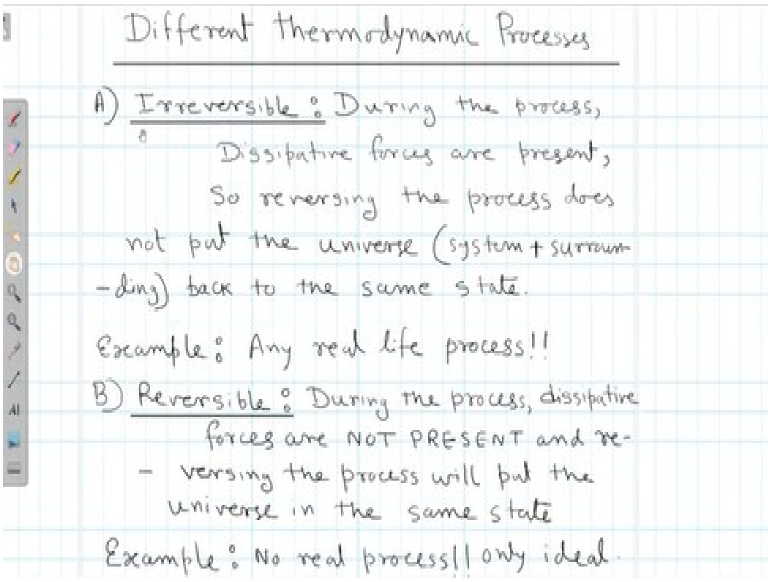
Thermal Physics
Prof. Debamalya Banerjee
Department of Physics
Indian Institute of Technology, Kharagpur

Lecture - 32
Basic Concept of Classical Thermodynamics (Continued)

Hello and welcome back to another lecture of week 7 of this NPTEL course on thermal physics. Now, in the last lecture or basically the first lecture of this week onwards we have started discussing classical thermodynamics and the last lecture we have discussed we started discussing the terms we need to learn before we go into the details or the formulation of classical thermodynamics so we started by defining a system a surrounding.

We started by discussing thermodynamic state thermodynamic equilibrium thermodynamic process and maybe some other parameters. I do not remember exactly but all I think these things were covered. Now, today we will continue from there and we will discuss about two main thermodynamic processes that we need to encounter frequently during the discussion of classical thermodynamics.

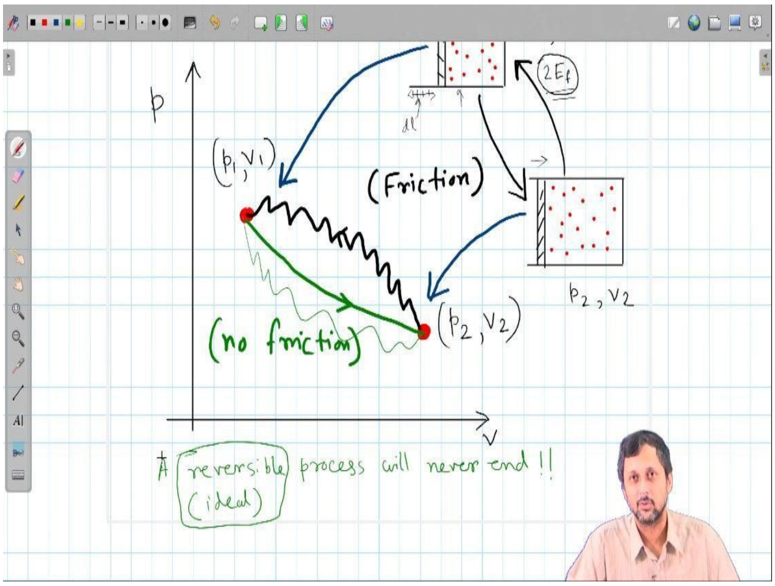
(Refer Slide Time: 01:22)



So, the first thing we when there are two major types of or rather three major types of processes, we will be discussing. The first one is the irreversible process second one is the reversible process and there is a third type types that we call the quasi-static process. But quasi-static process is not actually you know it cannot be categorized like we have categorized we have already categorized reversible and irreversible process here it is a more of a conceptual categorization.

So, we will come back to that. Now let us start with the definition of an irreversible process. So, in the last class we talked about a diagram.

(Refer Slide Time: 02:08)



So, let us go back to this type I mean basically we talked about one such diagram where the process the system in our case it is a closed cylinder closed gas system inside of Piston cylinder arrangement. So, the initial state was sorry P 1 V 1 and then if we just let it expand then the piston will move out so the volume will increase pressure will drop so it will go to the second, another state which is given as P 2 V 2 on this PV indicator diagram.

Now, there are and I said that there are many different paths the system can follow from going by for going from the first point to the second point. Now there are 2 such illustrative paths here. There is a green path which takes the system from P 1 to our or just a state 1 to state 2 and there is a zigzag black curve that takes the system from this state 2 to state 1 once again. Now, what are the implication and why I have put one smooth line here, once exact line here.

So, let us look into it. So, far we have discussed about processes which are idealized although I have first written irreversible will start with the definition of reversible. So, what do you mean by idealized process? Idealized process is in the process where there is no dissipative force present. For example, we have always ignored the friction between the cylinder of the, I mean the cylinder inner cylinder or inner wall of the cylinder and with the piston.

Similarly, if there are other forces for example inside the gas assembly, when we are compressing the gas when we are compressing it there must be some kind of a viscous force which is also acting between the gas molecules and we have discussed about this already. So, these are all dissipative forces. What do you mean by dissipative forces? Dissipative forces means let us say if there is a friction. So, let us first forget about these dissipative forces.

And discuss the ideal process. Now in an ideal process there is no dissipation present and the piston moves by following let us say this green path which is a smooth curve joining point the first state and the second state here. And when we say that we assume that if we can now reversibly or we so sorry once again if we considered the idealized situation so we considered that if I now start compressing the gas then we can have take it back to this state.

And so basically, we can draw another path another smooth curve from here to here and after this one complete cycle the universe that means the system. So, this is our system and this is the surroundings you know basically system plus surrounding is the universe in the concept of thermodynamics. So, the universe will be in the same state once we go from here to here. So, basically if we go from here to here sorry so, we go from here to here.

And in reverse we can go from here to here so there is no change in the universe after the cycle is complete. So, this is called a reversible process. Also, one more thing when we are talking about the expansion or compression of this piston we always assume that this process is infinitesimal we have heard about this every time. So, basically what it means see we talk about a displacement here sorry this stylus right and displacement by.

So, I mean finally it has to be a finite displacement but when we talk about infinitesimal process what do we do, we basically divide this entire travel range into tiny subdivisions and each such subdivision is called the infinitesimal displacement dl. Now, what is the value of dl? Ideally speaking in terms of mathematical definition dl is the value of dl is smaller than you can think of.

If you say that in your perception is one if 1 micrometre is the smallest distance then dl is definitely less than 1 micrometre. If you think 1 nanometre is the smallest possible distance then dl mathematically speaking is smaller than 1 nanometre. So, dl is an idealized concept and the reversible process what we see this is not possible in reality because of two reasons; first of all, in a real world there are always frictional forces present and secondly there are the so any real process cannot be made infinitesimally small.

So, these are two reason why and reversible process is not I mean it is only ideal in reality it can never be realized. Now, what happens in a real process? In real process we have or rather all the real processes are practically speaking irreversible. What do we mean by irreversibility? Forget about this infinitesimal displacement let us assume that we are making finite displacement only.

And but we are making this displacement you know such that somehow the system stays in equilibrium during the entire displacement which is once again is not possible but let us assume that for a moment. But now if the frictional forces are present here if we have frictional forces between these two wall and the cylinder, I mean inner wall and the cylinder then while the piston is moving outward or when the piston is moving inward.

In both cases there will be a dissipative force or there will be a there will be a certain amount of energy that will be lost in this frictional dissipation and let us call this energy dE. So, it is de or rather not d let us call it E f. So, E f will be exhausted when we are going from state one to state two and same E f will be exhausted when we are going back from state two to state one so altogether in this process an energy of 2 E f will be lost.

I think I can make you understand. So, the frictional forces are not reversible, the state might go back from here to here but there will be a net loss of 2 E f where E f is the frictional energy dissipated in one particular direction. So, altogether there is always a loss and because of this loss a process although we on this PV indicator diagram we can take this gas assembly back from one state one to state two.

Even, in an idealistic situation even if there is no friction. I mean sorry even if the intermediate states are in equilibrium which is once again not possible, we still have and lost energy that is here that is given here. And this is why although the system goes back to its original state the rest of the universe there is some change. So, that is called an irreversible process where the process does not put the reversing the process does not put the universe which is system plus surrounding back to the same state.

So, the example any real-life process is a irreversible process. Now, what is the way out? First of all, so before that so generally we represent an irreversible process by this type of a zigzag diagram. This means an irreversible process, now in irreversible process exact amount of energy dissipated can be calculated but the only thing is it cannot be reversed. So, what I mean to say is even if we reverse the process that dissipative energy will still be lost in once again it will be lost.

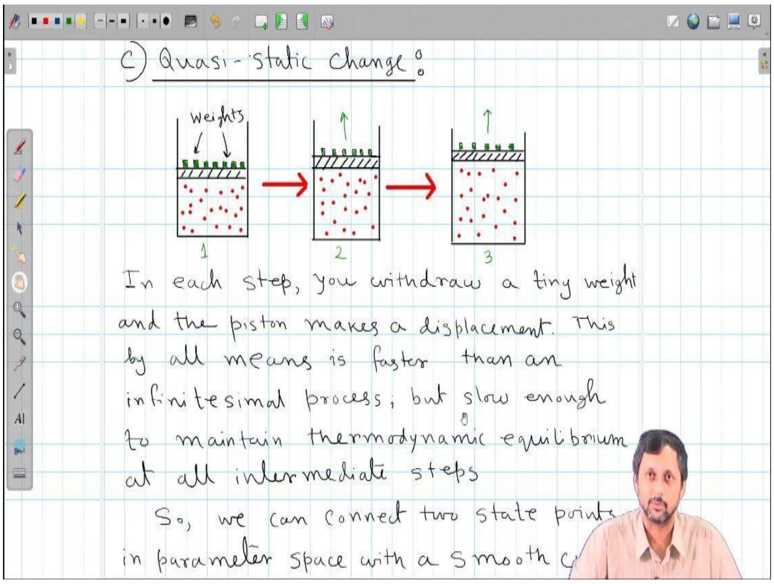
And the total change in system plus surrounding will be non-zero. So, I just intentionally have made one part of it you know in a reversible manner the other half in an irreversible manner. But in reality, for any process both these sides are irreversible both the forward process and the reverse process are actually irreversible anyway now. So, what we can do in order to make things close to ideal is one by reducing the friction that we can do.

There are many different ways of reducing the friction of course we cannot make it 0, but if let us say the total energy involved in the process is much higher as compared to the dissipation loss then probably, we can ignore the dissipation loss. But one then comes the question of infinitesimal displacement. Any reversible ideal process is infinitesimal I mean it is a collection of infinite decimal displacement.

And as I have already said an infinitesimal displacement is smaller than what you can think of. So, what I mean to say is an ideal reversible process a reversible process will never end. Why? Because, the displacement is smaller than you can think of the time it will take to make any finite this the piston will take in to make any finite countable displacement is infinity. So, a reversible ideal process will never end.

So, I should also write the word ideal under this one. So, basically it is not only a reversible process but it is a reversible ideal process that will never end. So, we have to find out a way and so basically, we have to strike a balance between the ideal case ideal word and the real life word and that is where we come up with the concept of a quasi-static change.

(Refer Slide Time: 13:19)



So, once again we take an example of a piston gas piston and cylinder arrangement. Let us say we have a certain amount of gas enclosed inside this piston and we have small weights placed on the piston ring on the piston plate. So, now this weight in the first position in this case position 1 this weight is exactly equal to the internal pressure. I mean it is sufficient to balance the internal pressure and there the piston is in a stationary position.

And these weights are small finitely small not infinitely small few grams depending on the situation maybe few grams maybe tens of grams but these are small ones. Now, what we do? We start reducing this one-by-one and we go to position two you see we have reduced some of the weights and as a result the piston is moving upwards. We reduce some more weight, go to position three and piston is again moving upwards.

So, you see there is a when I go in the same line every time, we reduce a weight the piston move upwards. So, this is a kind of practical compromise to realize a reversible process in it is a realization of reversible process in real life. Of course, here we cannot ignore friction because it is a real-life process but we can say that friction is negligible as compared to the actual work being done or the energy being exchanged during this process.

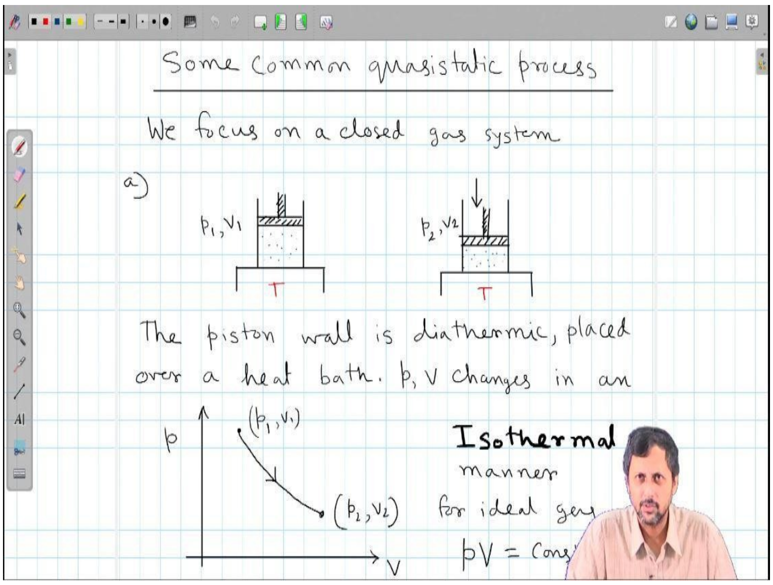
So, this is called a quasi-static process and in a quasi-static process you see this is a smooth line which eventually means going from state 1 to state 2 every point basically straight line is an infinite array of point. At every point the system is in equilibrium which is not practical every time we reduce this tiny weight it will move up slightly and there will be an intermittent, I mean non-equilibrium state in this gas assembly.

That is must you cannot ignore that I mean you cannot avoid that it will happen for any finite change. So, what happens is we although we draw a straight line in reality what we can the best we can realize is a line sorry which closely follows the straight line but it is actually not a smooth line but it is a collection of closely spaced finitely spaced points. So, it is not an infinitesimally slow process but it has to be a slow process so that we can connect the point.

Once again, we will see that actually in most of the time when for example when we will be discussing engine. The displacement of an engine piston is not slow, but we assume that the process is quasi static and we can treat it using the classical thermodynamics. Otherwise, you see all the equations of state we write all this integration we are going to so, what I mean very soon we will come back to work and we will see there are integrations involved.

So, let us discuss it then so basically what I mean to say we have quasi static process which is a balance between ideal process and a completely non-ideal process.

(Refer Slide Time: 17:03)

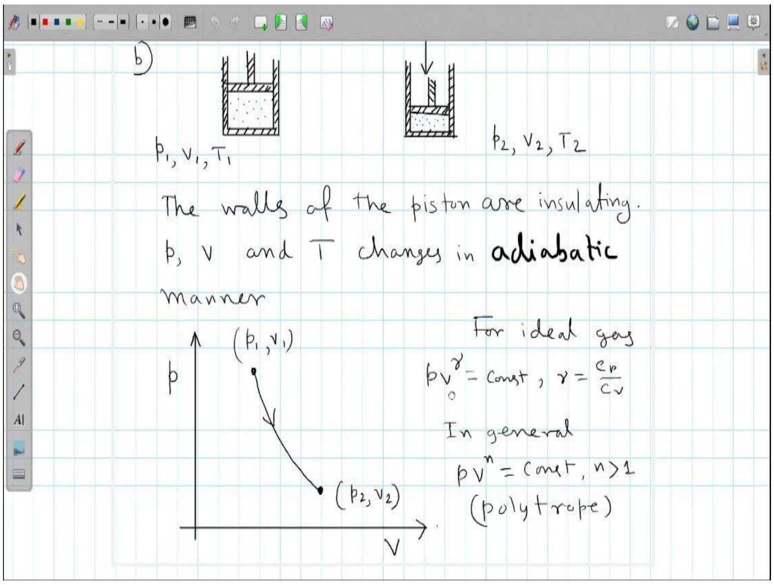


So, let us take some example some common example of quasi static processes which we commonly encounter in classical thermodynamics. The first process is let us say the cylinder piston arrangement we place that on a heat path and then we slowly compress it. So, when we slowly compress keeping it on a heat path and let us assume the wall of the cylinder is diathermic. So, that means heat energy can exchange.

So, if the process is slow enough then we will have intermittent equilibrium and the temperature of this thing will not the gas assembly will not change. Then we know that from for an ideal gas we will have something like a PV is equal to constant and in a PV isotherm or this is this process is called an isothermal process and we can draw a PV and isotherm in the PV diagram please remember that although we are drawing it like a smooth line.

It is actually a combination of discrete points, because it is a quasi-static process. This we have to always keep in mind I will not be telling this explicitly every time but please keep in mind that every line we draw is actually not realized in reality, but what we have is a collection of closely spaced experimental points. So, this is an isothermal process and for ideal gas PV is equal to constant.

(Refer Slide Time: 18:33)



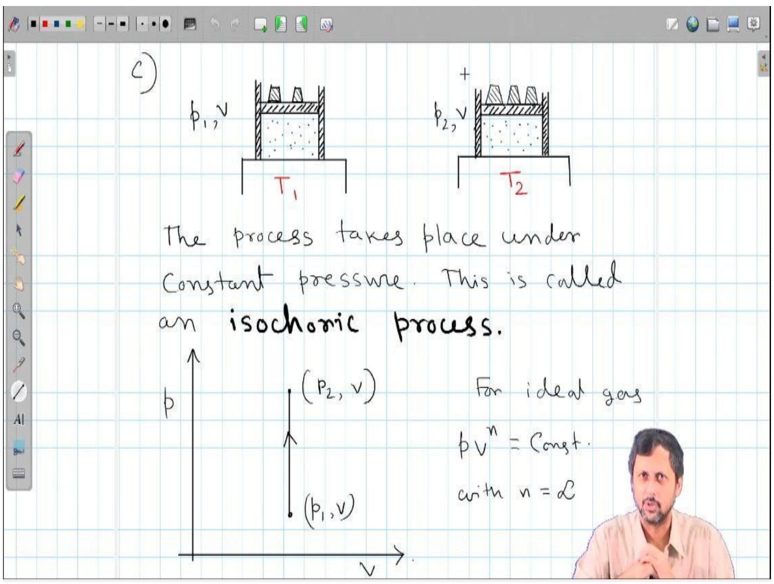
Now, if we do this compression for an isolated cylinder that means if we have a thermally isolated cylinder and we still compress it then not only PV but also temperature changes. So, we have PV T 1 P 1, V 1, T 1 and from there we go to P 2, V 2, T 2 and in this case, there is no exchange of heat energy with the surrounding. So, this process is called an adiabatic process. Now for an ideal gas we know that adiabatic process is PV to the power gamma = constant.

We will prove that in a when we will be discussing adiabatic process once again or actually you can do it yourself, I mean I need not do this it is so simple. So, this is gamma = C p by C v. Now, in a PV diagram like I you know like the isothermal process we can also draw the indicator diagram for an adiabatic process. Only thing is in this case the slope will be more as compared to the isothermal process.

So, this probably we will discuss or I have not decided yet maybe I will just give it to you as a problem. One more thing for interest is the polytrophic process. So, in general so for ideal gas we have P v to the power gamma = constant but, we might not have the exponent exactly equal to gamma we can have an exponent which is anything greater than n that is possible. So, in general this is called a polytrophic process.

And we will only assumption we have during this process that during this process the heat capacity of the system remains constant. So, we will come back to that so please remember this PV to the power n with n greater than 1 is the equation of a polytroph and for any polytrophic process we have a indicated I mean a slope which is greater than the corresponding isothermal process.

(Refer Slide Time: 20:37)



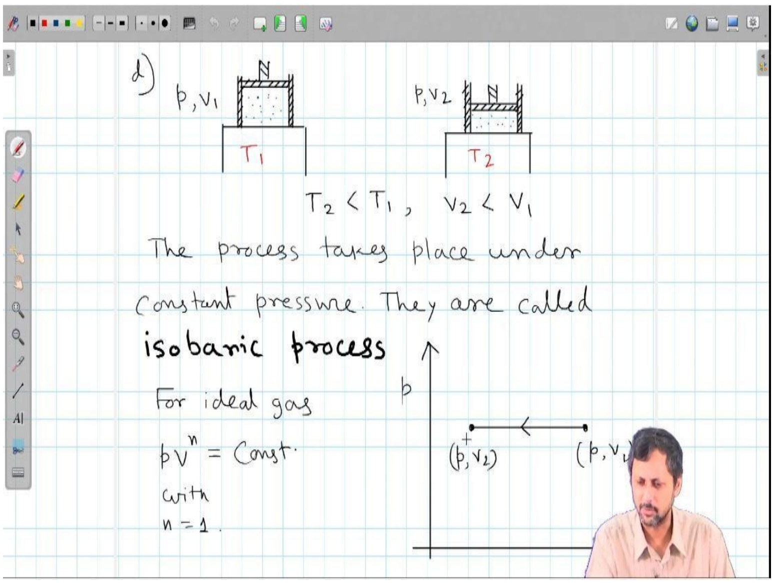
Next one is, let us say we have the gas assembly we once again the bottom layer is diathermic. So, it can exchange heat with the heat reservoir sorry in this case also only the bottom reservoir or sorry the bottom part should be diathermic. So, we should not allow any heat exchange or heat leakage from the sides. So, we should have a completely isolated site and a diathermic bottom so, I hope you understand this.

So, in this case also the same picture, but now we are so with these two words we are putting it at a pressure P, P 1. Now what do we do we just move it to another heat path we do not allow the volume to change volume remains at V. But now if T 2 is greater than T 1 what happens? Pressure increases. So, we need to put some more weight instead of two maybe we need to have some third weight in place. So, that the piston does not move.

So, this process in which the volume does not change is we called an isochoric process now in an isochoric process, isochoric process can be represented on a pivot indicator diagram as a vertical line. See the volume does not change only pressure goes from P 1 to P 2 and for an ideal gas we have PV to the process can be represented by this equation PV to the power n = constant with n is equal to infinity or rather n tends to infinity.

And n can never be equal to infinity I should write n tends to infinity. So, for very high value of n without any change in P we can sorry without any change in V we can have change in pressure.

(Refer Slide Time: 22:50)

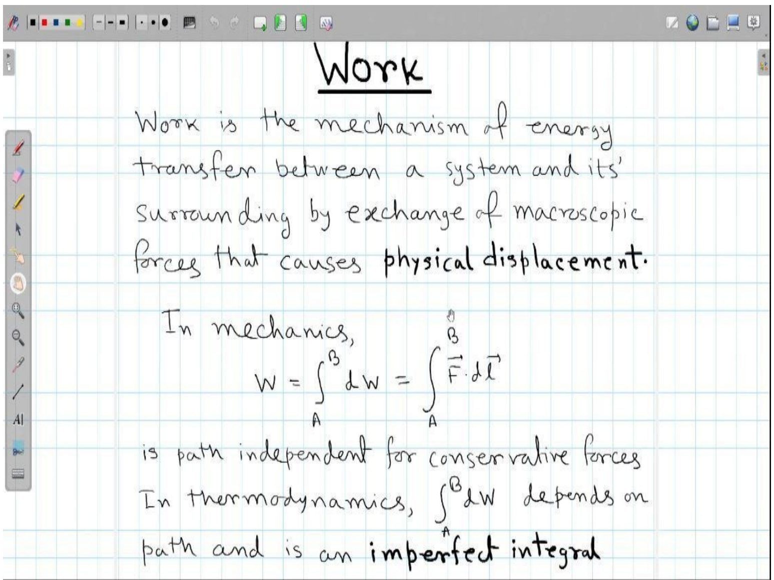


Similarly, if we now maintain the process the cylinder in, we change the temperature such that we maintain the pressure inside the cylinder. So, it is very simple if T 2 if the second heat was T 2 is less than T 1 then what happens the pressure drops and correspondingly sorry the so let us assume this pressure inside is just good enough to hold this cylinder or sorry the piston in in a floating position.

Now, when we place it on another heat path where temperature is low what happens is pressure in initially the pressure will drop because the temperature is low. And then after a certain time the volume will be compressed such that the pressure increases again and once again this gas assembly will be sufficient to hold, I mean the pressure inside will be sufficient to hold this weight in floating position.

So, the pressure here and here is exactly the same only the volume changes. So, in this process which takes place under uniform pressure is called an isobaric process and this is given by a horizontal line in this PV indicator diagram. Once again, we can for an ideal gas, we can write PV to the power n is equal to constant with n is equal to 1 in this case. So, this is an example of isobaric process.

(Refer Slide Time: 24:22)



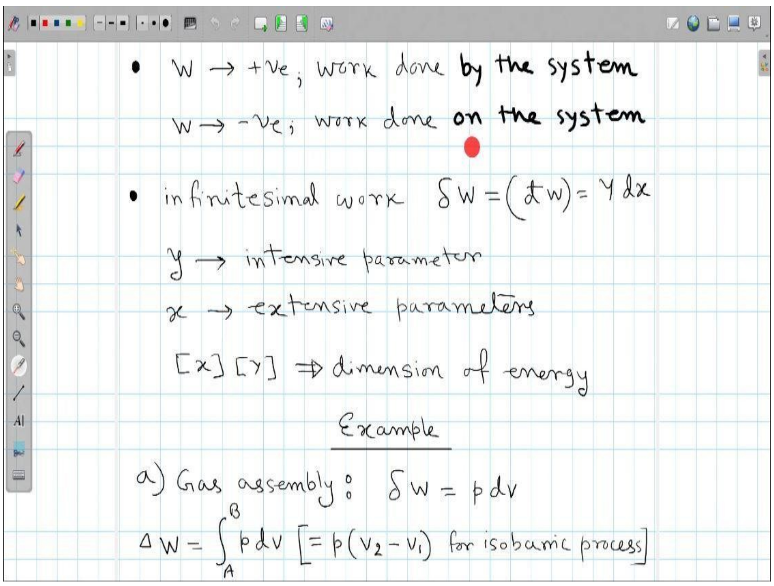
Next comes work. Now what is work? Work is the mechanic or basically work is an energy transfer in which the; exchange of energy transfer by means of exchange of macroscopic forces which causes physical displacement of the system. Physical displacement of any part associated with the system, in this case the examples which we have taken so far is the piston that is moving. So, there is a physical displacement involved.

Now, in mechanics we know that the work done W is equal to A to B dw which is A to B F dot dl. Where F is the force and dl is the infinite decimal displacement. So, we have to compute this integral from the initial point to the starting point and for any conservative force field this integration is path independent. So, irrespective of whichever path we take going from the first and the last between the first and the last point we have equal work done.

That is from classical mechanics for conservative forces, but in general in thermodynamics the forces are not conservative. And what we have is an imperfect integral that means the integration is path dependent. Depending on which path the system takes from going from first state the state a to state b or first state 1 to state 2, if the work done will be different so let us go back to this diagram.

So, it if I take this path, we will have one work done if I take this path, we will have one work done so on and so forth. Now, just to you know give you a little more insight that although we are talking about gas and you know gas, I mean closed gas systems in general but as we have discussed there could be many different types of thermodynamic systems. And we can define a suitable work function or you know the suitable definition of work for those systems as well.

(Refer Slide Time: 26:44)



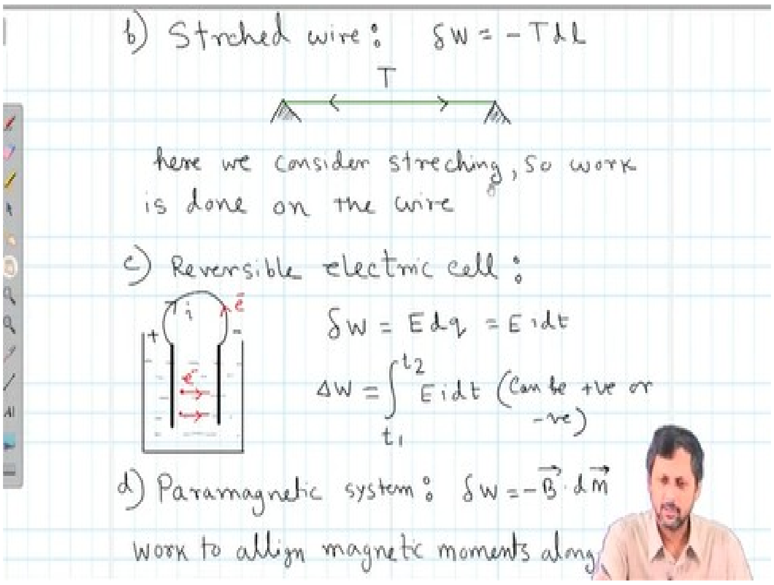
In general, the work done is written as delta omega or curly delta why curly delta or d cut either curly delta or d cut because, to distinguish it from a perfect integral which is given by small t. So, this is an imperfect integral represented either like this or like that depending on the textbook you choose and in general the form is y dx where y is an intensive parameter of the system x is an extensive parameter of the system.

Such that the product x and y, x y has a dimension of energy. So, if you are confused just hold on for one more minute but before we go there w is equal to w is considered positive when work is done by the system w is considered negative when work is done on the system. This is a very important convention please keep this in mind we have to use this positive and negative sign over and over again.

So, let us take some examples both things will be clear gas assembly our standard example, we have dw is equal to pdv PV the product PV has a dimension of energy. P in this case is the intensive variable, because it does not change with system mass, we have discussed it already in the last class, x is the extensive variable which is volume if we reduce the mass of the total mass of the system keeping all other parameters same the volume will also decrease.

So, we have a combination pdv, which is representative of the work done. So, delta w is in in our case or sorry capital delta W which is the total work done is integral A to B pdv. Once again it is a path dependent integral. So, just take an example let us for an isobaric process P is a constant. So, this integration with simply is d over dv so it is p v 2 minus v 1. So, we will take up examples and we will compute work done for different processes. But for gas assembly but before that let us look into other thermodynamic systems as well.

(Refer Slide Time: 29:00)



Let us take the system of a stretched wire we have a stretched wire, which is you know it is an elastic wire so the work done dw is given by minus T d l because we are stretching it. We really cannot compress wire we cannot do that. So, that is why this is always comes with a negative sign because work is done on the system what I mean once again for a gas assembly when I am compressing the gas so, I am working on the system.

So, that is why it is a negative quantity that work done is negative, when the gas is expanded the work is done by the system gas is doing the work so that work will be positive. Similarly, for a stretched wire, because we are always stretching the word the name suggest that we are stretching the wire we are doing work on the system. So, it is minus T d l and it is always negative by definition.

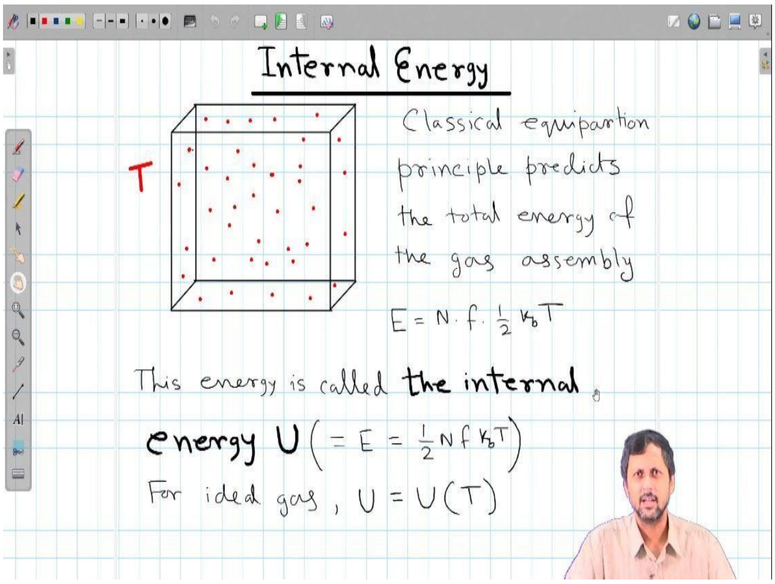
Reversible electric cell we have electrons going from positive and in a positive to negative electrode inside this electrolyte medium and from negative to positive electrode outside when there is a wire connected between the positive and the negative terminal of a battery. So, the current is flowing from positive to negative. So, here the work done is given by E d q, E is the extensive parameter sorry E is the intensive parameter and q is the extensive parameter.

Think of it think about it why one is extensive one is intensive and the product E d q which is equivalent to E i d t because i is equal to dq dt essentially i being the current flowing in the circuit. So, dw delta w is equal to E i d integration T 1 to T 2, T being the variable. Now, this can be both positive and negative depending on whether we are you know charging the battery or we are taking out power from the battery we can have both positive and negative work.

So, we are just keeping it like this. Now, for a paramagnetic system let us say we have a paramagnetic solved sample we are placing it inside a strong magnetic plate. Then we have del delta w is equal to minus B d m B being the magnitude of the magnetic field dm being the magnetic moment of in every infinitesimal small magnet you know molecular magnet. So, the work this work is once again negative.

Because it is the work done on the system to align the magnetic moments along B. So, these are the few examples which we have taken.

(Refer Slide Time: 31:42)



And the last thing is internal energy. So, last thing for today's lecture is internal energy. Now, going by the classical equipartition theorem we have total energy of a gas assembly as E is equal to N f half K b T f being the number of degrees of freedom N being the total number of molecule. So, this energy is called the internal energy of the system, once again I am just giving you an example of a gas assembly because that is easy to understand.

Now, you see the energy as we see from classical equipartition theorem is half N f K b T. So, for an ideal gas U is equal to U of T only, but once again we have already seen that this relation is not strictly valid. And you know we can have different degrees of freedom of a you know of a of gas molecule participating in the part I mean being activated at different temperature ranges. So, and there are other effects also which we will be discussing later on.

So, in for any real gas you cannot be a function of temperature only. But this is just an example to give you an idea of what internal energy is. So, the classical definition of internal energy, I mean this is only the example of a gas assembly. Now what is the classical definition of internal energy and what are the implications of internal energy we will start from there in the next lecture and we will hopefully by next lecture we can talk about the first law of thermodynamics.

So, that is where we stop today. Once again thank you for listening to me very careful very patiently for these last two lectures, I know it is been little boring because we are not solving any problems, we are not doing any mathematics. We are discussing pure concept but trust me this discussion will really help when we will be going deep into the formulation of classical thermodynamics mathematical formulation these fundamental discussions you will realize that these are actually helpful.

So, my suggestion is try to follow the notes and listen to my lectures as carefully as possible. Any question post in the forum or you can ask directly to me during the discussion session online discussion session and still if you have doubts the best thing is read the best possible textbook you have in hand that will really help. So, see you again in the next lecture bye.