Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

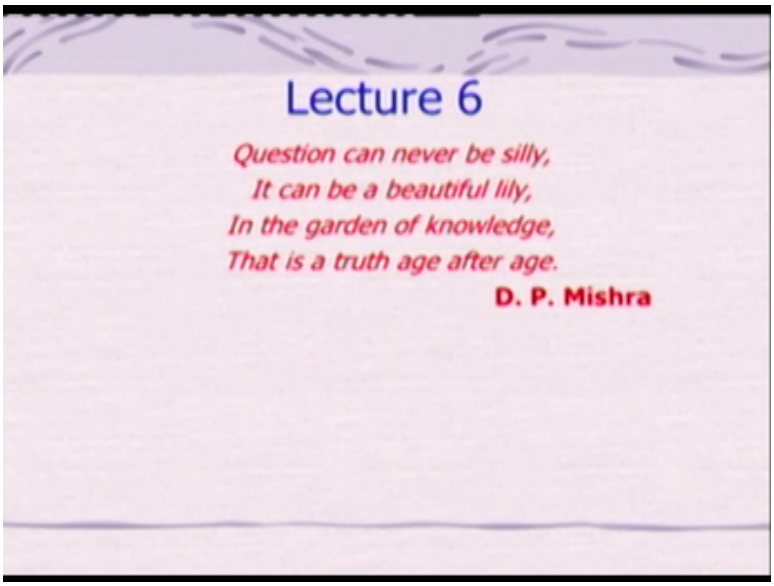
Course Title
Engineering Thermodynamics

Lecture – 06
Energy and its Interactions

By
Prof. D. P. Mishra
Department of Aerospace Engineering

So let us start this lecture.

(Refer Slide Time: 00:15)



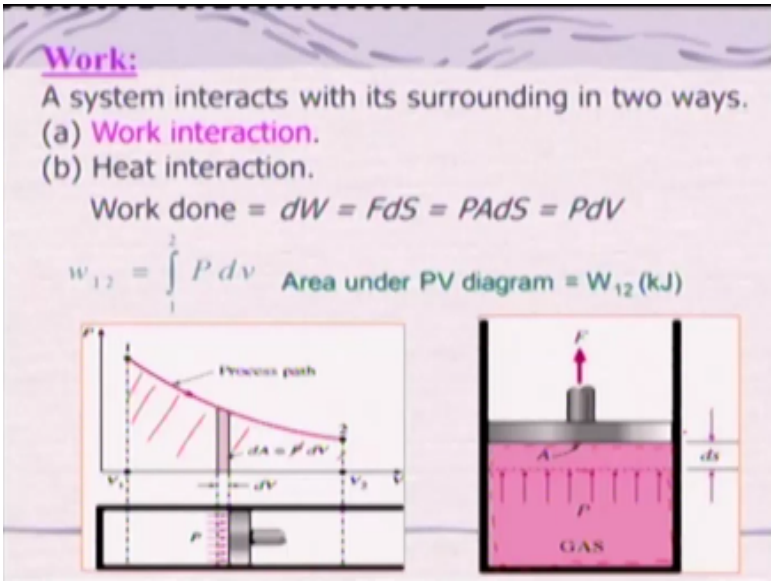
With a thought process that question can never be silly it can be a beautiful Lily in the garden of knowledge that is the truth is after age and when we wear all of you where you know in your baby stage you were asking too many questions but as you were growing you are not asking any question so that is the hard truth of life but it is very important to have questions. So let us you know talk about thermodynamics today and was before that let us recall what we learnt in the last lecture.

We basically looked at the equilibrium and various kinds of equilibrium and a thermodynamic system can attain equilibrium only when it can attain thermal mechanical and what you call

chemical equilibrium Allah also the phase equilibrium and then we looked at the what you call stability of the equilibrium process and for kind of situation we've looked at the stable unstable meta stable and neutral stable and will be most of the time discussing about the stable equilibrium phase but however in case of phase changes another thing we may invoke the meta stable conditions.

And we said this we learned a very important concept which is very essential for the classical thermodynamics that is a quasi-static process or a quasi equilibrium process, so we will be looking at the thermodynamic concept of work because if you look at a thermodynamic system can interact with its surrounding only two ways one is the work interaction other is the heat interactions first we will consider the work interaction and work interaction.

(Refer Slide Time: 02:35)



If we look at we will take our as usual you know piston cylinder arrangement which will be containing certain amount of gas and which will be having you know like a system here let us say kind of things to start with and which is balanced by this force and if this is being what you call reduced by δ F this force whatever acting then the piston earlier it was here with this and then it system boundary will increase you know this is the what you call movable boundary right and there is a displacement DS.

So if you look at mechanics from point of view right it is basically the you know force into displacement right as a result the volume like you are at the state one here and as you go on

decreasing the force and there will be increase in volume and it will be reaching a steady state another state - right and all the time you can think of that it is you know attaining the quasi equilibrium because we were changing the what you call the force by a very, very small amount very slow and there is no friction between the cylinder and piston or any other kind which will be really allow the system move reversible right in other words it will be make it for the process irreversible.

So if you look at from the mechanics point of view the work done will be what if I take this tiny strip here right and that is nothing but your you know this displacement you know like and if you look at this displacement you know piston has moved through this DS and force and DS and force is acting so that you know the force is acting with pressure P because from the system and then this is the surface area.

So it become PA and Ds and this what you call change in volume a and D and if you integrate this thing between the state one and two you will get PDV and so if look at for this to integrate what you need we should know the relationship between the pressure and volume right is in it then only you can integrate otherwise if the pressure is remaining constant what will happen then you know you can find out what is the change in volume and then you can do the work but however for and that is possible only for what isobaric process right.

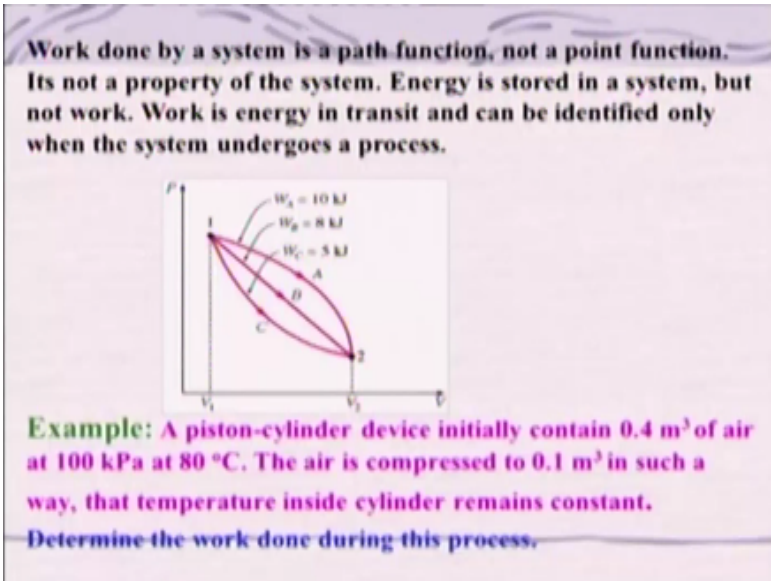
Where the pressure is remaining constant only the change in volume right but for other processes you should know the relations between the pressure and volume and if you look at this integral is basically this area you know that will give me the work done that means this area will give me if I integrate will give me P and V diagram that is in the plot PV diagram it will give me this area will give me the and which will can be expressed in the kilo joule.

Now during this process right is it the work is possessed by the system or not see if you look at the unit of the work is kilo joule or joule whatever you call right but that is the unit of energy am I right or wrong yes sir no is a energy, so is it work is same as energy is possessed by the system okay or if there is a you know interaction between system and surroundings there will be change in energy but is it there will be change in work also of the system actually it is not.

Basically work is work is done by expending the energy okay work is done by expending or by using the energy but the work is basically not the energy it is the energy in transit during the you

know process it occurs that means it is a basically boundary phenomena if you look at this way piston you know piston is moving if it is not moving because that is the boundary like if you look at this is a system boundary changing right.
Earlier it was started with this and then after the displacement it has moved through distance you know so therefore the work you know we call it as a boundary phenomena kind of things.

(Refer Slide Time: 08:12)



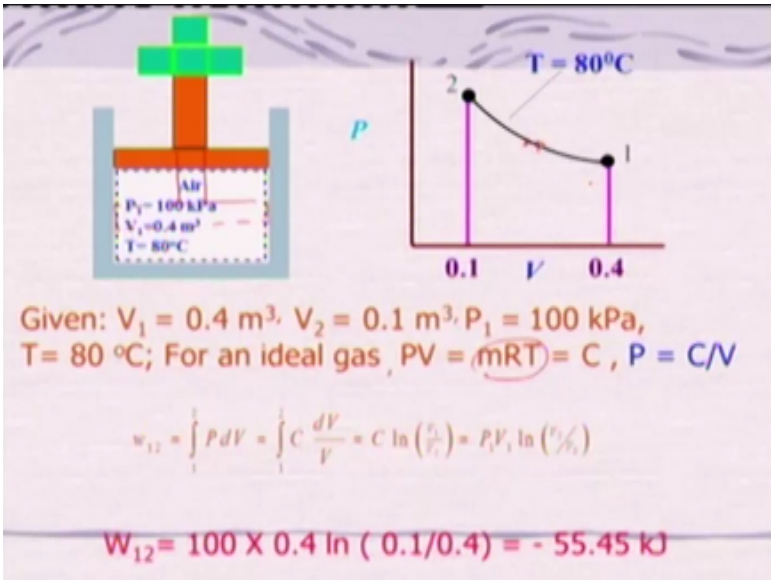
So and it will be dependent on you know like let us say if it is a it is going from station 1 - it is going to the station -it can go through path A it can go through path B and it can go through path C right the work like it can occur and if it is taking different paths the work done will be different for example the path if it take the path it will be ten kilo joule, if it is path B it will be eight kilo joule and if it is path C it will be something five kilo joule in this example right.

And then that means the work is basically dependent on the path, so therefore work done can be considered as a path function it is not a point function whereas energy is basically what is a point function therefore the work is not a property of the system because it is dependent on the path whereas the energy stored in a system, but not the work, work cannot be possessed by the system okay but whereas energy can be possessed by the system.

So therefore we call work is energy intrans it can be identified or can be manifested in only when system under goes the process if there is no interaction between the system and surrounding right okay then one man will be what right. So therefore one has to understand the difference between

work and energy let us take an example like a piston-cylinder device initially contains 0.4 meter cube of air at 100kPa at 80^0 Celsius that means you know if you look at volume is given to you pressure is given to you so also the temperature, here is compressed right to 0.1 meter cube in such a way that temperature inside cylinder remaining constant this basically isothermal process temperature remaining constant. And we need to determine the work done during this process.

(Refer Slide Time: 10:56)



So let us consider these as our system boundary right is a piston cylinder arrangement and air and 100 kPa and initial volume is 0.4 meter cube and temperature is 80^0 Celsius right and we will what you call it will be stationed here at this point and it will become press that means we will be putting some weight here, so that it will be compressed as that pressure of the system will be attaining a higher pressure with and it is a quasi-static process where as a week.

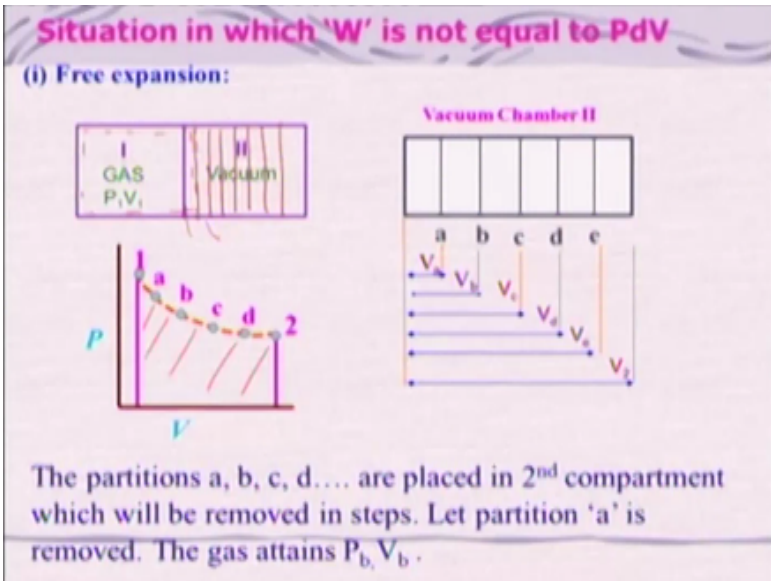
So the process will go on in this direction so that it is a attend the state to at which the volume is vertical 0.1 meter cube let us say you know by that piston may be moving through this process this is your station 2. So we need to find out basically work done, so these are the things are given like v1 is given 0.4 meter cube V 2 is given point what you call 0.1 meter cube and p1 is given and read kPa and temperature T resources.

So what do we can apply the ideal gas law we know that PV is equal to M RT and this R is basically specific gas constant here and if you look at if temperature is the remaining constant then what will happen to this term this is mass is remaining constant inside the system so therefore this is this term is basically a constant C. So therefore we get a relationship between P and V right P is equal to C / V.

And if we integrate take this thing that work done is equal to P DV 1 to 2 then you know you can put this relationship between the P and V here and you integrate it and we know that C is nothing but your P 1 V 1 right and you know the V 2 you know we want you put this thing to I mean put all the numbers whatever is there and then. So now this is coming with a negative sign what is the meaning of that that means what who is doing work here system or surrounding it is the surrounding that is doing the work on the system right are you getting?

If the system will be doing work then it will be positive that means this is basically compression work and if it is expanded that means piston will move if instead of from station to station one if you come back right it need not to take the same path okay, it may take path if it is reversible right if it is irreversible it need not to take the same path suppose I am here I will have to go to this then what will happen work done will be positive suppose I am at Station two and the eunuch I will be coming to the station one following the same path then I will get the same work done 55.45 kilo joule but with a positive design that means the work is done by the system on its surrounding is that clear okay.

(Refer Slide Time: 14:55)



So now let us take a situation in which one is not equal to PD because we have seen this is the PDV work okay but we can consider a situation where ET PDV is not there in picture let us say we will consider a free expansion one example I will be taking few example for that let us say that there is a two chambers right the chamber one contains gas at p1 v1 and in a chamber 2 is a vacuum, now there is a partition here I can remove this partition okay and the pressure here is vacuum.

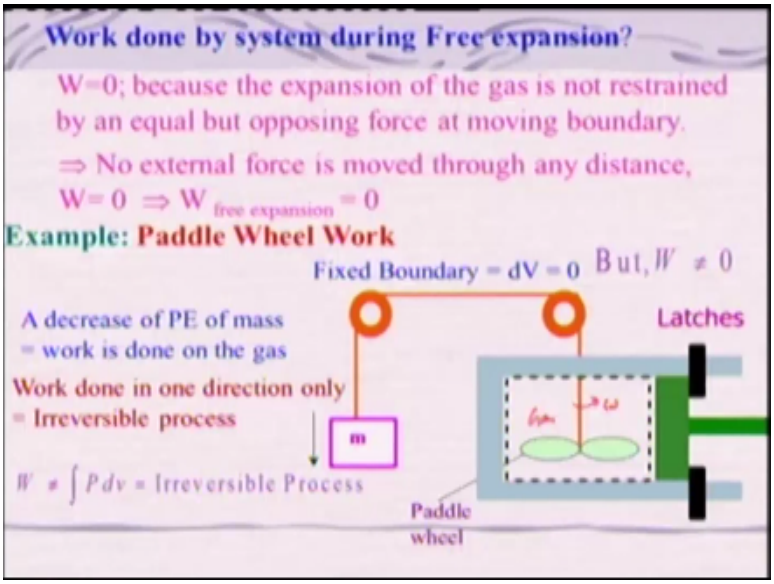
So what will be the work done let us you know do in another way for example what I will say I will place several you know partitions here these are all partitions right I will remove this partition first condition then what will happen the volume become this you know V 1 plus V a 1 this is your void chamber - okay v a1 this is begin new volume okay. Then what will happen the pressure will change am I right.

Because the gas is same in the system right and this system becoming like that you know for here earlier it was in this chamber1 and became increased, so that pressure will be what to come reducing am I right. So you can think of the pressure is here1 here and when this if the partition is removed here and then you know you will go to the point a right you can get and similarly another partition is being removed here this is being removed right you will get B and C D like that all the partition you will be removing and you can come up to a point with known as point 2 right.

You can say look I will take this area right and say that this is the what you come was done in a PD V since right is it true or not is it true or not actually it cannot be that is why that is the reason you know like I have put into this dashed line just to indicate that it is not a reversible process generally when you draw a you know process diagram in thermodynamic particularly classical come on I will use a solid line.

If it is a you know process reversible and irreversible process we use the dashed line that convention you should keep in mind but important point is there the work done will be not corresponding to this area what have shown here okay, why because the work done will be in this case what will be work done one then will be zero.

(Refer Slide Time: 18:28)



Because the expansion of gas is not restrained by equal but opposite force and the moving boundary because all the time it is zero pressure right is experiencing through therefore it is not cannot be as such and no external force is moving through a distance you know as such because the prayer the vacuum is remaining there. So free expansion is basically you know walk free expansion work or work done due to the free expansion will be zero.

So let us consider another example that is the paddle wheel right what we will do we will consider again a piston cylinder arrangement right but however you know this piston movement is being latched latch means it is fixed okay it is fixed that means it is not moving, so I will take

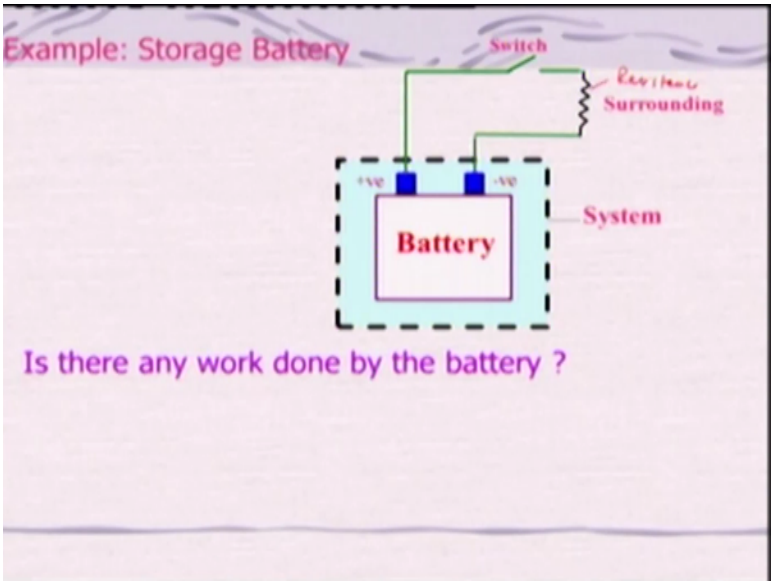
this as my you know system this is the dashed line I have put and there is a paddle wheel which is rotating which is rotating it is like a fan you are putting okay.

And then I can think of using joining with this you know pulleys to a mass and then mass is going down right so if it will go down and he is subjected to gravity what will happen right what will happen there will be change in some kind of potential energy okay but however when it is rotating here with some Omega in what you call some rpm or angular velocity Omega then you know like the there is no change in the bound fixed boundary.

That means there is no PDV work there is no change in volume right that means can you say that work done will be zero am I right or wrong what then will be zero or not or will it be finite actually it will be definitely finite because that is as I told earlier this mass is you know changing its position going downwards. So therefore there will be decrease in potential energy mass that means his work is done on the gas if I consider here as the you know in the system we call it as a gas you know.

So therefore the work done you know will be equal to that whatever is the change in potential energy keep in mind that this work done in only in the one direction suppose what will happen I will you know change this position like you know mass from the lower to the higher height what will happen it would not right and what will happen it may be you know rotated in the opposite direction that is all you can do right okay. But however it will be not reversible and then that work done in case of reversible process is not equal to P DV however for a reversible process we call it as basically the PD mean work right. Let us take an another example this is storage battery right.

(Refer Slide Time: 22:49)



So we take this as my system what you call this is my system and it is connected the battery is connected to a résistance this is the resistance and with a switch when I connect to that you know this resistance will be what you call activated and you can get some heat you know and you know that means the system if you look at is doing some work on it surrounding means in this case it is the resistance right now you understand.

Like what I call surrounding can I say air as a surrounding no is the resistance which is surrounding and which is acted upon by this system snow I want to find out how much work is done by this with the definition that means you know force will be acting it will be going through the displace mentor PDV work can I do that so in other words let me ask is there any work done by the battery of course it is being done am i right he said no because otherwise how the resistance is you know going and we are getting some heat heating effects if you can measure the temperature nearby resistance and then find out that is it change whenever the switch is on.

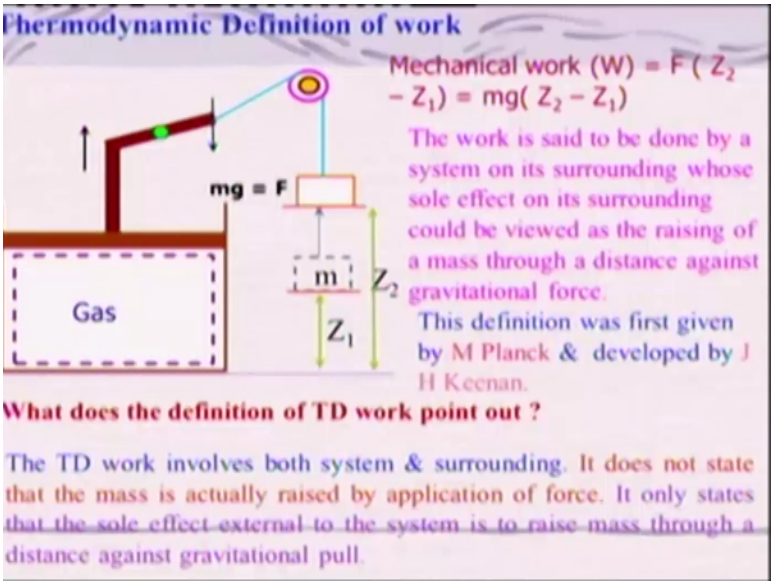
And batteries you know connected to the resistance right from the definition of war in mechanics what we have discussed till now in this casework done will be zero from that definition which why because there is no force which is moving through any distance however as I told the system has interacted with the surrounding that is the resistance hence the definition of work from the mechanics what we have seen has a limitation right.

It is not really working for all the things and whatever we will be handling in thermodynamics because the battery another things lot of non PDV work can be handled so therefore we need to

define the work in the thermodynamic sense right for that we will let us consider again our ten cylinder arrangement right which contains the gas here and this is my system and if you look at it disconnected to a lever to a and a pulley with a mass M.

And if this you know pressure is higher here and it may go upend as a result the hinge this will go down and it will be the mass will be letups say at in instant j21 and it is going to the you know to distance right so then what will be the work done what will you be work done because this masses moving through a gravitational force field so therefore the change in potential energy is nothing but your mechanical work that is if in into J 2 minus J 2 on this distance right and the F we know is the gravitational force so m into g massif this weight and G is the acceleration due to gravity and this from this what we can observe can we define can you redefine the definition.

(Refer Slide Time: 26:01)



War what we had seen in the mechanics from this so basically you can think of that the works said to be done by a system and its surrounding whose sole effect on its surrounding could be viewed as the raising of a mass through a distance against gravitational force and this definition was historically given first by the M plank which is the one of the pioneer in thermodynamic and developed later on by JH Kaman.

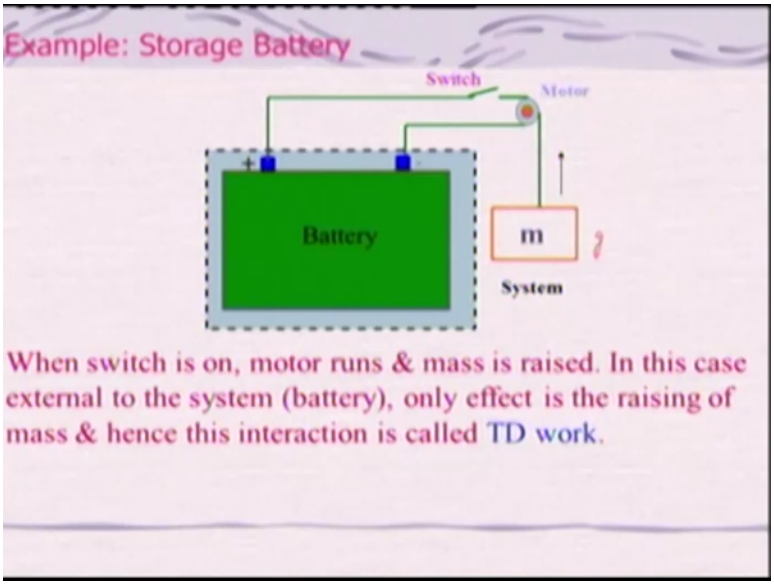
And what is the meaning of this is it is it that we will be telling look it has to be always raising a mass through the you know distance against gravitational force certainly know and what it says that the thermodynamic work involves both the system and surrounding it does not stay that

masses actually raised by the application of force in this case you know gravitational force what we are talking about it only states that the sole effect external to the system is to raise the mass through a distance against the gravitational pull.

You can take this you know as a imagination and then put it and then you can get the work done for all the system you know including the PDV work in other words by you know for non PDV work this definition can work now what we'll say to illustrate this point further we will take this again the storage battery example what we'll do instead of resistance what let it was here we will imagine that it is being you know connected you know replaced by a motor and then the motor is connected with amass and which is you know it can braised to the gravitational field right.

And then you can you know fit into the definition of thermodynamic very well right so although it is not a very we work but however it is being treated well in the definition of the thermodynamic form so if you look alike wind switches on motor runs admass is raised I have already explained this thing in this case external to the system that is the you know system in this case is battery only effect is the raising of mass is the interaction is called the thermodynamic.

(Refer Slide Time: 28:03)



World so keeping mind that no mass is raised through any distance against gravitational field however we are just saying that you know it is just a what we call adding this concept so that you can put into the vertical thermodynamic definition voice. So let us look at other work what will

be handling you know work done on the elastic solid bars so if you look at this a solid bar which is subjected to a force and it is having some cross sectional area.

Which is not being shown here let us say this will be a cross sectional area and when the force is applied what will happen that will be what it will elongate it and if you remove this force what will happen it will go back to the original position provided it is in elastic region righting which Hooks law will be valid you must be knowing from your mechanics right and one way it is you want to call reversible process right and one canals think of like as if the solid bares behaving like a spring whenever the force is applied within the elastic range of course in the plastic range .

It cannot be rights therefore the if you look at the work done is basically the force into the displacement if you look at their willed the displacement let's say the DX and what is the force is basically you know can be expressed in terms of what normal stress because when this force is applied this material will be trying to resist and it will develop a stress and this is this force is perpendicular tithe cross sectional area of the bar.

So therefore this is the normal stress and you can integrate this thing and get the work done as such so work associated with the stretching of a liquid fillet’s say you know there is a vertical moveable bar and then you can you know of course with is it frame here and if you leave this you know frame in the soap solution and you move this thing moveable where and then you can what you call get a fish right whenever you are applying certain force and it is this film is formed due to your surface tension.

I mean surface tense and you might be think what you will do is this you know like you know like your droplets are being formed due to the surface the raindrops and other thing and you can use this film for the Even flow visually yes and in fluid mechanics so we need to now of course look at how much work is done by this example like where the liquid film is being stretched by a force F so that is basically surface.

Or I am like you know tension work surface tension work will be Sigma s into a and this Sigma is basically surface tension force per unit length that is being defined into T and what will be this day here if you look at this diagram what will be data will be you know this is the length let’s say this is your X right and thesis your B what will be the change in length and this is your D X so

what will be the change in a day what it will bait will be see there are two surfaces there one is here another is other siderite .

So therefore it will be to the change in area will be to be in to be Right that is a change okay and then you can integrate this and then get that work done so let us look at some no mechanical forms of work like for example if you look at this reversible Daniel cell of course nowadays people are talking about fuel cells and other things you know which is a very hot topic and let us look at this Daniel reversible Daniel cell.

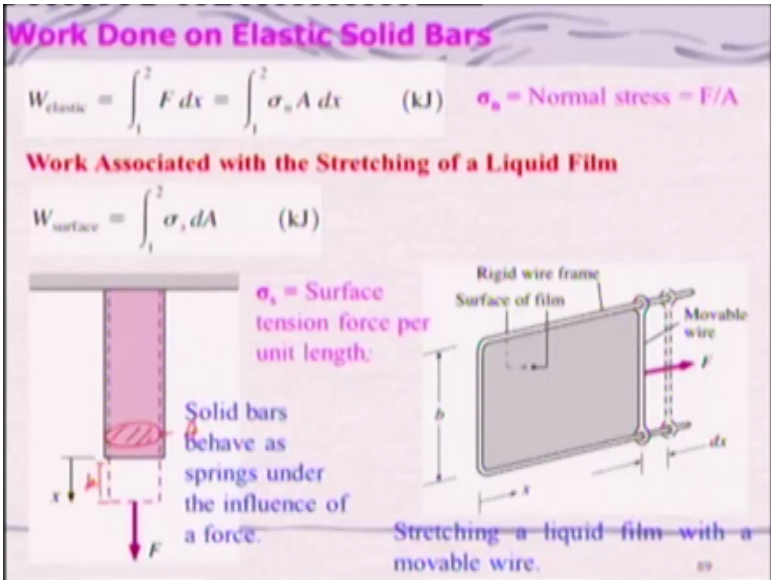
And which is having a copper electrode dipped into this solution copper sulfate and zinc electrode dipped in this zinc sulfate and with a membrane here and it disconnected to a potentiometer and of course this is G is basically galvanometer which is subjected to the voltage e and it is in equilibrium right let us say what will happen like in the potentiometer you will reduce the voltage very tiny amount okay then what will happen that there is some charge will be flowing through this and then you know some work will be done on that.

And if we do the other Way around you I mean like you know increase this voltage and such that the more you know charge will be coming from here and current work done by the surrounding on the system if I consider that so if you look at the work done will be nothing but e DS it where the DJ is the quantity of charge transferred through the external circuit like this is your external circuit and this is basically not mechanical and there will be a electrical work right electrical work is basically being you know produced due to the EMF .

That is the electric potential or there is basically a force and there will be displacement one can think of electrical charge will be moving and then we cancel it as basically what you call some kind of work we can really find similarly the magnetic work the magnetic work is basically defined as the production of magnetic field strength and the total magnetic dipole moments so there are various forms.

You know work one can think of and which we may deal with sometimes but most of the time we will be working with the PDF work right and so various forms of work you know you may brush it up and see that let us now we generalize is by considering various modes of work we have taken here compression and expansion.

(Refer Slide Time: 29:15)



If you remove this force what will happen it will go back to the original position provided it is in elastic region right in which Hook's law will be valid you must be knowing from your mechanics right and one way it is you want to call reversible process right and one can also think of like as if the solid bar is behaving like a spring whenever the force is applied within the elastic range of course in the plastic range it cannot be right.

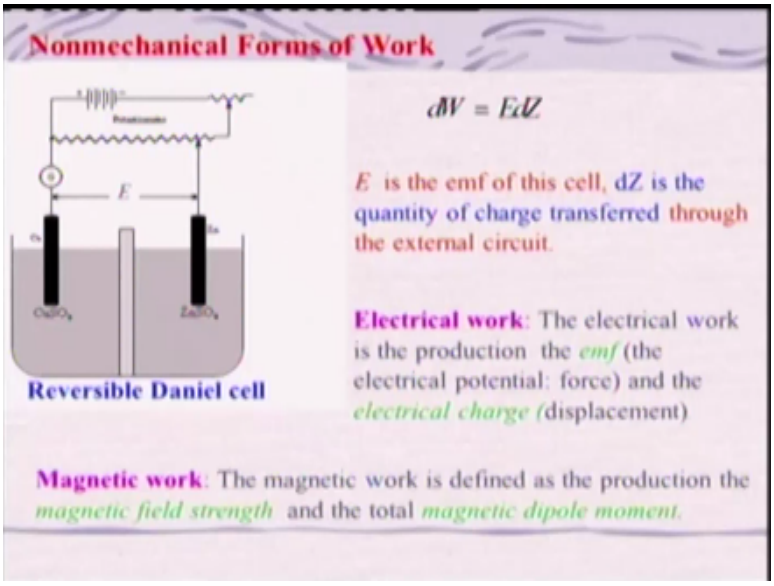
So therefore the if you look at the work done is basically the force into the displacement if you look at, there will be the displacement let us say DX and what is the force is basically you know can be expressed in terms of what normal stress because when this force is applied this material will be trying to resist and it will develop a stress and this is this force is perpendicular to the cross sectional area of the bar.

So therefore this is the normal stress right and you can integrate this thing and get the work done as such, so work associated with the stretching of a liquid film let us say you know there is a vertical moveable bar and then you can you know of course with is it frame here and if you leave this you know frame in the soap solution and you will move this thing moveable where and then you can what you call get a fish right whenever you are applying certain force and it is this film is formed due to your surface tension I mean surface tense and you might be think what you will do is this you know like you know like your droplets are being formed due to the surface the raindrops and other thing and you can use this film for the Even flow visually yes and in fluid mechanics.

So we need to now of course look at how much work is done by this example like where the liquid film is being stretched by a force F so that is basically surface or I am like you know tension work surface tension work will be Sigma s into a and this Sigma is basically surface tension force per unit length that is being defined into T a and what will be this da here if you look at this diagram what will be da that will be you know this is the length let us say this is your X right.

And this is your B what will be the change in length and this is your D X so what will be the change in a da what it will be it will be see there are two surfaces there one is here another is other side right so therefore it will be to the change in area will be to be in to be X right that is a change okay and then you can integrate this and then get that work done as such.

(Refer Slide Time: 33:52)



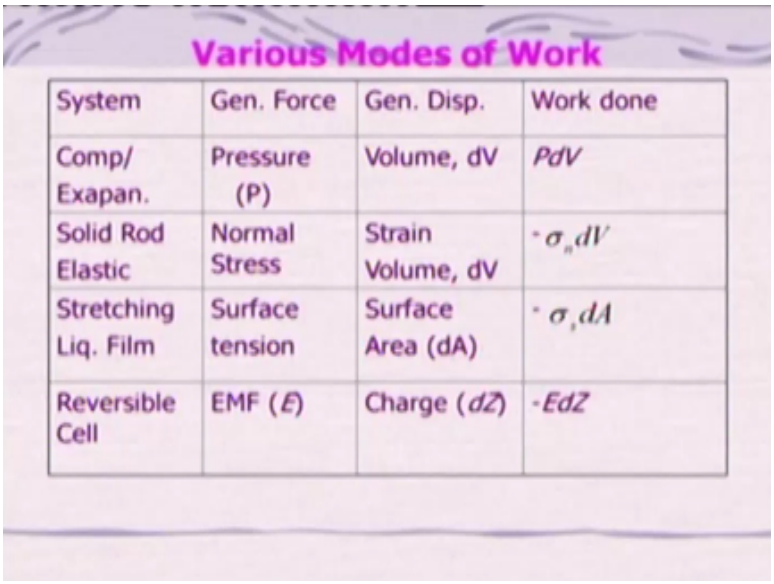
So let us look at some non mechanical forms of work like for example if you look at this reversible Daniel cell of course nowadays people are talking about fuel cells and other things you know which is a very hot topic and let us look at this Daniel reversible Daniel cell and which is having a copper electrode dipped into this solution copper sulfate and zinc electrode dipped in this zinc sulfate and with a membrane here and it is connected to a potentiometer and of course this is G is basically galvanometer which is subjected to the voltage e.

And it is in equilibrium right let us say what will happen like in the potentiometer you will reduce the voltage very, very tiny amount okay, then what will happen that there is some charge will be flowing through this and then you know some work will be done on that and if we do the other way around you I mean like you know increase this voltage and such that the more you know charge will be coming from here and current work done by the surrounding on the system if I consider that.

So if you look at the work done will be nothing but e DS it where the DJ is the quantity of charge transferred through the external circuit like this is your external circuit and this is basically not mechanical and there will be a electrical work right electrical work is basically being you know produced due to the EMF that is the electric potential or there is basically a force and there will be a displacement one can think of electrical charge will be moving.

And then we can call it as basically what you call some kind of work we can really find similarly the magnetic work the magnetic work is basically defined as the production of magnetic field strength and the total magnetic dipole moments. So there are various forms of you know work one can think of and which we may deal with sometimes but most of the time we will be working with the PDF work right and so. So various forms of work you know you may brush it up and see that.

(Refer Slide Time: 36:54)



Let us now we generalize is by considering various modes of work we have taken here compression and expansion that we have seen that is in the from the mechanics point of view and then pressure and if you look at general forces your pressure and there is a general displacement which can be to the DV change in the volume and the work will be basically PDV in case of solid rod which is elastic in nature I mean like elastic you can say elastic regime then only we can talk of that is the normal stress right.

So if you look at that is basically normal stress and the strain volume change then we can saw Sigma n DV kind of things and we have also seen the stretching of a liquid film which is you know with the surface tension force rate per unit length and then surface area comes into picture like and then we will get Sigma similarly the reversible self the EMF E is being you know change and it is make this charge to move either you know from the cell to the outside surrounding or from the surrounding to itself and we call it is it right.

So now if we put it you can put in a very general form that is changing the work or the work done is equal to FK that is a generalized force and DX is a generalized displacement right so if you look at although we started with you know criticizing the mechanics definition of the work but we are trying to assimilate like all the forms of work in this form and which is coming within the realm of the thermodynamic definition of work.

So therefore we will be using these various modes of work as a told earlier that work is basically energy you know in transit and also it is dependent on the path of the system and unlike the

energy is dependent on this energy is possessed by the system and it is basically a point function is a property of the system and whereas the work is not a property of the system. So these are the things which we will be dealing with and we will be looking at in the next lecture about the heat interaction and as I told that in a thermodynamic system will be interacting with surrounding with the two modes one is work as it is it so in the next lecture we will be discussing about it in direct. Thank you very much.

Acknowledgement
Ministry of Human Resource & Development

Prof. Satyaki Roy
Co-ordinator, NPTEL IIT Kanpur

NPTEL Team
Sanjay Pal
Ashish Singh
Badal Pradhan
Tapobrata Das
Ram Chandra
Dilip Tripathi
Manoj Shrivastava
Padam Shukla
Sanjay Mishra
Shubham Rawat
Shikha Gupta
K. K. Mishra
Aradhana Singh
Sweta
Ashutosh Gairola
Dilip Katiyar
Sharwan
Hari Ram
Bhadra Rao
Puneet Kumar Bajpai
Lalty Dutta
Ajay Kanaujia
Shivendra Kumar Tiwari

an IIT Kanpur Production