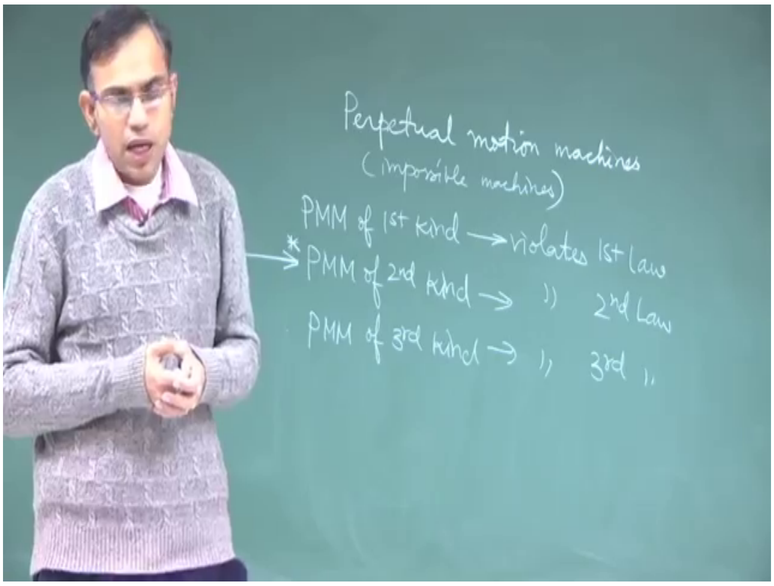
Concepts of Thermodynamics
Prof. Suman Chakraborty
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 35
Perpetual Motion Machines; Reversible and Irreversible Processes

In the previous lectures we learnt the motivation behind learning the 2nd law of Thermodynamics and some statements on 2nd law of thermodynamics. In the process we learned what is heat engine or what is a heat pump what is the refrigerator and how they are performance parameters are constrained by the 2nd law of thermodynamics.

Given all these there are certain devices, there are certain machines which are you know not practical and 2nd law discuss some typical such types of machines, but you know those types of machines are very generalized in a sense, but it’s not just 2nd law these types of machines which are hypothetical, but they will not actually satisfy even other laws of thermodynamics so, these are called as Perpetual Motion Machines.

(Refer Slide Time: 01:22)



So, these machines are you know like I mean machines out of fiction rather than fact they will out of nothing for example, produce energy these kinds of devices. So, this perpetual motion machines are a various kinds so, these are impossible things, impossible machines as for laws of thermodynamics. So, perpetual motion machine of

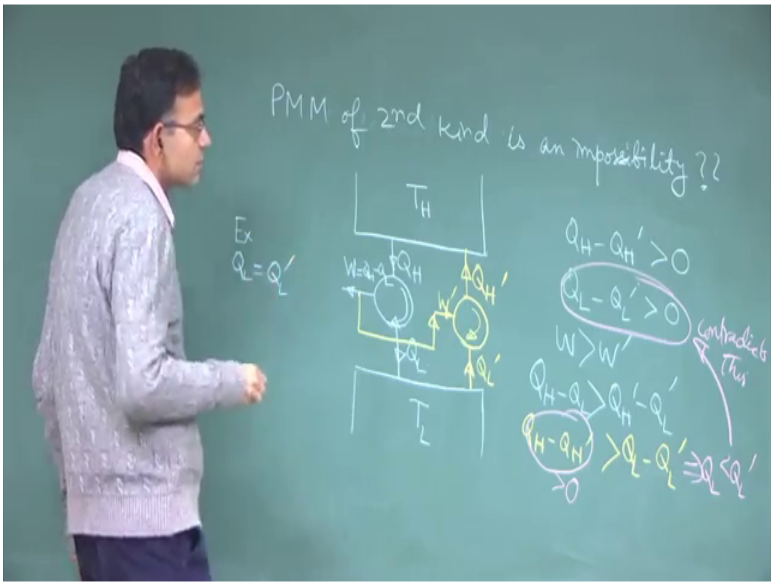
1st kind it violates 1st law; that means, device it's a machine that does not satisfy energy balance and so, even if somebody designs such a machine that machine will not work.

Perpetual motion machine of 2nd kind, it violates 2nd law I will discuss more about this in a moment. Then we have perpetual motion machine of 3rd kind, it violates a law of thermodynamics which is called as 3rd law, which we will briefly discuss later on.

So, I will emphasize more on PMM of 2nd kind in the context of 2nd law, but just for completeness what is PMM of 3rd kind? It's a machine that works without friction. So, it in definitely keeps on working because there is no friction which is you know dissipating its energy and then that will violate the 3rd law of thermodynamics which we will discuss later on.

So, our focus here is not PMM of 1st kind or PMM of 3rd kind, our discussion is mainly on PMM 2nd kind, that is a machine that violate 2nd law. So, some of you might argue that so, what, it violate 2nd law, but in the machine that machine is still work and 2nd law is the 2nd law after all. So to understand that whether a perpetual motion machine of second kind is a possibility or not we will design a thought experiment with the question.

(Refer Slide Time: 04:20)



So, people who are educated with 2nd law of thermodynamics we will say that it is impossible because any process that or system that violate 2nd law is not feasible, but somebody who is ignorant about 2nd law will say that well let us try to see whether it is feasible or not. So, we make this thought experiment, what kind of thought experiment? There is a thermal reservoir heat source at T H and heat sink at T L, there is a heat engine that produces a net work.

Now, out of this net work you take a part of the work to a device which will effectively transfer heat from a lower temperature body to higher temperature body. So, such a nice you know that using this you can effectively run heat pump without requiring any external power input, it’s just this using this work only a part of this work you are successfully transferring heat from low temperature to high temperature. So, this work input let say this is W dash.

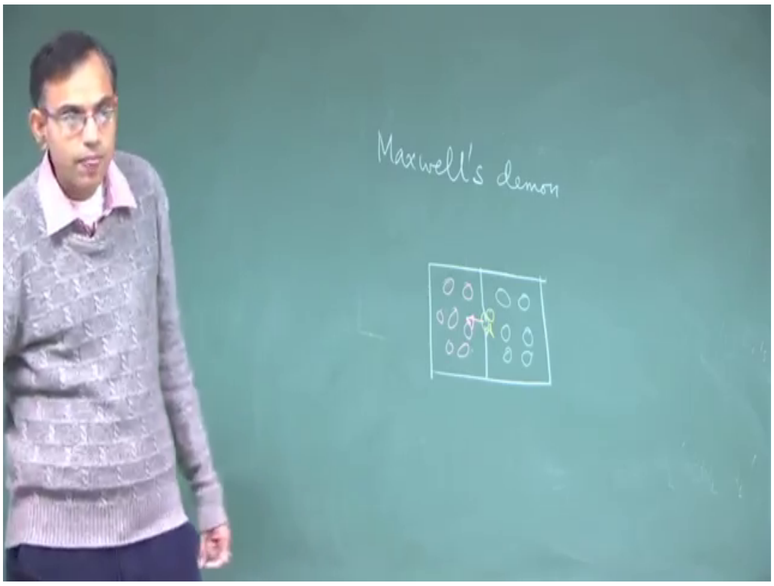
So, to make this integrated device work what are the constraints let us look into the constraints. So, you have Q H minus Q H dash greater than 0, that is the net heat taken from the heat source. Similarly Q L minus Q L dash greater than 0 and W greater than W dash right, that is how a part of this is running this right. So, w is Q H minus Q L is greater than W dash is Q H dash minus Q L dash right. So, Q H minus Q H dash is greater than Q L minus Q L dash, Q H minus Q H dash is greater than 0 right.

So, what is the constraint that you can have from here Q L less than Q L dash right, this contradicts this one which says that Q L greater than Q L dash right. So, so, you can so, this what it attempted to do is to indefinitely run this refrigerator or heat pump without requiring any external power input just by drawing from power from it, but it is not possible to do that. So, there are devices which will you know which will not satisfy the 2nd law so; that means, consider a special case when Q L equal to Q L dash. So, take an example.

So, when you have Q L equal to Q L dash then you must have W this Q H minus Q L if this Q L dash which is equal to Q L, then in that limiting case it may be possible to run this device with the net work input, but it will violet the 2nd law how if Q L equal to Q L dash there is no net heat exchange with this reservoir. So, either you exchange heat with both reservoirs and come up with a condition that is contradictory or you exchange it with a single reservoir do whatever you want, but then it will violate the 2nd law because it is attempting to do a network with exchange of heat with the single reservoir.

So, the moral of the story is do not try to run a perpetual motion machine. Now something impossible always has been a matter of fiction, like you see young children studying you know science fiction stories where you know within the core of the sun the demons are fighting and all those things.

(Refer Slide Time: 11:20)



So, there is such a fiction in thermodynamics a very classical fiction known as Maxwell's demon a beautiful and very interesting fiction. So, what it tries to do is something like this. So, there is a chamber this chamber is partition like this and then the whole objective is you know to separate across this partition high temperature and low temperature molecules.

So, initially chamber is filled up with molecules of various temperatures you want to separate this total molecules into two parts; one is a high lower temperature another is high temperature, let us say there are only two levels of temperature. So, two levels are very important because as information it can represent a binary system either 0 or o1ne so, two levels of temperature.

So, how this is achieved? There is a demon sitting here I am drawing it small, but it's a huge demon sitting here this is the frictionless gate. So, everything is ideal and then these demon is like a gatekeeper it freeze that you know across this whatever molecule is going it has put at the molecule has a tag. So, either its high temperature or low temperature, if it is high temperature it allows it to say go along this side which is red if it is lower temperature it do not allow to go in this way; in this way after sometime all the red molecules come on this side and all the white which are low temperature molecules come on this side.

So, in this way out of nothing just by the demons decision making process you have a separation of molecules higher temperature and lower temperature. So, this is definitely something which as per 2nd law of thermodynamics would required some work otherwise they will spontaneously mix with each other, this is not a spontaneous process. So, one of the philosophical understanding is that if something is not spontaneous you have to invest some work to get that effect, if something is spontaneous you do not require to invest any work to get that effect

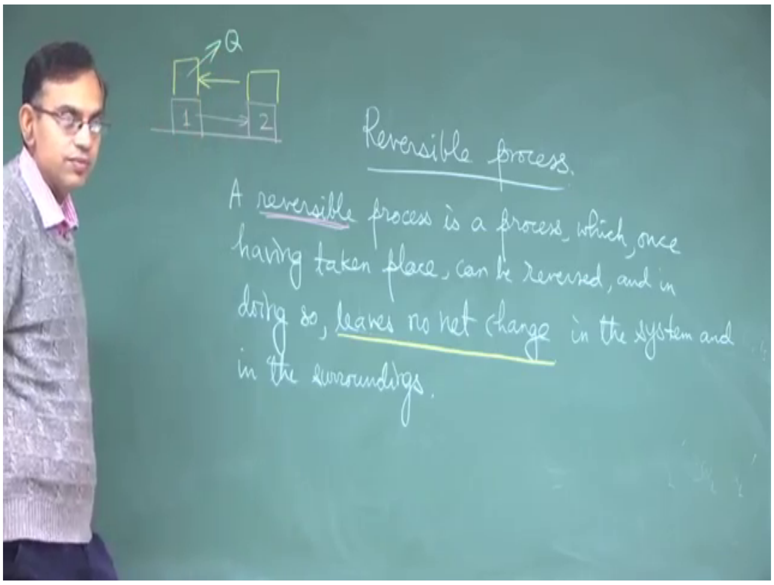
So, but here no work is invested so, where is the paradox? So, the paradox can be resolved in a very interesting way. So, how will the how will the demon know that which is a you know fast moving, which is the slow moving and all those things, demon is you know which like robot know it do not have a velocity measuring device. So, every molecule has a tag and when the molecule comes demons memory has an information of that molecule you know so, the demon is like computer. So, in its memory that information it checks that whether this is fast moving or slow moving, if it is fast moving it will allow it here if not it is on the other side what demons memory is fixed.

So, every time you know the memory is occupied that old memory has to be erased and it should be refreshed with new information. So, this you know continuous cycling of data in the memory that itself involves a work, which is not equivalent to raising of a weight as you can see, but conceptually it is also you know an effort that needs to be put to get the thing done. So, the demon just by standing there without any decision making capability, without any memory refreshing capability, without any memory retrieval capability will not be able to achieve this function and all these will required some kind of work which may not be the classical raising of a weight, but that can be thought of as an equivalent to thermodynamics work

So, this is the very interesting example a passing example, but you know just to get you know that how so, the philosophical understanding that we are developing gradually to the 2nd law of thermodynamics is to get something special you have to put some effort, if you do not put an effort you will not get anything special this is not just a law of thermodynamics, but is law of nature, this is law of life that you get anything special you have to put also special effort.

So, now we will try to understand you know one promise we made while discussing about the 2nd law is that we will assess the performances of devices and cycles. And then I brought in this purview or in this perspective the example of you know some ideal scientific personality like professor Einstein. So, there is a similar conceptual ideality in thermodynamics which is called as a reversible process.

(Refer Slide Time: 17:28)



So, that is something which is the very ideal process in terms of the 2nd law of thermodynamics and that is called as a reversible process. So, what is the reversible process? The definition is something like this. So, this word is misleading because English word wise anything that can be reversed is reversible thermodynamics wise anything can be physically reversed may not be reversible.

So, what is the definition? A reversible process is a process, which once having taken place can be reversed and in doing so, leaves no net change in the system and in the surroundings. So, the whole idea is that you have a thermodynamic process, it leads the system from state 1, state 2.

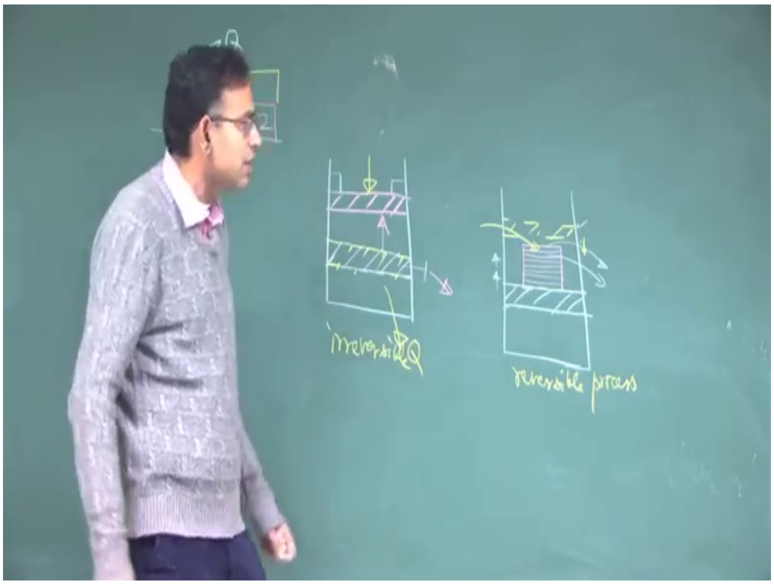
Let us say that you have a block which is sitting on the ground at state 1 you move this block and it comes to state 2 as you bring it here, once you do that let us say; let us test whether it is reversible or not. So, how do you test it? a laymen will tested in this way, well the block was here.

So, what I will do? I would simply bring this block from here to here ok. So, it has come back to the same location so, I am happy well it has we could reverse it so, it is reversible. Now the laymen will not look into this additional most important part of the definition, leaves no net change in the system and in the surrounding. So, when the block is moving from here to here there is friction between the block and the ground. So, the block gets heated right because of just like you know you have palms you rub the palms and your palms will get heated.

So, the block will get heated from 2 to 1 although the direction of motion is altered, but friction is always opposing that and again it is further heated. So, when it has physically come back to the same location it is heated as compared to with which it started earlier. So, once so, you have to bring the system and surroundings back to the original state then only we say it is reversible. So, to bring this back to the original state what you have to do? You have to transfer some heat from the block to the surroundings because it is heated, in the process this block can come back to the same original temperature, but the surroundings are not back to the same state because of a net heat transfer from the block to the surrounding.

So, this shows that physically bringing it to the same position does not mean that it is reversed. It is reversed thermodynamically when the system and surrounding both in the process have come to the same original state. So, this shows that friction can make a process deviating from reversible one so, that is called as irreversible process. I will come to the factors that can make a process irreversible, but I would like to think about or give you a thought on some design experiment or thought experiment that will give you a picture of what kind of process can actually be you know approximately reversible.

(Refer Slide Time: 22:58)



So, let us say that there is a piston cylinder arrangement and there is a stop here. The piston is initially here and there is a pin which prevents it from moving so, this pin is suddenly removed then what will happen? So, let us say that this inside pressure was more than outside pressure so, immediately this piston will start moving and why its inertia it will if it hits the stops it will tent to move further upwards, but stops us preventing it to do that.

So, this kind of example we have solved through various problems in the early part of this course. So, once you do that, then what is the end thing that is happening? That pressure here is building up because the piston is trying to go further forward, but the stops are disallowing the piston to move further forward; so, in the process the piston say gets stuck here.

Now let us say so, final the piston is here, now you want to bring the piston from here to here. So, when you want to bring the piston from here to here you have to put some work input the work input is now more than the work done during the forward process why pressure inside has build up.

So, you require to overcome a greater pressure in having the same displacement. So, you need to put a work input which is more than the work output in the forward process, in that process let us say physically the piston comes here. So, whatever energy left in the form of work more energy got input in the form of work to bring it back here. So, the system is actually more heated as compared to the state at which it started because more energy has thrown into it as compared to the energy that has left.

So, to bring it back to the same thermodynamic state say temperature there has to be heat transferred from the system to the surrounding; that means, the surroundings are not back to the same initial state so, this is new irreversible. How can you make this reversible? You can make this reversible in this way. So, imagine that the piston is here this is the height up to which we want to move the piston.

So, what we do is? We carefully put a large number of thin slices of load, we remove first this small slice and then this piston goes a little bit up. So, what is the key? The key is we are making the process very slow in small; small steps. In other words we are making the process quasi equilibrium of quasi static.

So, then we remove this load and it will move a little bit of in this way the loads are so, design that way we remove all the loads this will say go to this height, that is how it was design. Now, to bring it back what we do? We put back the loads one over the other. So, once we put back the loads one over the other this piston we exactly follow the same forward path as it was following in the reverse direction and then when all the loads are put back it will come back here because the forward and the backward processes where exactly the same and all the intermediate states were in equilibrium the piston will come back to the original position leaving no net change in the system and in the surroundings.

So, this is a reversible process, but you can argue that this being a reversible process there is no doubt about it that you know the slowness of the process makes it reversible, but could there be other factors that could make this process irreversible we will look into that. So, in our next lecture we will figure out, that what are the factors that can make a process irreversible and then we will discuss all those factors and imagine a sequence of reversible processes that will form a reversible cycle and that is how we will discuss the concept of a Carnot cycle we will continue with this in the lecture

Thank you very much.