Concepts of Thermodynamics
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Lecture - 33
Introduction to Second Law of Thermodynamics

So far, we have discussed about the first law of thermodynamics. Now, first law of thermodynamics is a statement of energy conservation, this much we have understood. The question is that despite the first law existing why do we require other laws of thermodynamics.

So, in particular, today we are going to be concerned about the Second Law of Thermodynamics. So, to understand that let us try to think about a hypothetical process, and try to see whether that process actually can take place or not.

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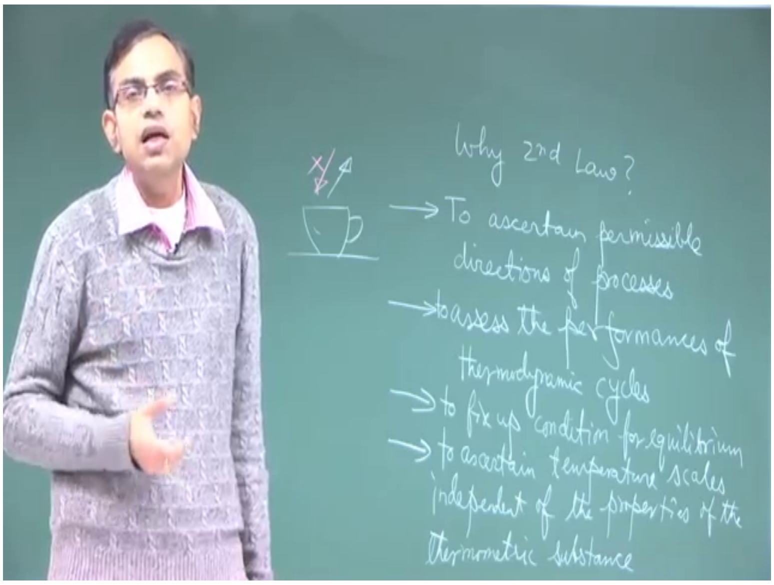

So, let us consider an example. Let us say that you have a cup of hot coffee in a room. So, now when you are keeping this cup of hot coffee in the room, what you expect? You expect that heat will be transferred from the hot coffee to the surroundings, till an equilibrium temperature is reached.

So, the spontaneous direction in which this natural process will occur, given you are not artificially disturbing it by anyway is a transfer of heat from the higher temperature body to a lower temperature body, which is the ambient here. How is the first law of thermodynamics related to this, the first law of thermodynamics is related to this in this way that in this process the total energy is conserved that means heat lost by the coffee cup is same as heat gained by the ambient, so that total energy is conserved.

Imagine that the same cup of hot coffee is kept, but heat is transferred from the surrounding to the system, and the coffee gets hotter and hotter spontaneously. So, in that process you can satisfy first law. How you can satisfy first law? You can imagine in a heat transfer which is heat lost by the surroundings is same as the heat gained by the cup of coffee ok.

So, in either of this cases you could satisfy first law, but from our common sense we understand that this process will not occur spontaneously, had it occurs spontaneously it would have been a wonder, because you know you could perpetually heat the hot coffee without requiring any heating machine, but that does not occur, so that means that there could be certain processes, which could be designed to satisfy the first law of thermodynamics, but such processes would never occur in practice.

So, there are feasible directionalities of spontaneous processes. In what direction a spontaneous process may occur and in what direction it may not occur. This directionality or spontaneity in a process through a particular direction of the chosen process, this is not a fixed up by the first law of thermodynamics.

So, we require another law, which should describe the permissible direction of processes. So, we can say that if we just enumerate these things, so to ascertain permissible directions of processes. This is one of the most fundamental reasons, why the second law is necessary despite you know the existence of the first law.

But, you know historically this is very interesting, although this is known as second law. This is something more intuitive than the first law that is you know the for example heat is transferred from a high temperature body to a cold temperature body, but spontaneously not the vice versa takes place. So, this is something which is more intuitive than you know a statement of the energy balance.

So, this is one of the most fundamental laws of thermodynamics that historically appeared in the forefront. To in addition there are many practical benefits like for example, you have a thermodynamic cycle. Now, can you tell that how good the performance of the cycle is so to do that you have to compare that cycle performance, so by cycle you mean a there is a cyclic process, which perform certain tasks maybe you get a net work output or you get a net effect, which is you know are not spontaneously achievable.

So, these kinds of things, when you do in a cycle or us thermodynamic cycle all of you understand a thermodynamic cycle that you start with a state point, you undergo a sequence of processes and you come back to the same thermodynamic state point. So, when you have such a cycle, the cycle has a performance say in terms of work done or anything else.

So, for what producing cycles, it is the work done that is very important, but work done relative to you know what energy you have to invest to get that work done. So, such parameters for performance of a cycle, so you have a cycle. How do you assess, how good or how bad it is? So, you can compare that with maybe a hypothetical ideal cycle.

For example, in high school physics you have you have learned Carnot cycle. So, we will discuss that again in this context of in the context of this course, but that is the hypothetical cycle. But, why do we study such a cycle, we study such a cycle, because we want to compare the performances of various practical cycles with something which is you know theoretically maximum achievable; so this is very important.

So, for example Professor Einstein has become a benchmark right in physics. So, I mean I have loosely seen that you know one parent you know scolding his son that oh you are telling this have you become an Einstein, so you know that is like Einstein is like a benchmark you know. So, I mean you may not be able to achieve that standard, but it is like a benchmark, and you know you can compare the performance of real practical systems with that benchmark.

So, you know to assess the performance of thermodynamics cycles. In addition it helps in certain things, for example to fix up condition for equilibrium. So, when you have a system in equilibrium, it is in mechanical equilibrium, thermal equilibrium and phase and chemical equilibrium. So, when you talk about phase and chemical equilibrium, there are properties which are introduced to designate the condition for equilibrium. And those properties evolve from the basic understanding of the second law; so, to fix up condition for equilibrium.

Then you know to ascertain temperature scales independent of the property of the thermo metric substance. To ascertain temperature scales independent of the properties of the thermodynamic thermometric substance. So, what it means is that you know the temperature that you measure in a thermometer.

Normally, how do you ascertain the temperature? There is a volumetric expansion of the thermometric fluid on heating, and that is how; for example, if you have a mercury thermometer, so if you keep that thermometer in contact with a heated body, then there will be expansion of the mercury, so the mercury column will expand. And the corresponding linear reading, because the cross sectional area is constant of the thermometer. So, the linear reading is proportional to the volumetric expansion, so that can indicate the temperature. So, this is a common principle of thermometry, but this depends on whether it is mercury or whatever fluid you are using for the thermometer.

So, can you fix up a temperature scale, which does not depend on the you know properties of the thermometric substance, so that is called as a absolute temperature scale. A temperature scale which does not depend on the properties of the thermometric substance. And that temperature scale not scales one scale that temperature scale known as absolute temperature scale is established by using the second law of thermodynamics.

Then there are other issues. For example, you think about a property say internal energy or enthalpy, you normally have direct measurement techniques for fundamental properties like pressure, volume temperature. You have measurement devices which can directly measure pressure by measuring force per unit area, you have measurement devices which can measure temperature, you have measurement devices which can measure volume, but do you have enthalpy meter, do you have internal energy meter? You do not have this.

But, in thermodynamic property tables, you see the values of these properties, so where from the are they determined are they determined from direct experiments? No, because there are no measuring devices which directly measure them maybe from some indirect measurement you can measure them, but not direct measurement. But, there are thermodynamic property relationships, by using which you can measure these properties in terms of other measurable properties. And these relationships evolve from the second law of thermodynamics.

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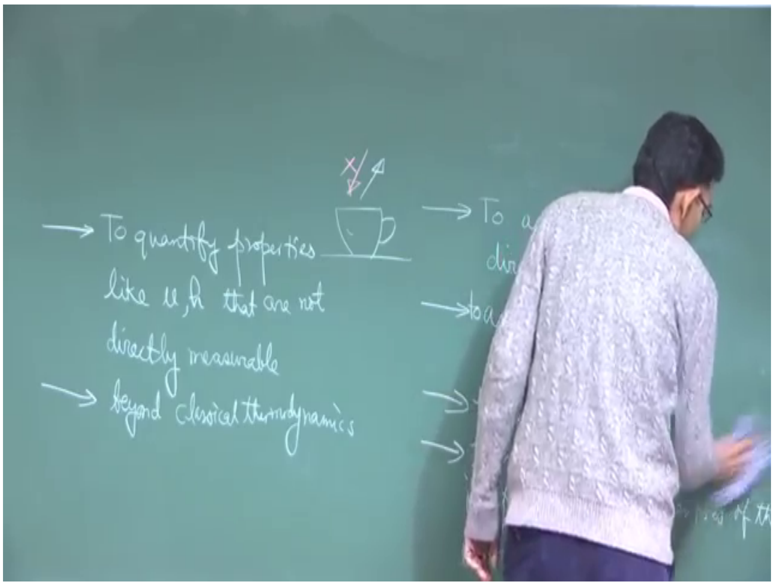

So, we can say that you know to quantify properties like u, h that are not directly measurable. So, these are still very you know classical reasons why second law is used, but there are many contexts in which the second law is used in modern times, which are you know beyond the classical thermodynamics.

So, I am just putting one point beyond classical thermodynamics, and I am trying to explain what do I mean by that. We will see later on that as a consequence of the second law of thermodynamics, we will learn about a property called as in entropy. So, this property entropy is very much relevant in the context of not just thermodynamics, but in the context of several other theories, for example information theory.

So, when you have an information, there is a parameter associated with that which is called as entropy of information and I will discuss about that later on in this course. So, when you have an information, how do you assess what is the amount of or when you have data, how do you assess what is the amount of information that can be you know gathered from the data that is the quality of information. Just like in terms of energy transfer, it is the quality of energy transfer that is you know fixed up by the second law in some way or the other we will see.

So, just like quality of energy transfer in the context of classical thermodynamics, you know the you know quality of data that is how much information the data contains that is also you know within the purview of modern thermodynamics that generalizes the picture of second law not just from the concept of heat and work or interaction between heat and work, but other modes of you know exchange of you know like information, data and so on. So, beyond classical thermodynamics also the second law is applicable.

So, with this little bit of motivation, you know why we require the second law, we will try to see what are the statements of the second law. But, you know this is again a very subject specific approach of talking about you know the statements of second law.

So, if you ask somebody, you know that how does the elephant look like? So, it all depends on from what angle or perspective you look at, somebody who does not have a clear picture of the elephant, but you know maybe a blind, just catches the tail of the elephant, we will say that the elephant is like a stream. So, somebody who catches the ear of an elephant, we will say that you know the elephant is like a flap. So, it all depends on you know from what outlook from what angle you perceive.

Similarly, the statements of second law, it all depends on from what angle you are assessing the second law. Are you assessing the second law from the classical thermodynamics viewpoint the concept of heat and work or you are approaching the second law from information theory. I mean these two are two very distinct examples that is why I am talking about this, but it could also be electromagnetism or any other branch of science, where law of laws of thermodynamics are equally applicable.

So, before entering into the statements of second law, I must emphasize here that here we will build up the concepts on second law from the purview of classical thermodynamics. And that is how the statements of second law, there could be numerous statements of second law, and all those could be valid. But, we will study those statements of second law, which pertain to the transfer of heat and work in a cyclic process and these are very classical processes in thermodynamics.

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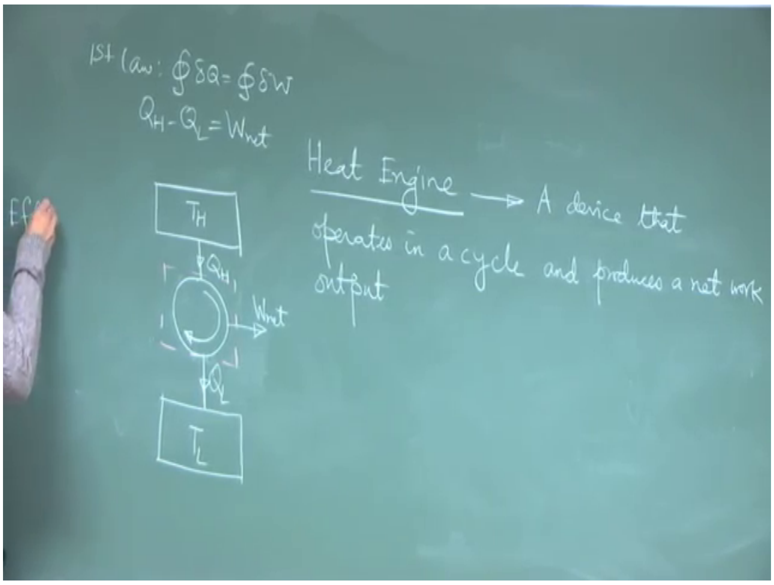

So, to understand that we will consider so before getting into the statements, we will define something. The first is heat engine, so what is the heat engine heat engine is a device that operates in a cycle, and produces a net work output. So, we will see that not all devices that operate in a cycle can produce a net work output.

So, there are constraints given by the second law of thermodynamics on how a heat engine should operate, what are the constraints under which a heat engine should operate, but the definition of heat engine does not give any constraint. The second law of thermodynamics gives a constraint on how a heat engine should you know work.

So, conceptually we can have a block diagram like this. There is a high temperature body, which we call a body at temperature T H. This is a heat engine, which works in a cycle to indicate that it works in a cyclic or cycle or it is a cyclic device, I am just putting this symbol. So, what this does is it draws some heat, so it wants to do some work.

So, when it wants to do some work, it cannot give that work free right. So, it has to draw some energy from somewhere and convert that energy to work, so that energy that it takes from that high temperature body, this energy we are symbolizing as Q H. Then it dumps or rejects some heat to a lower temperature body, and does a net work in the process. We will see later on, why this Q L is necessary, because to satisfy the first law even without rejecting this heat, this device could satisfy the first law; in fact, then whole of this heat can be converted into work.

So, now for this device you can apply the first law. The first law applied to this device is cyclic integral of heat is equal to cyclic integral of work, this is a cyclic device. So, what is the cyclic integral of heat, heat transferred to it minus heat transferred from it to the surroundings. So, Q H minus Q L, and this is net work W net.

So, you can see that if Q L is 0, W net is maximum right. So, ideally you could have got maximum work, had you not rejected any heat here. The definition of heat engine might be allowing it, but second law of thermodynamics will not allow it. And we will see that there is a statement of second law of thermodynamics that this allows it.

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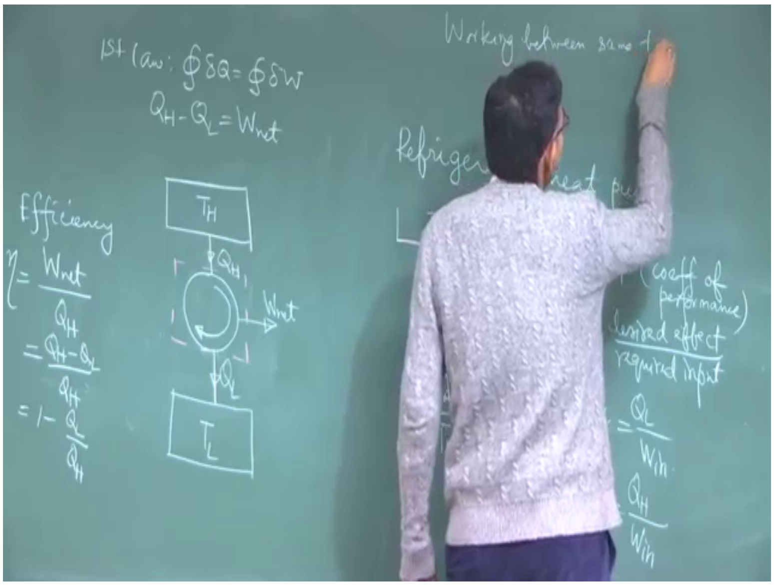

But, for the time being, we define the performance parameter of this heat engine, which is called as efficiency of the heat engine. How do you define the efficiency of the heat engine, so it is output by input right. So, this is what you need and in the denominator what you pay for. So, this Q H is what you pay for.

In a thermal power plant, this heat you pay for by burning the coal. So, this is what you pay for and this is what you get as an output. So, the net work by heat transfer, and because the network is Q H minus Q L. So, this is 1 minus Q L by Q H ok; so this is heat engine.

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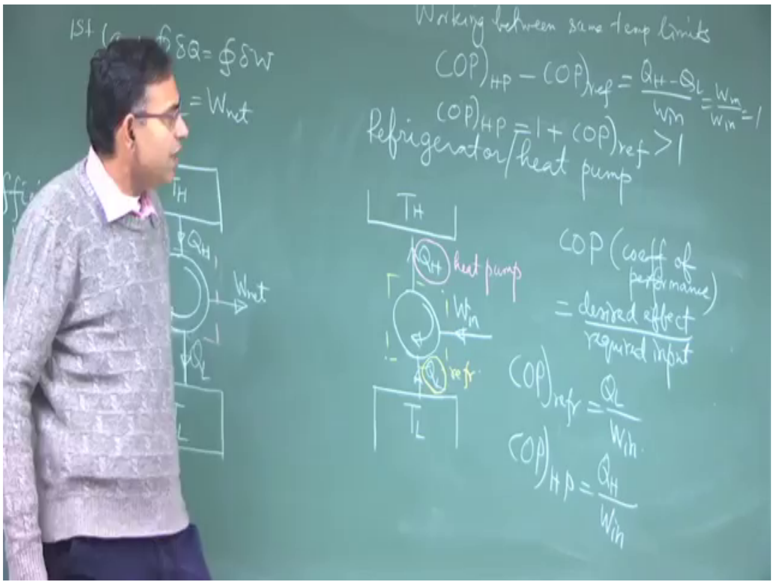

The next device that we will learn can be perceived conceptually as something called as refrigerator or heat pump. Imagine that you have a cold place say a movie theater, and outside is hot summer. So, you want to continuously reject heat from this low temperature place, which is the movie theater to keep it cold, but as we have discussed at the very beginning of this lecture, you cannot spontaneously transfer heat from here to the ambient which is hotter.

So, what you can do is you can imply a cyclic device which we will transfer heat, which we will take heat from here, and transfer heat to a higher temperature body, but you know it cannot do it spontaneously, because it is not a spontaneous process that is permissible. So, what it does is it considers, it performs this task by inputting some energy to the device which is a work input. So, this is what you pay for. So, if it is a refrigerator, what you desire for is this, so this is for refrigerator.

However, the same conceptual device, you can think of to use in a hot in a cold country. Let us say that the outside is cold, you want to keep a room hot in the winter season. So, this is that room. So, you want to transfer heat from this lower temperature ambient to this hot room to continuously, so that this room remains hot, because you cannot naturally do that again you require a work input.

So, only difference between this refrigerator and that heating in the room heating in the cold country is that for room heating this is what you desire, so this if you desire this is called as heat pump. So, the performance parameter just like efficiency of a heat engine, here the performance parameter is called as coefficient of performance or COP coefficient of performance.

So, it is the ratio of what, what is the desired effect that is your output divided by what you pay for that is the work input. So, COP so desired effect by required input ok. So, what is the COP of a refrigerator? What is the desired effect, desired effect is Q L, and the required effect is W in. What is the COP of the heat pump, the COP of the heat pump is the desired effect is Q H ok. So, the same device depending on what is your purpose, you can use as either a heat pump or a refrigerator.

So, working between the same temperature limits same temperature limits, you can you know get a relationship between COP heat pump minus COP refrigerator, so that is Q H minus Q L by W in. And from energy balance of this device that is cyclic integral of heat equal to cyclic integral of work you can say Q H minus Q L is W in. So, this is W in by W in that is 1 ok.

So, COP of heat pump working between the same limits that we have to keep in mind is equal to 1 plus COP of refrigerator. So, COP of refrigerator is positive right. So, I mean whether it is value is you know small or large it is it depends on the numbers, but we can very confidently say that this is positive, this is positive, therefore the cop is positive. So, whatever is positive if one is added to it, it becomes greater than 1. So, COP of heat pump will be greater than 1 right, so that means that is why, this is not called as efficiency. So, by efficiency we have a traditional perception that it is output by input ok.

So, when we say output by input, output cannot be you know greater than input right. So, output by input is always less than 100 percent, this is you know satisfied by this definition of efficiency for heat engine. But, this performance parameter this is simply a performance parameter, this is not output by input. So, there is no guarantee that this is less than 1, and that is why the name coefficient of performance which is a performance parameter instead of efficiency. So, with this little bit of introduction to some basic definitions, we will in the next lecture discuss about the statements various statements of the second law of thermodynamics.

Thank you.