Concepts of Thermodynamics

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Lecture – 34
Statements of the Second Law of Thermodynamics

In the previous lecture, we were discussing about you know why do we need Second Law and the basic definition of heat engine, heat pump and refrigerator. So, today we will learn about some classical statements of second law of thermodynamics, remember that these are not the only statements, but these are two very classical statements, which are very much conceptually related to the definitions and working of heat engine and heat pump or refrigerator.

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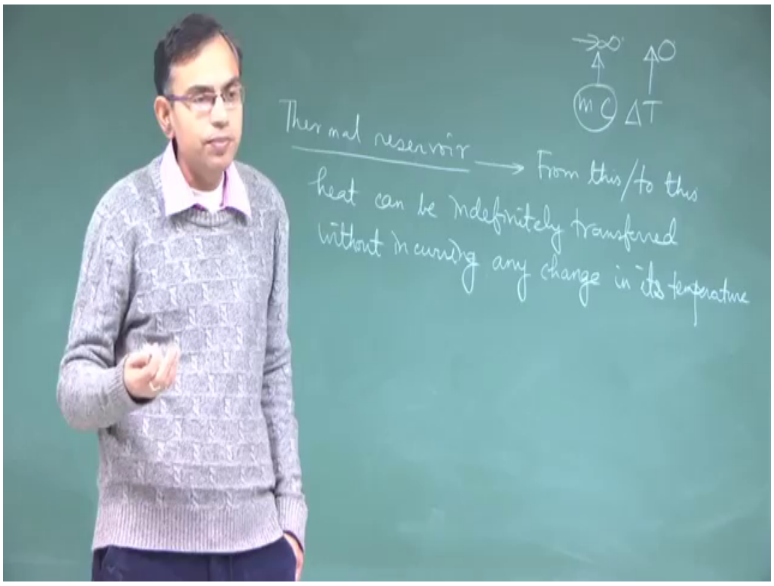

So, before that we will like to define something which is called as thermal reservoir. This is again a very important definition which is necessary for you know discussing the statements of second law. So, thermal reservoir is like something from which or to this whatever from or to depending on the direction of heat transfer. Heat can be indefinitely transferred without incurring any change in its temperature.

So, let me give you an analogous example. Let us say you have a big ocean and you take a glass of water from the ocean or you put a glass of water into the ocean. When you do that will the level of ocean change, I mean if for all practical purposes it does not change, theoretically it changes, because you know whatever is the small amount taken or given that is not 0; but practically the level of the ocean does not change with the addition or subtraction of one glass of water. The reason is that the ocean has such a vast volume of water with respect to that this little addition or subtraction does not make any difference.

So, similarly the thermal reservoir is like an ocean of thermal energy. So, how it can be perceived as a ocean of thermal energy, it can be something of huge heat capacity. So, by heat capacity you mean the mass into specific heat. So, this is very, very high. So, if the heat capacity so either mass can be very high or specific heat can be very high or their combination can be very high.

So, what about this product has to be very high, so when you transfers some heat to a body, then the heat gain by it in related to this right. Mass into specific heat into change in temperature, even heat lost is also that only delta T sign changes. So, if you have this tending to infinity, then this must be having tending to 0 to make the heat transfer finite right, so that is conceptually what is thermal reservoir? Again its a hypothetical concept, because nothing will have aiming to see tending to infinity, but if it is very large the delta T will be practically very small.

So, this thermal reservoir concept is very very important to relate the understanding of heat engine, refrigerator, heat pump with the statements of the second law of thermodynamics, so, we will.

Student: What are the practical examples of thermal reservoir?

Practical examples of thermal reservoir or maybe something which is of lots thermal capacity like a phase changing substance. So, when a substance is changing its phase, then its temperature remains constant, because the entire heat is dumped in the form of latent heat; the specific heat capacity can be thought of as infinity. So, phase changing substance can be a good model for a thermal reservoir.

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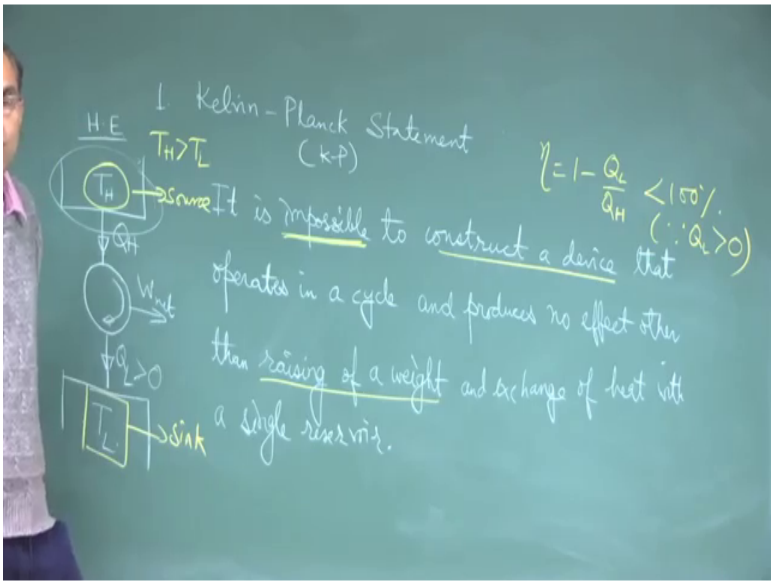

So, now we will first make the Kelvin-Planck statement, from now onwards to you know save the energy in writing I will call it, Kelvin-Planck as K-P Kelvin-Planck statement. So, the Kelvin-Planck statement let me first write the statement and then I will explain you what it means. So, it is impossible to construct a device that will that operates in a cycle and produces no effect other than raising of a weight and exchange of heat with a single reservoir.

So, see I do not know I mean most of you are very young and whether you have got the experience of reading, the sentences constructed by experience lawyers. So, I mean they are legally so tightly bounded that they are in most of the cases not you know very straight forward, simple sentences being constructed. So, this statement is almost like a statement from a lawyer, who wants to protect a law of which is the second law of thermodynamics.

So, what the statement is? The statement it starts with you know its it with looks very negative. So, it says it is impossible to do something, it does not say what is possible. So, philosophically this is very important, philosophically if we know what is possible, what is impossible, we will never go for that you will never try that.

So, for a long time people tried to convert anything into gold out of nowhere. So, these people were called as alchemists and they try to do that for a long time, because they never had a clue that you know by law of science, then by law of nature it is not practically possible to have such a process. So, similarly if you know for any particular process what is possible, what is feasible or what is not feasible, you will not try something which is impossible right. So, it is better to you know concentrate on what is impossible and discovered that as a you know possible practical development.

So, it is impossible to construct a device. What the device will do? Which kind of device is impossible that operates in a cycle that means, it is a cyclic device and produces no effect other than raising of a weight, it essentially means that it produces net work, because raising of a weight means doing work that we have discussed in the chapter of heat and work.

And exchange of heat with a single reservoir, now try to relate this with the concept of the heat engine, heat engine. So, you have the high temperature body. So, you know this law varies I mean straight forward way, it relates to this that it says that there is a cyclic device, this is doing a network, but it is impossible that it does so by exchanging heat with only one reservoir that means, this Q L must be greater than 0. You cannot make it run by doing work in a cycle without rejecting any heat to a low temperature body.

So, then so this we can say that it relates very nicely with the definition of a heat engine and the efficiency of the heat engine this will therefore be less than 100 percent, because Q L since Q L is greater than 0. So, what is the restriction on efficiency of a second law, efficiency of a heat engine that the this Kelvin-Planck statement imposes, simply it is less than 100 percent; it can be anything, but less than 100 percent.

Then what is that anything, we will see that it depends on again some parameters, which are primarily the temperatures of the heat source and the heat sink. So, by the way when we talked about thermal reservoir, the high temperature reservoir this is T H, it remains as T H, so that is why its a thermal reservoir. T H is greater than T L, so this is called as heat source and this reservoir is called as heat sink. So, these are you know some basic terminologies, I believe that you already know this from your school level understanding of thermal physics, but you know this is just study capitulation of what we are going to talk about.

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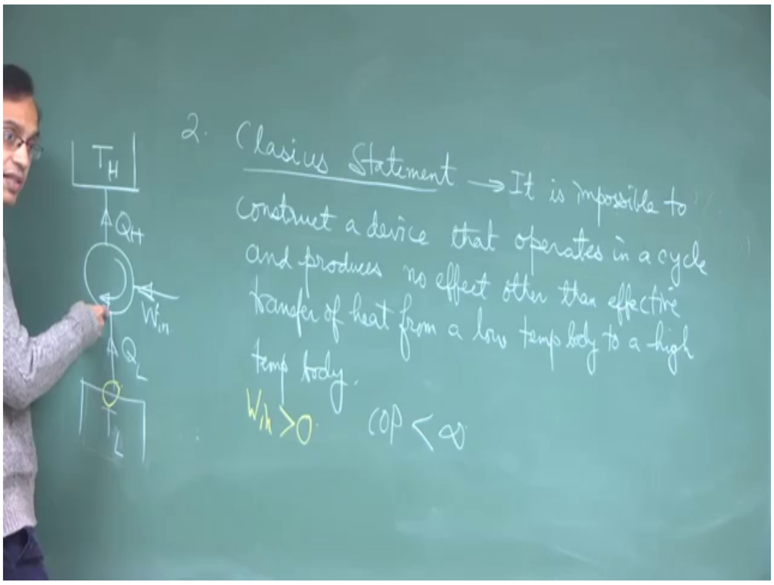

So, that other statement, so we have covered the heat engine performance with the aid of this definition, but we have not covered the refrigerator or the heat pump performance with the aid of this definition so, we require another statement which covers the refrigerator and heat pump, so that is governed by Clausius statement.

So, this statement is again it is impossible to construct a device that operates in a cycle, and produces no effect other than effective transfer of heat from a low temperature body to a high temperature body. Devices that atom to have an effective transfer of heat from low temperature body to high temperature body are refrigerators and heat pumps. So, this talks about the refrigerator or heat pump.

So, you have a device that operates in a cycle ok. So, this these statements say that you know this device cannot just transfer this Q L from here what cannot take some heat from here and directly transferred to the high temperature body without being intervened by a device that takes some work input in a cycle right.

So, according to this statement W input is greater than 0 ok. So, when W input is greater than 0, what it means is that the coefficient of performance which is either Q L or Q H by W input the coefficient of performance has W input in the denominator. So, if that is greater than 0 that means, coefficient of performances less than infinity. So, you cannot have an infinitely large coefficient of performance ok.

The other point that I would like to mention, you know this creates a very common misunderstanding that as if by doing this giving this work input, you can transfer heat from low temperature body to high temperature body, directly you cannot do that. That means, when you are transferring heat from here to here effectively, you are doing it through the device. So, the direct heat transfer is not taking place from here to here, direct heat transfer is taking place from here to the device and from device to here.

So, here if this temperature is whatever, this temperature has to be at least a little bit lower than this you know. So, locally this should be a temperature difference such that heat is transferred from high temperature to low temperature. Similarly, locally here should be a temperature difference, so that heat is transferred from high temperature to low temperature.

So, not that we are transferring heat directly from low temperature to high temperature why this means, what we are effectively transferring this heat from a low temperature body to a higher temperature body as mediated by an arrangement, which is a cyclic device that takes a network input in a cycle that is the whole idea behind this.

Now, the next question is that we have one statement which relates to the heat engine, another statement which relates to the heat pump or refrigerator. So, these are you know why these two are two different statements, heat engine is a work producing device and refrigerator or heat pump is a work absorbing device.

So, most of the thermodynamic devices, which involve work transfer or either work absorbing or work producing, so, they are covered by this statements. And then what the question remains that you know both are corresponding to second law of thermodynamics. So, are these statement equivalent? So, we will now show that although these two are two different statements violating one will imply automatically, violation of the other.

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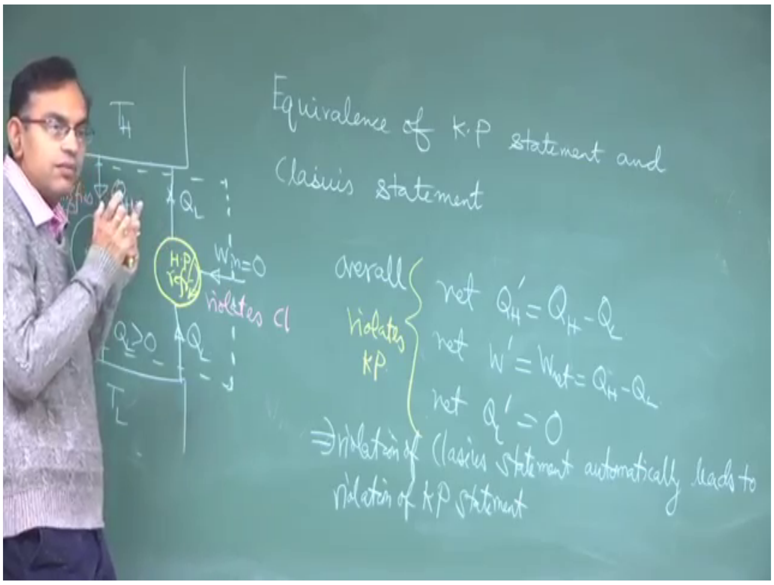

So, equivalence of let us say let me draw the schematic here.

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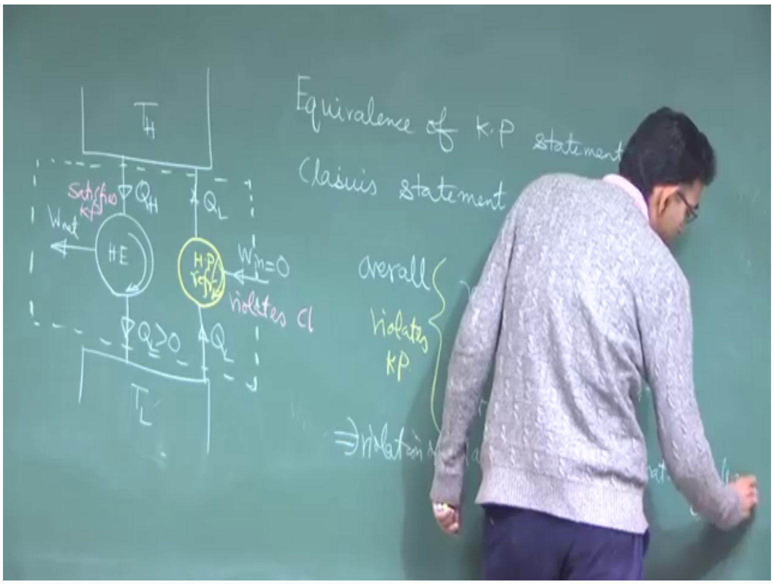

There is a heat engine that takes heat Q H from a high temperature heat source does a net work in a cycle. And rejects heat Q L greater than 0 to a heat sink ok. So, this satisfies the Kelvin Planck statement.

Now, let us imagine that there is another device, which is a heat pump or a refrigerator. So, this is heat engine, this is heat pump or refrigerator, this takes heat Q L from here, and rejects heat Q L to here with work input equal to 0 ok. So, clearly this satisfies energy balance, but violets the Clasuis statement. So, this satisfies Kelvin Planck, this violets Clasuis right.

Now, you take these two devices as a whole both are cyclic devices, you take this devices as a whole. So, overall the net Q H that is Q H minus Q L, net work this is W net this is Q H minus Q L and net heat rejected Q L taken from here and Q L taken in this direction, so, this is 0.

So, overall it takes the net heat from a thermal reservoir does a work, but does not reject any effective heat to the heat sink right, so that means overall heat violets which statement, it violets Kelvin Planck statement. So, this shows that violation of Clasuis statement will automatically lead to violation of Kelvin Planck statement ok. So, this implies violation of Clasius statement automatically leads to violation of Kelvin Planck statement ok.

Similarly, you can see these are all thought experiments in thermodynamics these are called as thought experiment know, what is actually you know putting a device and testing it in this way, but these are hypothetical imaginary experiments that can make you relate various statements of the laws of thermodynamics. So, violation of Clasius statement automatically leads to violation of Kelvin Planck statement.

And you can I leave it on you as a homework that you can imagine an example, where you can show that violation of Kelvin Planck statement will automatically lead to violation of Clasius statement, so that means, the Kelvin Planck and Clasius statements are equivalent, they are just different statements because of the context in which these statements are used.

Let us stop here today, thank you very much. In the next lecture, we will start understanding about you know based on this statements what are the possible processes, and what are the possible devices, what are the most ideal processes, what are the most ideal devices.

Thank you very much.