is like an elastic fluid, having no wet and it is conserved that means you know you can this heat is saying is conserved and later on the lab was here in 17 around 87 he also you might be knowing leverage it is one of the you know greatest scientist.

So he also told that look this heat whatever you call it can be termed as the calorie and that theory was very much you know being used and experimented by various people fell look these are and number of you know what have been were being reported at that time and it remains for a very longer period of time till you know like Joule come into picture JP joule of course before that there Thomson who gave a who happens to be a superintendent in the military in German

Munich right and while he was rebooting the gun you know he found out that this mechanical energy you know is converted into you might be knowing earlier days even in India.

We are having very big barrel guns you know and then you will have to put this kind of bored the what you call gunpowder something and then bore it and while mechanical work is converted into it then he says I look it cannot be you know true that what caloric theory is talking about and of course he with a lot of his influence with what you call in royal society at that time well society was a very big thing I mean the same scientific body.

And he tried to conduct experiment and also told like look this is not right and the mechanical war can be converted into heat right he gave that idea but nobody really took his idea for quite a bit maybe around 50 years kind of thing and later on the JP Joule who was a very young person like you like around 20 years old at the time he conducted series of experiment right and he was not educated in a formal education system and of course he was being tutored by a very great person known as you know Humphry Davy you might be knowing.

But he conducted series of experiment you know like the caloric theory was established but he demolished it by conducting series of experiments and related this work and heat which is against the caloric theory right, and what he did he basically took a what you call container in which there will be some kind amount of water or fluid he took right and then he insulated this thing and put a this paddle wheel and paddle will can be rotated and which is connected to pulley and this mass and mass can be you know basically can be lowered against the gravitational field right.

And what will happen if I take this as my system you know dashed line I have put then what will happen no heat is being transferred here right, no heat being transferred here and work be being done or not working done on the system by the this paddle wheel right and what will happen to the this water suppose it is at ambient temperature to start with and before the you know movement of this paddle wheel then what will happen to his temperature will definitely will increase right and means this temperature is increased that means the war whatever being you know put into the system by the paddle wheel right has been converted into heat.

You can think of that way right, okay and of course one can evaluate how much it is there and then by the work done potential energy that is mass into gravity into change in the elevation or the height right and then one can evaluate.

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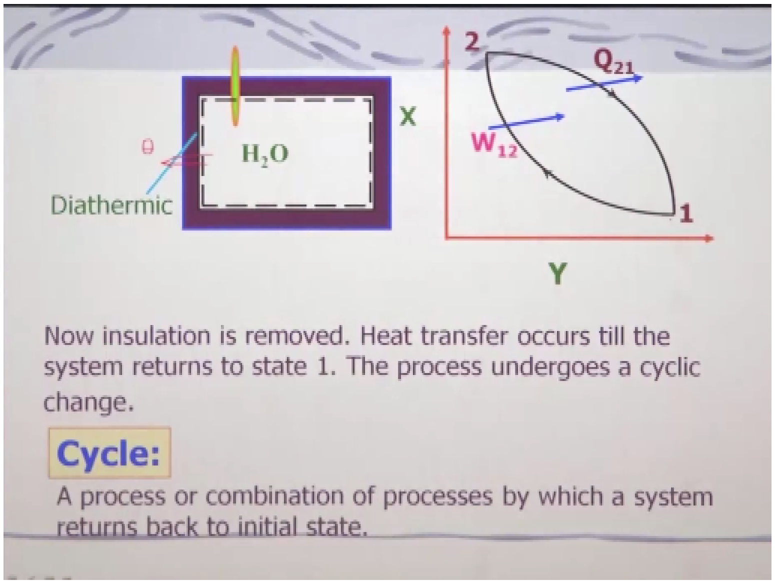

If you look at this process can be described in this you know like 12 to let us say system as at a station 1 and due to this work done it has gone to station 2 okay, now what it did he l now remove this insulation as a result right it can pass through this it can go out of this I mean all the site then what will happen temperature will be coming back to the ambient temperature whenever it will attain the thermal equilibrium right, so the process can come from state to state1 right so if you look at that means the process started a station state one and it some work is being done and then some heat interaction is taking place and coming back to the state won again and this process we call it as a cyclic process right.

Right and therefore we can define a cyclic process as a process or a combination of process of course in this case we are considering only one but there might be several processes which we will see in whenever we are discussing about practical cycles like your auto cycle diesel cycles or Rankin cycles right by which a system returns back to its initial state we call it as a cycle and he also conducted several other experiment I will be discussing one of them more like.

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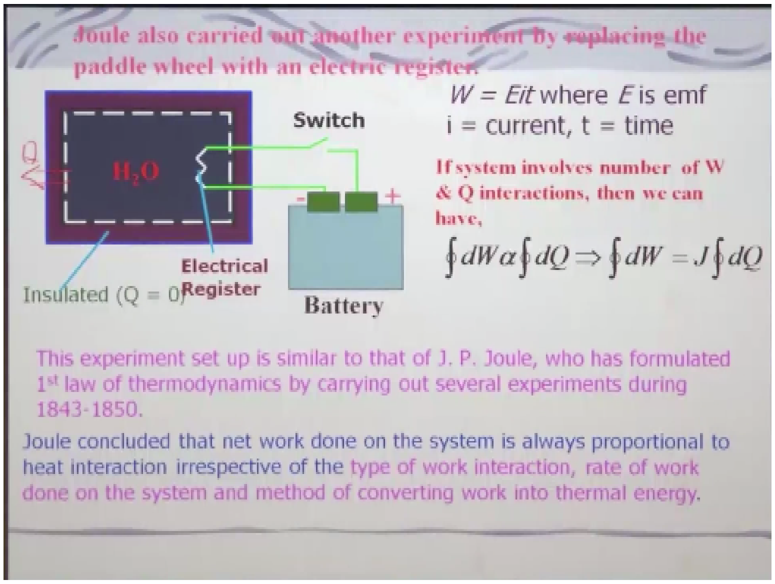

What it did actually he took another system like you know a system is same but instead of instead of what you call the paddlewheel he put a resistance here and connected to a battery and when this switch is on then what will happen the current will flow through and heat it the water and then temperature will group right you can call this as a heat interaction you can call it as a work interaction we have already seen right and that is equal to W we can say because we have taken the full you know the system boundary I have shown here it is including the heater therefore it will be work interaction right.

If I exclude the heater from the system then it can be heat interaction we have already discussed that earlier, so this work is basically what you call Ei and t where E is the emf I, is the current and t is the time so certain amount of heat and system again moves what we call state one to the state to and again when do you remove these installations right what will happen because temperature has gone up due to the heat due to the work done by this electrical heater on this the temperature of the system will go from ambient to certain temperature right.

It will be higher and then when it will remove this insulation right I will remove this insulation and allow the heat to pass through this says that and the temperature of the system will lower down it will be lowered down till it attains the thermal equilibrium that means it will be reaching back the ambient temperature if it is started from the ambient temperature right,. And then you can trace the path like a cycle the way we did that means you know it is a similar in nature that what he observed he did several of experiments and concluded.

You know and formulated the first law of thermodynamics he conducted series of experiment as I told1843 to 1857 year this experiment which looks to be quite simple you know you can say look why cannot he do in 4, 5 days or maybe one month not you know something seven years and joule concluded that net work done and a system is always proportional to the heat interaction irrespective of the type of work interaction because to type of work I have just now illustrated here at discuss here but there might be several other work kind of work right.

And the rate of work done he also varied this work like let says few you know what to call kilo joule let us say or else a five kilo joule I can say 50 kilo joule I can say 500 kilo joule you know like I can change that and method of converting work into thermal energy he did all these experiments and concluded that and then in other words if a system inverse number of work and heat interaction.

Then we can have that cyclic integral of the work is proportional to cycle integral of the heat interaction and which is not which is equal to you know cycle ∫ dW is equal to j a cycle in heat interaction then we can have that cyclic integral of the work is proportional to cycle integral of the heat interaction and which is not which is equal to you know cycle integral DW is equal to j a cycle in heat interaction I integral of the heat J is 0, J is a constant.

And in SI unit the J is basically equal to 1 and this we call it as a Jules constant and this is the basically first law of thermodynamics okay, is it you people are aware about this what you know you know as a first law of thermodynamics proposed by these things is different than this but how I mean we can utilize this first law of thermodynamics we will see later on, so if you look at this is the equation and this is the first law of thermodynamics right.

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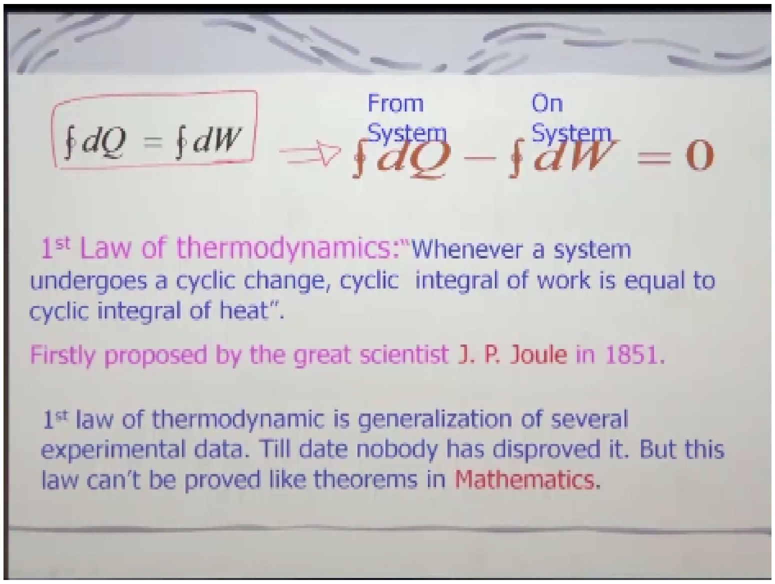

That we say the cycle integral of heat is equal to cycle integral of the work keep in mind this thing is valid this expression is basically valid for SI unit otherwise the J should come into picture okay in case of SI unit j Is equal to 1 but in FPS unit it will be different, so what its take the it states that is the first law of thermodynamics whenever a system unnecessary undergoes cyclic however the complex the cycle may be the cycle integral work is equal to the cycle integral of the heat rather I would put this way.

Little bit differently which is the you know first law of thermodynamics that is whenever system undergoes a cyclic change however the complex cycle may be the cycle integral of work is proportional to the cycle integral of the heat right because the J the constant is comes into picture that one can say also, so this was firstly proposed by the great scientist JP Joule in 1851 do not think that he was the only person who was working there was another person let me tell you little historical perspective name is mayor.

And he also working on this but he could not propose this statement very with argument he was having similar concept but he was not having you know enough arguments and also the evidence because what happened he was also conducting experiment but his son or the I think one of his you know child died and then you know he could not really man as well.

But later on you know he was very frustrated he also tried to commit suicide but he could recover and then he was also considered as a you know proposer of this first lock Dominic tree it was given to him much lateral you know not at that time he was having lot of wagon is he worked so hard but however it was not recognized so and there might be several other people who might be working you know on this to that.

So the first law of thermodynamics is a generalization of several experimental data right, till date nobody has proved it to be wrong right but however this law cannot be proved like a theorem what you do in mathematics and other things right it is on experimental basis there is no you know fundamental like where you will look at it and work on it see the other way around but however people do you know even today might be trying to prove that this is wrong you know.

So therefore there is always we always you know challenge the established concept and then go beyond it so that is the very important point you should keep in mind that do not accept the thing what it is but however if it is true will have to accept it, so therefore we can write it down as this cycle integral of the δQ that is the heat interaction minus the cycle integral of work is equal to zero this just I am putting over here you know. And this heat from the system right in this case and this is work done on the system it can be just a pause it also so what we will do that.

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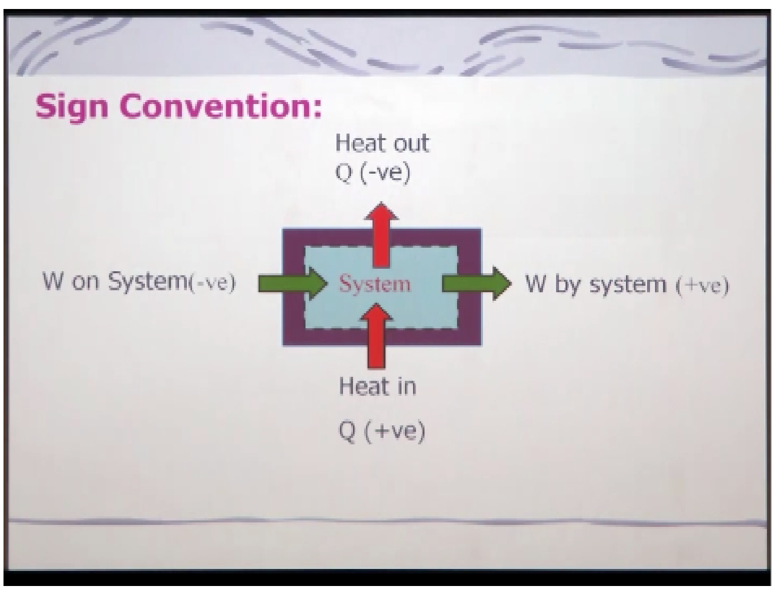

We will have to look at the sign convention again because you know that is the work done by the system is basically positive work done on the system by its surrounding right will be negative and heap entering into the system right from its surrounding is positive and heat is going out of the system you know to its surrounding is basically negative and this you will be using I can you just a positive that you know and also can manage and apply this first law of thermodynamic as well without any error. But one has to be consistent with that.

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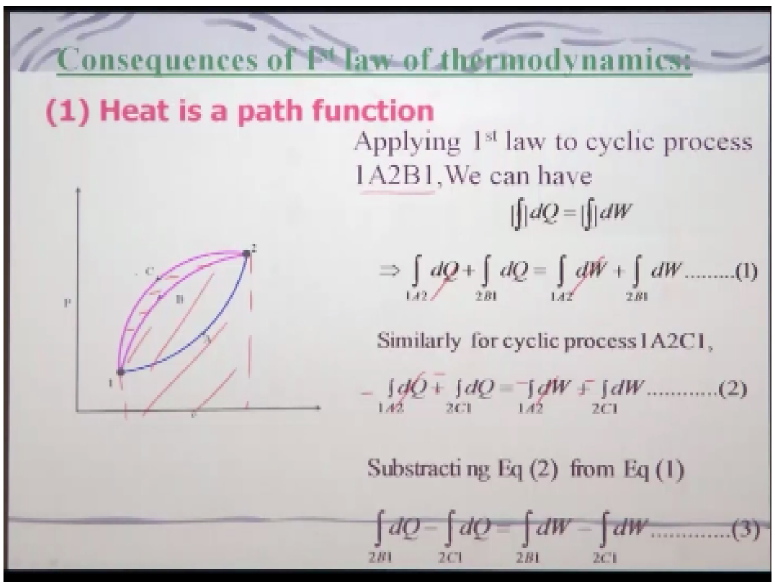

So what are the consequence of first law of thermodynamics that we will see right, so whether we can say it is a heat is a far function from the first law of thermodynamics or not that we will see for that what we will do we will say that let us consider a cyclic process like from the system he from the state one is moving through the path a and also returning back from state 2 through the path B this is one way of you know it is completing one cycle right.

I can apply the first law of thermodynamic for the cycle 1a, 2b1 and I can also apply the first law of thermodynamics from state 1 a2 and take another path from state 2 through C you know to state 1 right I can have I said no I can apply the first law of thermodynamics for both the cycle between two state point between the two points so applying the first law of thermodynamics to the cyclic process 1a 2b1 that is here1a, 2b1.

What we will do we can write it down that is δq 1 a2 + δq 2b1 that is integral we are saying right in this path is equal to the cycle integral of the work I am like the total and if you look at it consider two paths the work done in the path 1a2 dw and work done in the part 2b1 right we are considering now this vertical path 1a 2 b1 similarly we can also write down or rather apply the first law of thermodynamic to the another cycle.

But between the two state that is one a2 c1 right so that is the you know if you look at this term is same as that of that that is the path a1, 2 and of course the heat this path 2c1 is different if you compare the equation one and equation two and work done also is basically DW you know path 1a21 1a2 here both are same and these are two are different and what we will do will basically subtract this equation 2 from the equation one and if I do that what will happen this will cancel it out because I am- you know I can put a minus here I am just subtracting.

So this will cancel it out similarly I will put a minus here and this will cancel it out I will get you know d cube per the path 2b1 - DQ for the path 2c1 = DW - for the path to be 1 - DW 2c1, so from this we can I mean deduct we can deduce it right that what is that thing let us look at what happens to work is the work done per path 2b1 will it be equal to the work done part 2 c1 is it possible? No, because if you look at if I take this diagram the path you know the area you know for one case area will be this one right this area but path 2b1 for the path 2c1 there is a another area you know added so it is not same so it is different so if it is different that means we can say.

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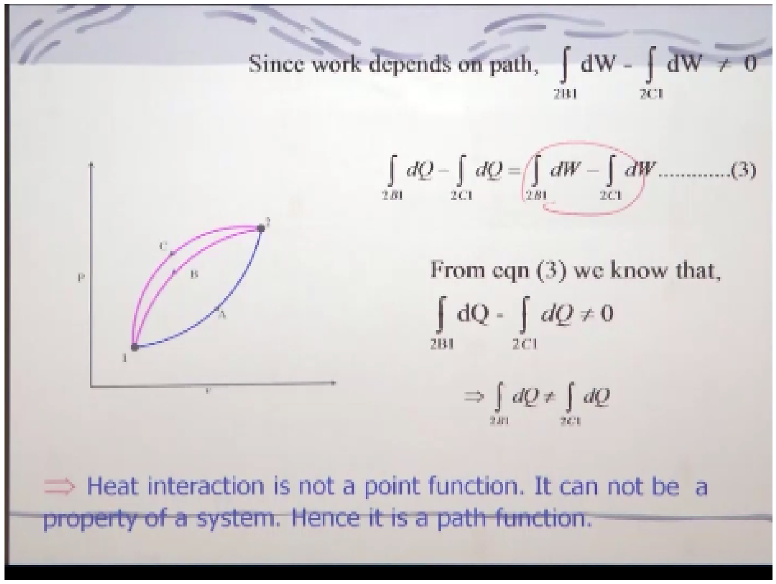

That this the work done in the part to be 1 minus work done and the path 2c1 is not equal to 0 that means the work done in the both the paths are different I have already told you then we can from this we can say that that DQ because this is not equal to you know this portion is not equal to you know zero right so therefore the work done the heat interaction between that part 2b1 minus the heat interaction part 2 C 1 is not equal to 0.

That means what because it is between the two step 2 and 1 state is same I mean like it is for both the path therefore from this we can say that the heat interaction for the path to be 1 is not equal to the heat interaction between path to c 1 therefore we can call it basically heat interaction is not a point function rather it will be dependent on the path hence as it is not a point function it cannot be a property of the system.

That we have already earlier discussed but now using the first law of thermodynamics we can prove or you can deduce that look it cannot be a, what we call point function or a property of the system rather it is a path function.

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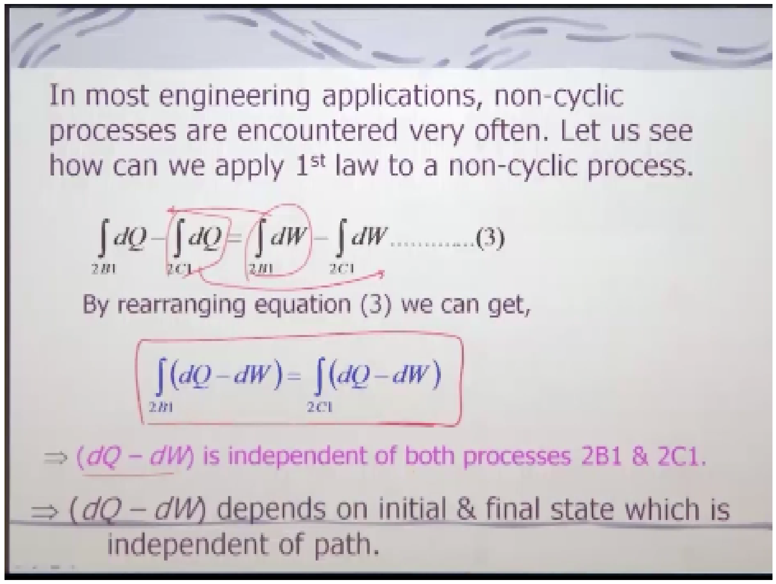

So now let us look at another aspect of that so before doing that like we need to know that in most engineering application non-cyclic processes are encountered very often right what we have derived till now is basically the first law of thermodynamics or a cyclic process right if the process is not cyclic then you know you cannot really use it but as the engineering application processes need not to be cyclic right.

For example you know in the what you call a system let us say there is a what to call cylinder gas cylinder and it is being leaked out right can I get it back to the original so if it needs to be put the work in to that it is not cycling however there are several cyclic process also as I told like your automobile engines right it is slightly its move go on you know working you know and then giving heat.

And other things it is doing, so now we need to see how we can apply the first law of thermodynamics which we have you know discussed just now mean for the cyclic process can be extended for a non cyclic process, for that we will have to use the same equation that is further you know like for the path to be 1, 8 in Direction minus the path 2c 1 is equal to work interaction to be 1 minus work in tourism to c1.

By rearranging this equation 3 what we will do by this basically we will take this term to this side and this term I can take to this side right so if I will do that what I will get I will get to DQ-DW for the path 2b1 = DQ – DW 2c1 right and this term if you look at DQ -DW you know is basically from this statement from this statement one can say that it is does not depend on the path that means the Q - W for the path to 2b1 = DQ - DW / path 2c1.

It is this term the heat and minus the work is basically this term is independent of the both processes 2b1, 2c1 and this is basically we can call it a point function or a property of the system right because it depends only on the initial and final step right it does not depend what path it takes whether the path B between the state 1 and 2 or C or D whatever it is we of course we have considered only two paths.

And these properties what we call is basically the internal energy right and when we say that then we say that energy is a property of the system right because this term we are saying DQ-DW.

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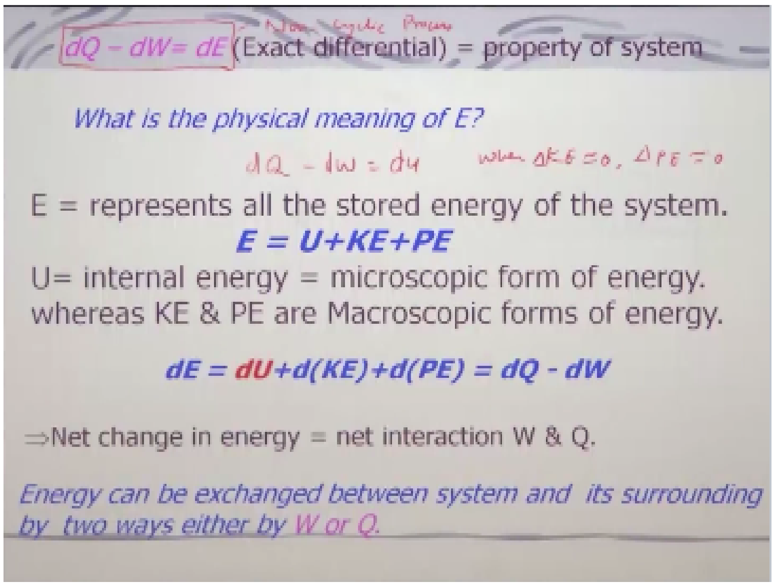

D is nothing but d e and d e is exact differential it does not depend on the path it depends on the point or rather it is a point function so it is a property and this equation you know if you look at you can apply very well for the what you call non cyclic process non cyclic process like a and this you areaway ok this is generally whenever you say that tell me the first law of thermodynamics a that DQ - DW is equal to DE what is the DE, DE is basically the total energy stored in a system like II will be consists of internal energy kinetic energy and potential energy and this is the microscopic form of energy we have discussed extensively on that right.

Whereas U is the internal energy you know like whereas the kinetic energy and potential macroscopic form of energy right, so and most of the cases you know kinetic and potential energy are neglected because of being smart therefore you always say that you know DQ -DW you know if this KE and PE is small then I can write down basically DQ -DW = DU, when K E is almost ma very negligible and PE right.

So we will be using this application and therefore what you call net change in energy is equal to net interaction between work and you know it, so therefore energy interaction between system and its surrounding can take place in through two mode one is work interaction other is the Hindi eight interactions. So I have already talked about that let me again repeat that energy can be exchanged between system and surrounding by two ways either by the work or the heat.

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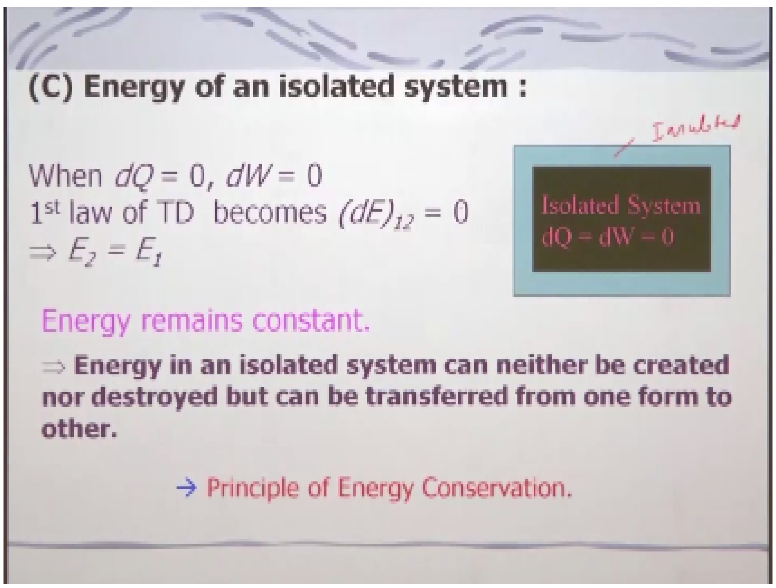

So now let us look at for an isolated system like isolated system means we will take a very rigid you know kind of a chamber where there is insulated this is insulated, insulated means you know it will insulate through such an extent that no heat will be going passing through the its boundary right and there is no work done of course it is rigid and there is no other you know shaft work and other things in this case there might be you know the ypd we work or the boundary work and there might be also the shaft work or some other form of work like electrical heating and other things but nothing is there.

So therefore DQ and DW is equal to0, so when DQ and DW is 0 then fast thermodynamic it turns out to be DE = 0 between you know state 1and 2, so therefore the energy at state 1is equal to energy at state 2 provided it is an isolated that means no interaction you know like either work or the heat is taking place and this you can state as energy remaining constant and which we always say that energy can neither be created nor be destroyed but can be transferred from one form to another and that is valid only for an isolated system not for all system okay.

So that is the, you know principle of energy conservation which we will be using in several places you know like in your application will be using that.

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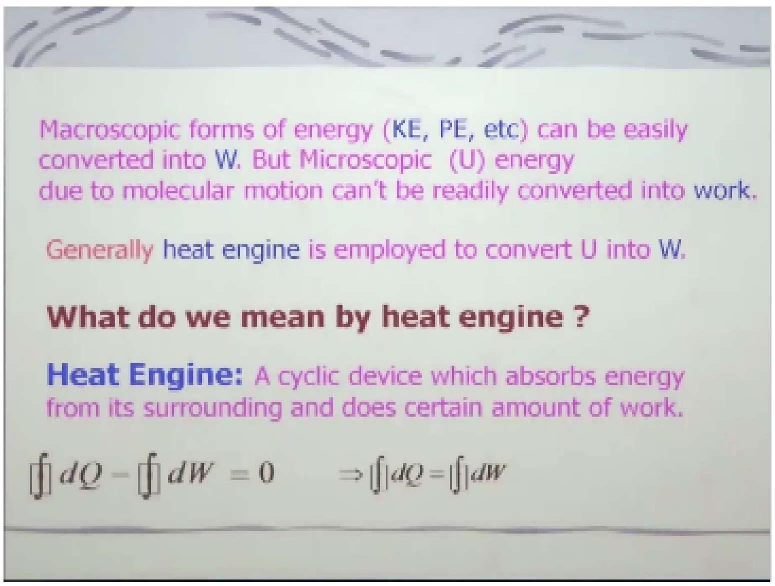

And as I told that microscopic forms of energy is kinetic and potential energy which can be easily converted into walk in contrast the microscopic form of energy that is internal energy which is due to the molecular mesh motion cannot really be converted into work it is quite difficult to do that and that is why we will have to find out various ways and means of converting the internal energy into walk and generally the heat is being employed heat engine is being employed to convert the internal energy into one right.

But what is a heat engine what do you mean by that? Heat engine is basically cyclic device which observed the energy from its surrounding and does certain amount of work that means it has to observe certain amount of energy I mean either it can be heat or it can be any other form right and then does certain amount of work whether it does all the work I mean convert all the heat into that into the work or not that question into a right to look at it.

So therefore as it is cyclic device therefore we can apply this DQ for the cycle integral minus the DW is equal to0 and DQ is equal to the DW of course the cycle this symbol is basically cyclic integral right.

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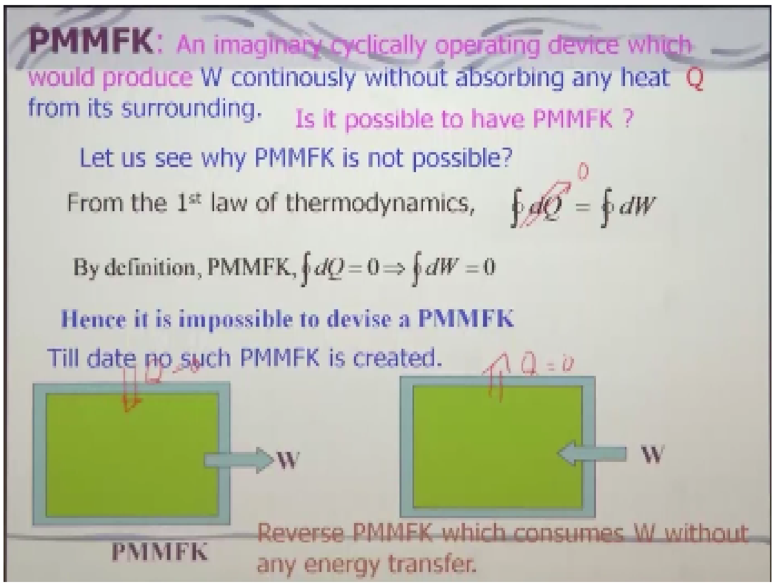

So if you look at is it really possible to have a engine heat engine which can absorb you know certain amount of heat but don't do any work in other words is it possible that without absorbing any energy from its surrounding can we have a engine and that kind of imaginary cyclic operating device which would produce the war continuously without absorbing any heat from a surrounding is known as perpetual motion of machine of first kind.

Later you might not be remembering few years back there was a person who is maybe a cool drop off but he was a what you call a technical nerd kind of things and then he started saying that he could produce some kind of oil you know without really doing this now were Raman Pillai his name you know and there was a lot of euphoria in this you could get something from the you know kind of this thing that is similar to that of course if you look at this concept has been captured this by the several people who try to work until today also some people will be thinking look I can get energy you might be knowing that there are several mystic people are the spiritual loop profit they say look I will get a something out of nothing you know like let us say I will get a wondrous will love out of nothing now how it is possible.

So it is similar to that that means you do not have energy and you will start working for example if I will not take food can I work really yes I may work for few hours you might be knowing that several people like who go on fasting a steelwork but those they use the stored energy which is there already in the body because if you go beyond maybe a month of fasting you cannot really do much work right, so therefore it is what you call violating let us see how it is violent that for example if I say that there is a without any observing for example like Epson can heat you need to observe certain amount of heat.

And then some do some work that is a basically heat engine suppose I say this is zero then that is known as perpetual motion machine of first kind if somebody of you know who do that it will be great you know like we need not have a lot of things right without absorbing energy, now is it possible to have a perpetual motion of first kind or not that what we will do we will have to apply the first law of thermodynamics and say look whether it is possible or not.

Because the several device you will find people have you know put forward adore they are claiming that they are having a machine if you look at your internet and you will find out like oh there are several of them you know even till today also some people will be trying but it violates the first let us see how why the perpetual motion machine of first kind is not possible from the first law of thermodynamics so I say that cycle integral of DQ is equal to DW and if this is 0 right 0 that is saying that without absorbing any heat right from the surrounding then what will happen the work done will be 0 okay work done will be 0 over a cycle.

So therefore you know it is not really possible to have a perpetual motion of machine of first time right let us look at other way around that means reverse that is the work being done on the system. Let us say there is a engine right by the surrounding and there is no heat being dissipated out like if you look at it has to be dissipated out here whenever you know work is done some heat has to go out and leave it is not then you know that is also not possible if it is zero but let us look at you know some of the examples where you may think look I can have that you know like I can have a perpetual motion abysm.

So let me just tell you also the till date no such perpetual motion of first kind is created although there are several claims are being made by various people starting from the jewels on words you know but nobody is successful in doing that.

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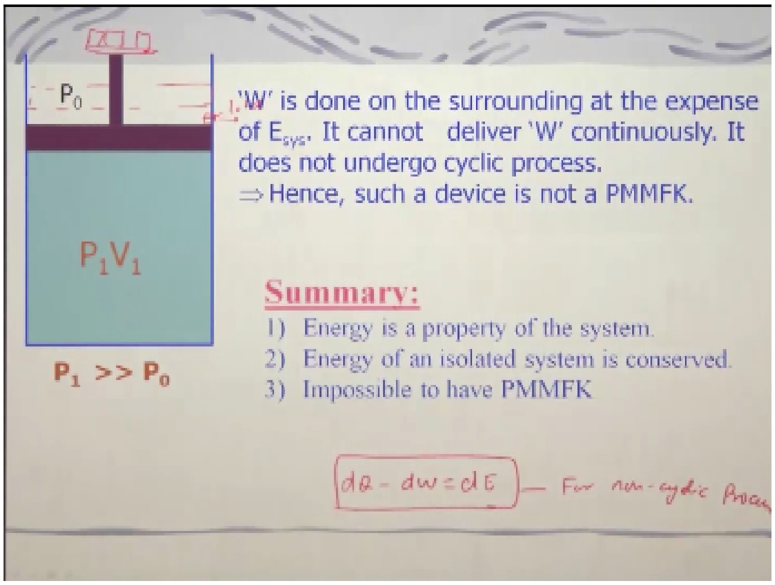

So let us consider a piston and cylinder kind of arrangement where it contains let us say gas at pressure p1and v1 and where p 1 is greater than the P_0 okay you can say that look let us have a latch here right which will stop I will remove this latch you know I will remove this latch right and then what will happen piston will go up or not piston will go up that means if I connect this piston to a rotary motion or something and then you know I can make it to rotate some work can be done right is it some work being done or not.

Because if I put some weight right here and then it is going against that and then some work being done right piston can be moving up then can you call it as a what you call because what's being done you are not giving any Heat are you giving any it and as you know but work being done can you call it as a perpetual motion of machine of first kind is it yes or no see there is a gas is here at high pressure and then you will you know and this is a lower pressure that whichever is acting as latch I will just remove it and then it will be expanded some work being done yes or no.

Now I have not given any you know heat here that means this is a perpetual motion machine of first kind am I right or wrong? Actually it is not because it is not cyclic process and this process will go on till it you know reaches equilibrium with the P_0 P1 goes on decreasing till P_0 that means where I am getting energy this energy store here and that is being expanded and converted into the work right and after that you cannot really come back to the original position.

So therefore it cannot be so and hence such a device is not a perpetual motion of machine of first time in summary what I can say is that energy is a property of a system right that we have seen energy of a nice old system is conserved impossible to have a perpetual motion machine of first kind that means that you can do the work without absorbing any energy okay.

So therefore this is the things what we have seen let me what you call just tell you that we have seen the first law of thermodynamics is applied for the what for cyclic process but however we have learned that derive an expression from the first law of thermodynamic foreign which can be applied for non cyclic process that is DQ - DW = DU or DE rather because if I say internal energy that means it is basically change in kinetic change in potential energy is niggle or negligible or almost equal to zero.

So therefore that equation is what we have you know we have derived that is DQ -DW = DE this is applied for non cyclic process right, so therefore this will be using it for various you know problems to solve and other things that will be discussing maybe in the next lecture thank you very much and we will continue also may be after this.

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