Introduction to Aerospace Propulsion

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Module No. # 01

Lecture No. # 08

First Law of Thermodynamics for Closed Systems

Hello and welcome to lecture 8 of this lecture series on Introduction to Aerospace Propulsion. In the last few lectures - lecture 4 onwards, we were discussing about some of the very fundamental aspects of thermodynamics. We came across several terms that we are going to use very frequently in this course. So, I hope you have understood the significance of many of these terms like - what is a system; what is the boundary of a system; what are the different types of the system like closed system, opened system and so on; what is meant by internal energy; what is enthalpy and so on. These are some of the terms that we are going to use very often during the rest of the course. It is very essential that you understand the significance and the implications of each of these terms.

In today's lecture, what we are going to discuss about is a very fundamental law of thermodynamics and that is known as the first law of thermodynamics. We have already discussed about the zeroth law of thermodynamics. If you recall, during one of the earlier lectures, we had discussed about the zeroth law of thermodynamics. What was the zeroth law of the thermodynamics? It was essentially stating that if two bodies are in thermal equilibrium with a third body, then all these three bodies are in thermal equilibrium with each other. As we had discussed, zeroth law of thermodynamics forms a very basic law of thermodynamics. Because it was formulated only after the first and second laws of thermodynamics formulated, it was termed as zeroth law of thermodynamics. This is because it is a much more fundamental law than the first and second laws of thermodynamics.

After this zeroth law, as I had mentioned during the first lecture, we shall also be discussing about the first law of thermodynamics, the second law and the third law of the thermodynamics. In today's lecture, what we are going to talk about is the first law of thermodynamics applied to a closed system. If you recall, a closed system is one wherein you can only have energy transfer across the system boundaries and no mass transfer. So, we shall be discussing the application or the implication of first law of thermodynamics as applied to a closed system. Let us look at what are the different topics that we are going to discuss in today's lecture.

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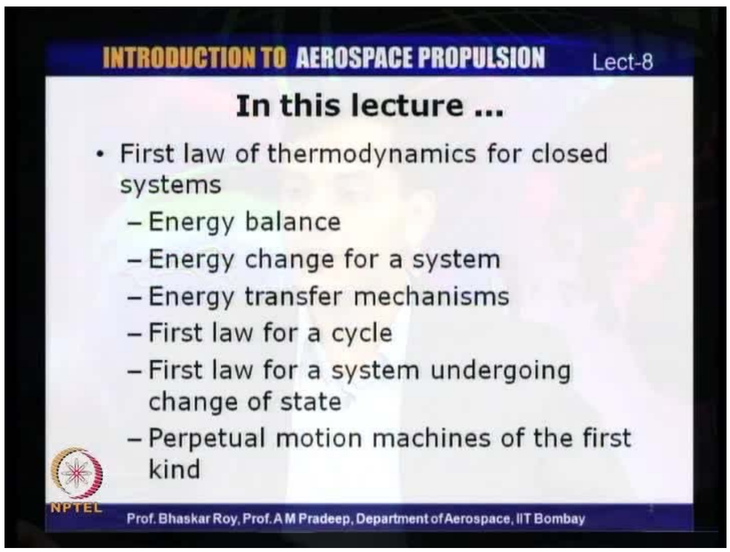

In today's lecture, we are going to discuss about these following topics: We shall primarily be discussing about the first law of thermodynamics applied to closed systems. We shall be discussing about energy balance. Then, we shall talk about energy change for a system. Then, what are the different energy transfer mechanisms that are involved. Then, we shall formulate the first law of thermodynamics as applied for a cycle. If you recall, a cycle is one wherein the initial and final states of the system are the same.

Subsequently, we shall formulate the first law of thermodynamics for a system, which is undergoing a change of state. Towards the end of the lecture, we shall also discuss some very interesting aspects known as perpetual motion machines of the first kind. These are devices, which have been proposed, which obviously violate the first law of thermodynamics. Therefore, these are devices, which never worked. We shall discuss these interesting devices towards the end of the lecture.

Now, we shall start our lecture with discussion on a very important experiment, which was carried out more than 250 years ago. In mid 1800s, Joule carried out a series of experiments, which laid the foundations for the first law of thermodynamics. These experiments were very interesting in the sense that till the time Joule carried out the experiments people considered heat to be a form of an invisible fluid, which they called as caloric. Caloric as people believed in those days was a fluid, which is basically heat. So, heat transfer takes place between a body, which has a higher caloric to a body, which has a lower caloric. That was known as the caloric theory of heat.

Joule was not very convinced with this concept of heat being a type of invisible fluid. So, he decided to carry out some experiments to find out whether heat is indeed a type of fluid. So, what he did was in his experiments, which we shall discuss in detail. In his experiments, he transferred work across an adiabatic system and then he observed that transfer of work across the adiabatic boundaries caused an increase in temperature of the system boundaries. After you remove the insulation, what happens is - whatever temperature the system had acquired will be transferred back to the surroundings in the form of heat. Using this experiment, Joule was able to prove that essentially heat is not any fluid, which flows from one body to another, but it is just a form of energy. So, Joule’s experiment laid the foundations for defining what is known as the first law of thermodynamics.

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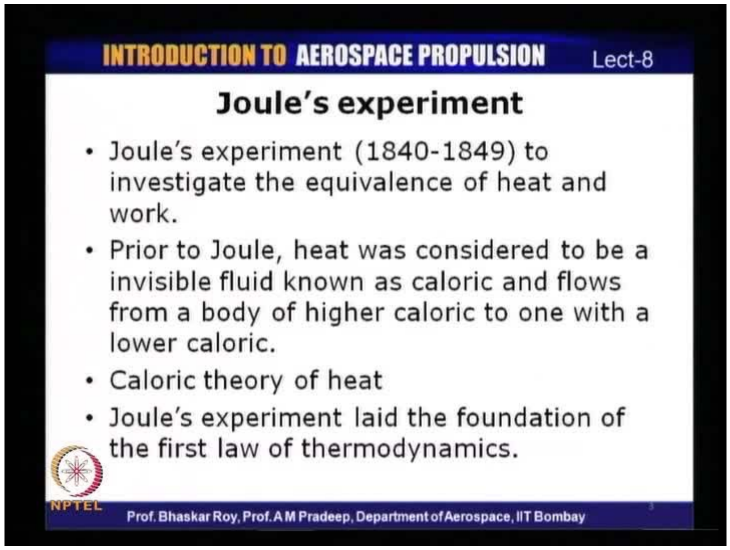

If you look at what Joule did during 1840s to 1849, he decided to investigate the equivalence of heat and work. During that time, it was only considered that heat is a form of a fluid, but will not work. Joule decided to carry out experiments, which can prove that heat and work are two different forms of energy transfer. Therefore, thermodynamically, they are the same.

As I had already mentioned, before Joule's experiment, heat was considered to be an invisible fluid and it was known as caloric. It flows from a body of higher caloric to one which has a lower caloric value; the same way as we discussed today that heat is a form of energy transfers, which takes place from a body, which has a higher temperature to a body, which has a lower temperature. So, heat is a mode of energy interaction between a system and its surroundings or between two systems simply by the virtue of temperature difference.

This concept of flowing of caloric from a body with higher caloric to one with lower caloric was known as the caloric theory of heat. Joule's experiment was kind of an experiment, which proved that heat and work are identical and they are just two different forms of energy.

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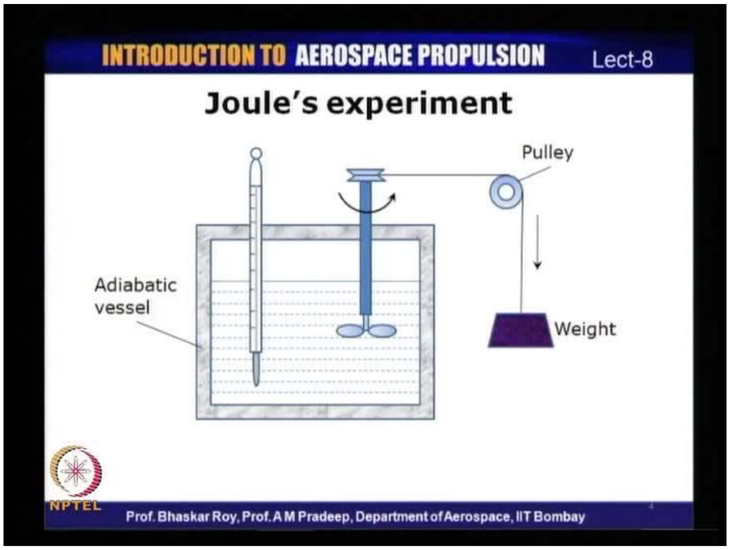

This is the basic experiment which Joule carried out. It is a very simple experiment as it looks like. However, the important thing to remember here is that it was this experiment, which proved that heat is essentially not a form of fluid, which flows from one body to another, but it is a form of energy.

Let us look at what are the different constituents of this experiment. As you can see here, the experiment consists of an adiabatic vessel. Adiabatic vessel contains a fluid, which cloud be water or any other fluid. There is a paddle wheel, which is immersed in the fluid. This paddle wheel can be driven by pulley on which a weight is suspended. So, as the weight is dropped, it causes rotation of the paddle wheel.

Across the system boundaries, you can see that there is a work transfer, which is taking place if there is work done on the system. As a result of this, Joule observed that there is a change in the temperature of the system from what it was originally. Let us say the system temperature was initially t 1. As the weight is dropped, it causes the paddle wheel to rotate. As the paddle wheel rotates, it is basically doing the work on the system. Therefore, that energy has to appear in some form or the other on the system itself. So, where does that energy appear? Will that energy appears in the form of increasing temperature of the system? Let us say the temperature of the system, which was initially t 1 would now become t 2, where t 1 is less than t 2. This temperature was measured using the thermometer, which was also emerged in the fluid.

This is a very ingenious experiment which Joule devised to show that it is possible to convert work into heat. Therefore, thermodynamically, heat and work are equivalent in the sense that both of them are just two different forms of energy transfers or energy interactions. What Joule did was - to take a certain fluid in an adiabatic vessel that is insulated and then do work on the system through a paddle wheel. That is, as you drop the weight, what happens is - when the weight is dropped, it rotates the paddle wheel. Therefore, that paddle wheel does a work on the fluid resulting in increase in temperature of the fluid.

After you have done work on the system, if you remove the insulation, what happens is that - the system has a temperature t 2, which is greater than the ambient temperature. Therefore, there is a heat transfer taking place across the system boundaries because there is no more insulation now. So, eventually, the system will come back to its position where it was before the experiment began. Now, you can see that what you have done is a process, which is cyclic in the sense that the system has returned to its initial state. This was possible by two processes: one of the processes is work transfer into the system or work done on the system and the second process involves heat transfer from the system.

There is no change in internal energy of the system after the cycle is completed. We have already discussed this that for a cyclic process the change in cyclic integral of a property is 0. Since internal energy is a property of the system, cyclic integral of internal energy should be 0. Therefore, for this particular system at the end of the cycle, there is no change in internal energy of the system. So, what it means is that we have done a certain amount of work on the system, which appears in the form of increase in temperature of the system. Now, if you were to transfer that much amount of energy back to the surroundings by heat transfer then essentially there is no change in the internal energy or net change in energy of the system. Therefore, this means that work done on the system is now equal to the heat transfer from the system. So, this is what Joule was trying to prove. Therefore, work done is not equal to, but it is proportional to the heat transfer from the system.

Joule was able to find out the constant of proportionality through a series of experiments on different fluids. So, instead of water, he then used some other fluid. In fact, he also did experiments on solids; that is, he did work on the solid system containing a set of solid blocks. That work done on the system essentially caused friction between the different solids inside the system leading to an increase in temperature. However, what he found was - at the end of all these different experiments that the proportionality constant between work done on the system and heat transfer from the system is the same irrespective of what material or what substance you use in the system.

That proportionality constant is known as the Joules constant. It is after these set of experiments that the SI unit of energy has been termed or has been named after Joule. Therefore, the SI unit of energy is Joule as a mark of respect to the person who did these very fundamental experiments. This defines one of the fundamental laws of thermodynamics - the first law of thermodynamics. So, let us look at some more details about the experiments, which Joule carried out.

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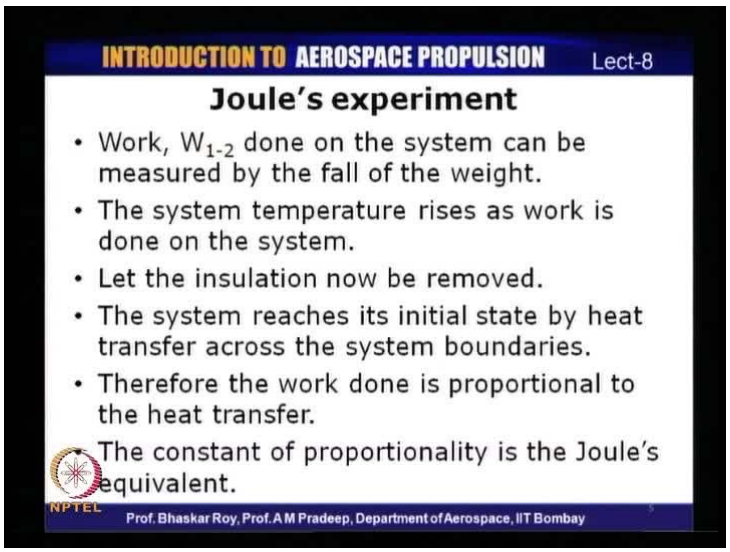

In Joules experiment, let us assume that we had work done between states 1 and 2. Therefore, the work done W subscript 1-2 is the work done on the system. You can easily measure this work because it is just a paddle wheel work, which is implemented by dropping of a weight or displacement of a weight.

As you displace the weight, you know how much distance the weight has moved. Therefore, you can determine the work done on the system. This work done on the system manifest itself in the form of an increase in temperature from initial state t 1 to state t 2. So, the system temperature rises from temperature t 1 to temperature t 2 at the end of the work done process.

Now, if you remove the insulation, what happens is that the system comes back to its initial state by heat transfer across the system boundaries. Therefore, the work done is proportional to this heat transferred. As we have already discussed, this constant of proportionality is known as the Joules equivalent. So, Joules equivalent is a constant of proportionality, which relates the work done on the system to the heat transfer from the system. So, Joule found that if you were to carry out an experiment of this fashion, it does not really matter what is the fluid, which is held inside the system boundaries. The equivalents of work done and the heat transfer from the system is the Joules constant of proportionality.

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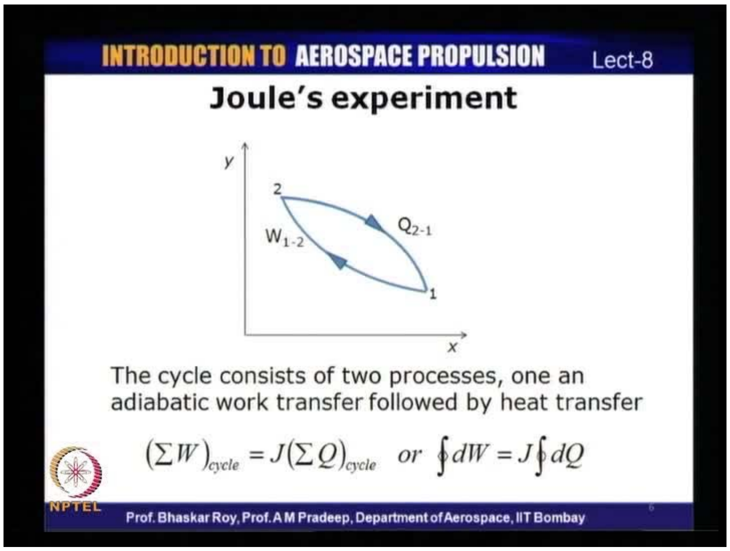

If you were to look at this particular system, which we are discussing, we have work done between states 1 and 2. Let us say the process path by this particular process is as shown here - between states 1 to 2. So, the work done on the system is W sub script 1-2. Joule showed that the work done on the system can be plotted in terms of some properties x and y. As we discussed at the end of this process, if you remove the insulation of the system, then that results in heat transfer from the system to the surroundings. Therefore, that heat transfer process is shown by this second process as shown in this process diagram from state 2 to state 1. So, this represents a cycle wherein - the system initially was at state 1; the first process was work done on the system by means of the paddle wheel work, which resulted in change of state from state 1 to state 2; from state 2, by heat transfer the system comes back to its initial state. So, the first process of energy interaction is a work transfer process or work done process and second is the heat transfer process.

What it means is that for a cyclic process, the net work done or the sum total of all work done on the system is equal to some constant J times the sum total of all heat transfer that has taken place during the cycle. This constant of proportionality is what we had discussed as the Joules equivalent. We can also express the summation in the form of a cyclic integral, which is cyclic integral of W is equal to J times cyclic integral of Q. That is, for a cyclic process, it is possible to equate the work done and the heat transfer through the proportionality constant, which is the Joules equivalent ratio. As I mentioned, this Joules experiment forms the basis for the first law of thermodynamics.

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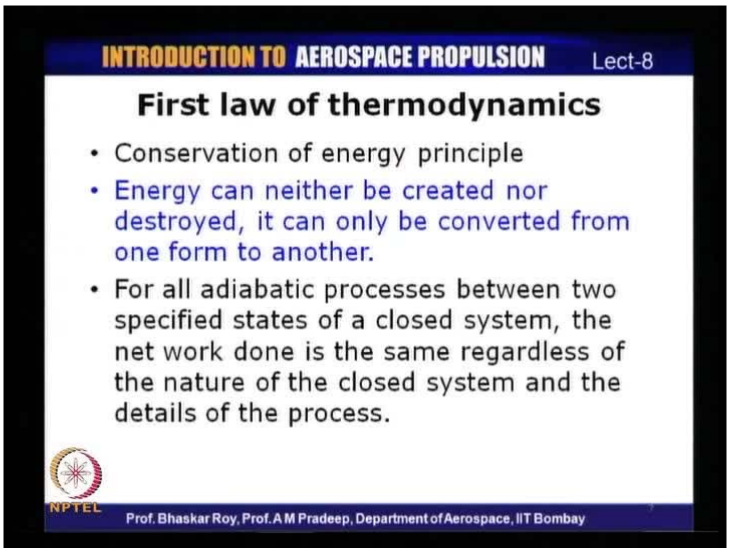

First law of thermodynamics is the conservation of energy as you are perhaps aware that there is something known as conservation of energy principle. That is essentially the first law of thermodynamics that energy can neither be created nor be destroyed, but it can only we converted from one form to another. So, this is the essence of the first law of thermodynamics that you can neither create energy nor destroy it, but you can transfer it or convert it from one form to another. As a result of this first law of thermodynamics, for all adiabatic processes between two specified states of a closed system, the net work done will be the same. It is regardless of the nature of the closed system or the details of the process because it is an adiabatic process and the processes between two specified states of a closed system. Since we are discussing first law for a closed system today, we will only talk about closed systems. In the next lecture, we will be talking about first law for an open system or flow processes.

The first law of thermodynamics is stating that energy is something, which you cannot create and there is a net energy of the universe, which does not change. So, there can only be energy transfer between two systems or between a system and its surroundings. It is not possible either to create energy or destroy energy. We shall see towards the end of the lecture that there are some devices, which people have proposed. This violates the first law of thermodynamics because they either create energy in some form or destroy energy some form. Therefore, these devices violate a fundamental law of nature. Therefore, these devices are infeasible. It is for this reason that such devices have never been demonstrated. Though there are numerous examples of devices, which have been proposed, they have never been demonstrated because they violate a very fundamental law of nature.

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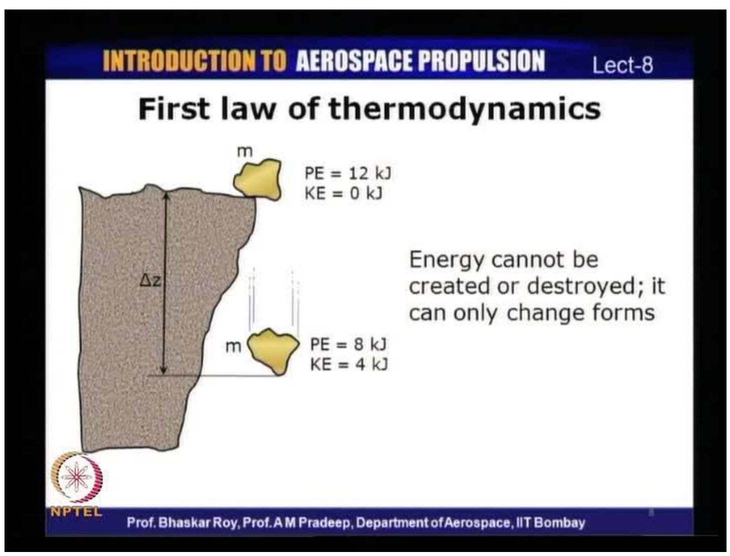

Now, let us look at how we can understand the first law of thermodynamics in little more detail. There is a simple example given here. So, this example is about change of energy from one form to another form. Here what you see is a cliff at the end of which we place a rock, which has a certain mass m. By virtue of the height of this rock above the base line of the datum, it has a certain potential energy. Let us say it is 12 kilo Joules. Because the rock is at rest, its kinetic energy is 0. Remember: We are looking at macroscopic forms of energy. So, the potential energy of this particular mass is 12 kilo Joules. Kinetic energy is 0 because it at rest.

If you drop this rock from the edge of the cliff, as the rock falls down, there is a change in its energy. You know that the potential energy is a function of the height of the particular system from the datum. As the rock falls down, potential energy decreases because the height of the rock with reference to the datum is reducing. So, its potential energy reduces and it becomes 8 kilo Joules at this end state. Because the rock has a certain velocity, it also has certain kinetic energy. However, the sum total of potential energy plus the kinetic energy will still be equal to what it was originally; that was 12 kilo Joules. Therefore, even as it is falling, the net energy of the system will still be the same as it was earlier; that is, 12 kilo Joules.

Now, you may wonder what happens after the rock has reached the datum. After the rock reaches its bottom, then potential energy should become 0 and kinetic energy also becomes 0. So, you may wonder that you have actually destroyed that energy and where has that energy gone. There is no destruction of energy here. What happens is - after the rock falls on the ground, whatever energy was contained with the rock with the initial state that was 12 kilo Joules, gets converted to heat and work. That is, that much energy gets dissipated in the form of heat and sound.

You know that as the rock falls down, you would hear a sound. Where does that sound come from? Sound is also a form of energy and that is the energy, which the system had initially; that was 12 kilo Joules in this case gets converted to sound. There is also some amount of heat, which is generated as the rock falls on the ground. This is a very simple example of how you can use first law of thermodynamics for any system. As you can see in this case, you are neither creating energy nor destroying energy, but it is only converted from one form to another. In this case, it was converted from potential energy to kinetic energy and finally, it got dissipated in the form of heat and sound. So, there is only conversion of energy that is taking place between different forms. There is neither creation nor distraction of energy. So, the first law of thermodynamics is what explains this kind of energy interaction between a system and the surroundings.

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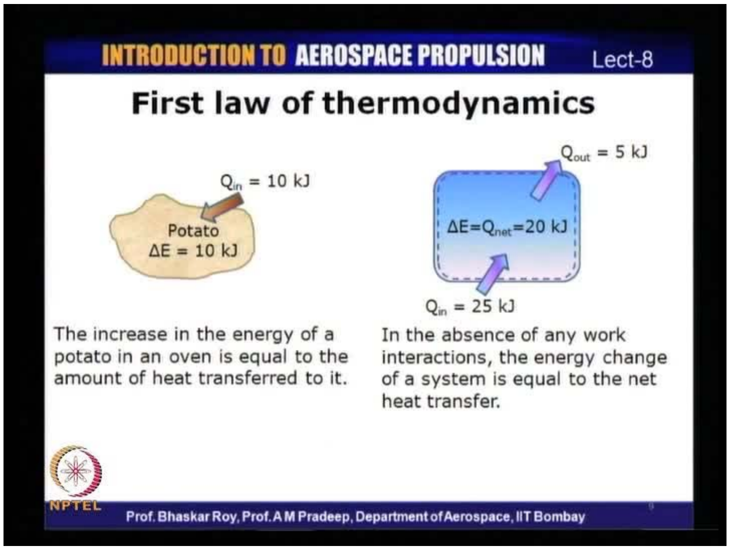

Let us look at some more examples. We have some examples here, which describe application of first law to different types of systems. For first example, let us take an example of a potato, which we are trying to boil or cook. If you place the potato in an oven, you know that there is heat transferred into the potato, which is why it gets cooked. So, the increasing energy of the potato in this example is equal to the amount of heat that is transferred to the system. That is, the potato in this case. Let us say - if you were to transfer 10 kilo Joules of heat on to the potato, the energy of the system that is, potato increases by the same amount; that is, 10 kilo Joules. So, there is no work interaction here, but there is just heat interaction taking place between the system and the surroundings

In the absence of any work interaction, the net change in energy of the system will be equal to the net heat transfer. On the right-hand side, (Refer Slide Time: 24:10) you can see another example of another system wherein there is heat transfer into the system as well as heat transfer out of the system. Let us say - we are transferring 25 kilo Joules of heat into the system that causes a change in net energy of the system and there is also heat transfer out of the system. In this example, it is 5 kilo Joules; 25 kilo Joules is the heat transfer into the system and 5 kilo Joule is the heat transfer from the system. Therefore, the net change in energy of the system, which is delta E is equal to Q net should be equal to Q in minus Q out, which is 20 kilo Joules.

In the absence of any work interaction; there is no work interaction here, the energy change of this particular system is equal to the net heat transfer. That is, heat transfer in minus heat transfer out. So, in this example, we have seen that if you look at a system where there is heat transfer into the system as well as heat transfer from the system and if there are no work interactions. We shall look at work interactions in the next example. The net change in energy of the system will be just be equal to the difference of the heat transfer in and heat transfer out of the system. So, this is again a consequence of the first law of thermodynamics applied for closed systems.

We will now look at some examples, where there is also work transfer into the system across the system boundaries. One of the examples we shall look at is - electrical work done on the system. We have seen in the previous lecture that there are different forms of work done. One such form is electrical work, which involves heating of a resister and that causes work done across the system boundaries in the form of heating of the resistor.

Let us say - you consider an adiabatic system, which means there is no more heat transfer across the system boundaries. However, you can still have work transfer across the system boundaries by means of - in one example, we shall look at a resistor. So, if you have a resistor inside a system, which is adiabatic or which is insulated, there is no heat transfer from the system boundaries.

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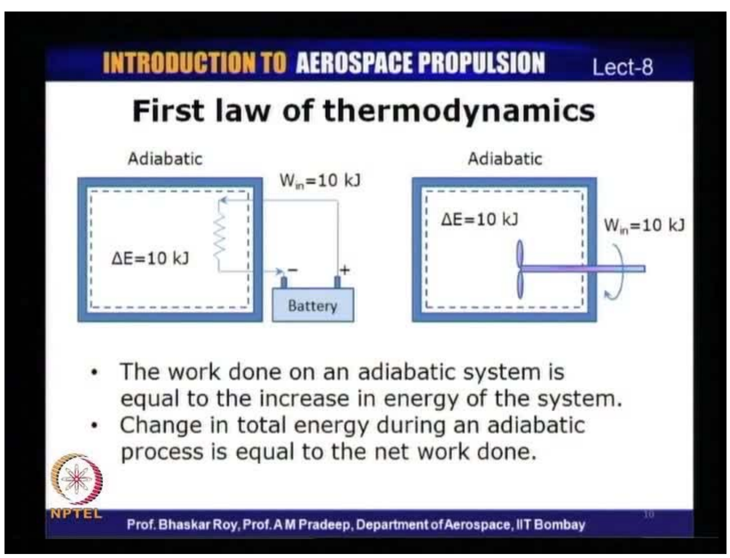

Now, you are able to do work across the system boundaries using two modes: one is electrical resistance and other example we will see is shaft work or paddle wheel work. In this example, in the left-hand side, you can see the first one; that is, electrical heating of the system. Using a battery, if you were to heat a resister, then the net change in work done on the system will be reflected in the form of increase in energy of the system. In this case, let us say that W in was 10 kilo Joules. That will be seen in the form of increase in energy of the system by the same amount; that is, 10 kilo Joules, if the system is adiabatic.

On the right-hand side, we have a similar example, but instead of electrical work, we have a paddle wheel work wherein you rotate a paddle wheel using some work. In this case again, if the work input was 10 kilo Joules, that will result in an increase in energy of the system by the same amount of 10 kilo Joules. This is again applicable as long as the system is adiabatic. If it is not adiabatic, one also needs to consider the heat transfer from the system boundaries. The examples we shall see in the next few slides will be systems, which have both heat and work interactions. Then, we will see what the net change in energy of the system is.

We shall apply first law of thermodynamics to different types of systems. One is - if it is cyclic process, which we have already seen some hint through the Joules experiment wherein he proved that the net work done on a system is proportional to the net heat transfer for cyclic processes. That is first law for a cycle. We will see that in little more detail little later. We will apply again the first law of thermodynamics for system, which is undergoing only a change of state, but not a cyclic process. Then, we will also the first law of thermodynamics for isolated system. We will see that as we progress in this lecture.

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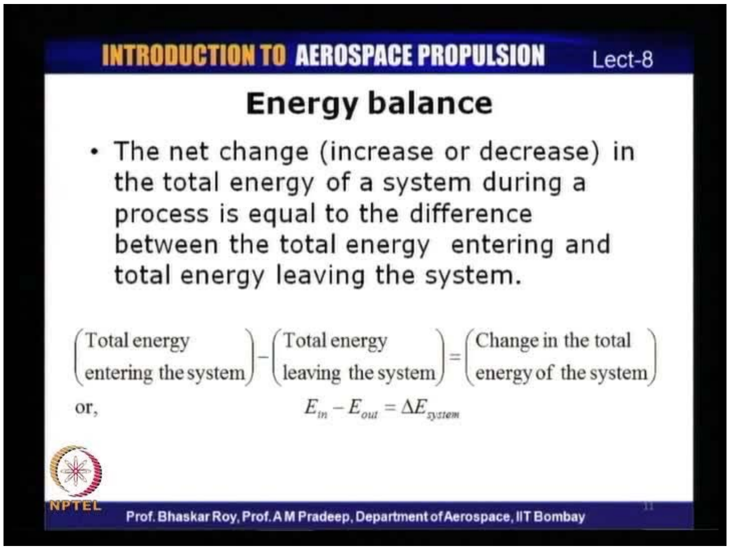

Now, let us look at how you can carry out an energy balance for any particular system, which is undergoing some energy interaction with it its surroundings. The net change, which could be either increase or decrease in total energy of a system during a process is equal to the difference between the total energy entering the system and total energy leaving the system. In other words, total energy entering the system minus total energy leaving the system is equal to change in total energy of the system.

This again is obviously a consequence of the first law of thermodynamics. That is, E in minus E out is equal to delta E system. That is, E in refers to the total energy entering the system; E out is the total energy leaving the system; delta E is the net change in energy. So, if you were to consider energy per unit mass, this would be total energy by mass for each of them. That would be small e in minus small e out is equal to delta small e system.

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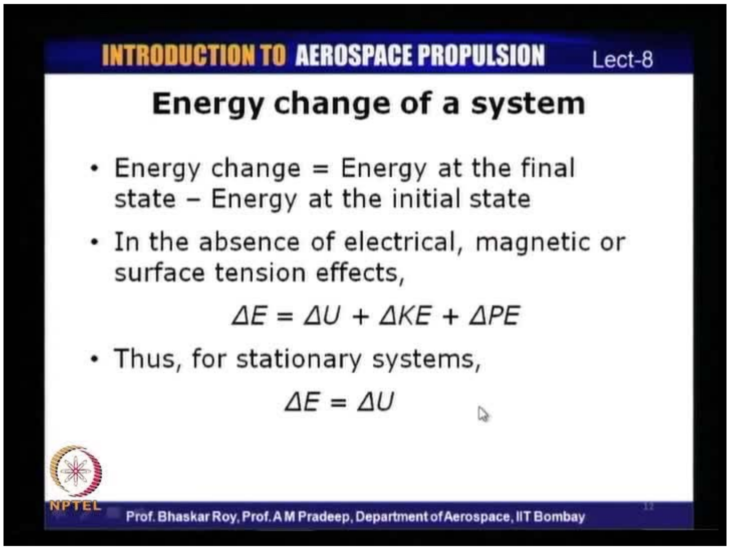

Energy change is energy at the final state minus energy at the initial state. We have already seen that in the absence of any electrical, magnetic or surface tension effects, the net change in energy delta E is equal to delta U plus delta KE plus delta PE; where, delta KE is kinetic energy change; delta PE is the potential energy change; delta U is the internal energy change. Therefore, for stationary systems, the net change in energy of a system will be equal to the net change in internal energy of the system.

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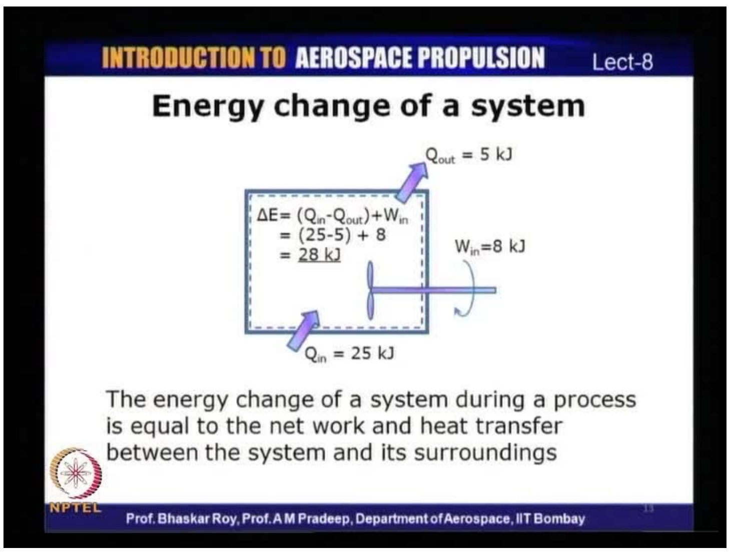

To explain this further, let us look at a system, which has both heat interaction as well as the work interaction across the system boundaries. Here we have an example of a system, which is no longer adiabatic and also there is work done across the system boundaries. Let us see what the net change in energy of this particular system is. Here there is a system, where there is some heat transfer into the system, some heat transfer out of the system and work done on the system.

How do you calculate the net change in energy of a system? You know that if there were no work done on the system, then delta E would have simply been equal to Q in minus Q out. So, that is 25 minus 5, which is 20 kilo Joules. However, in addition to this, we also have a work done on the system, which is 8 kilo Joules here (Refer Slide Time: 31:23). Therefore, the net change in energy of this particular system is equal to Q in minus Q out plus W in, which is 25 minus 5, which is corresponding to net heat transfer plus 8, which is work done. Therefore, the net change in energy of this particular system is 28 kilo Joules. Therefore, this is an example, which shows that you can calculate the net change in energy of a particular system, which has both heat interaction as well as work interaction across the system boundaries by looking at what is the net work done on the system and what is net heat transfer across the system boundaries.

So, that will determine the net change in energy of this particular system. What we shall see next is that what are the different modes of energy transfer? I think we already discussed that energy interaction for a closed system can take place only in two modes: one is heat and the other is work. That is, you can transfer the energy across the system boundaries. If it is a closed system, it can be done only in two modes: that is, heat and work.

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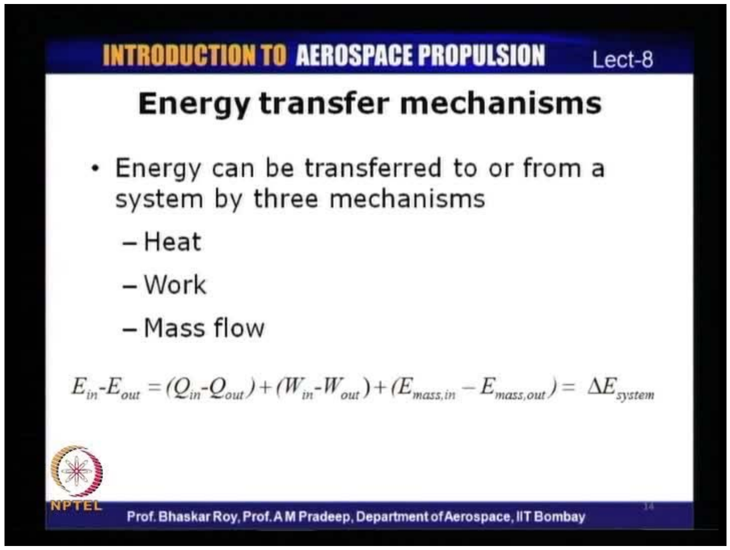

What if the system also has an open system? In addition to heat and work transfer for an open system, it is also possible to have energy transfer through mass flow. If this was the case, which we will discuss in much detail in the next lecture; that is, energy transfer for open systems. In general, energy transfer will be equal to E in minus E out. That is, net change in energy is equal to net heat transfer, which is Q in minus Q out; plus net work that is W in minus W out; work done on the system minus work done by the system; plus the energy due to mass flow. So, it could be E mass in minus E mass out. This will be equal to net change in energy of a system.

Now that we are dealing only with closed system, this particular term will be 0 (Refer Slide Time: 33:31). There is no mass flow across the system boundaries. There is only heat transfer. Therefore, delta E system as we have seen in the previous slide should be equal to just delta Q and delta W.

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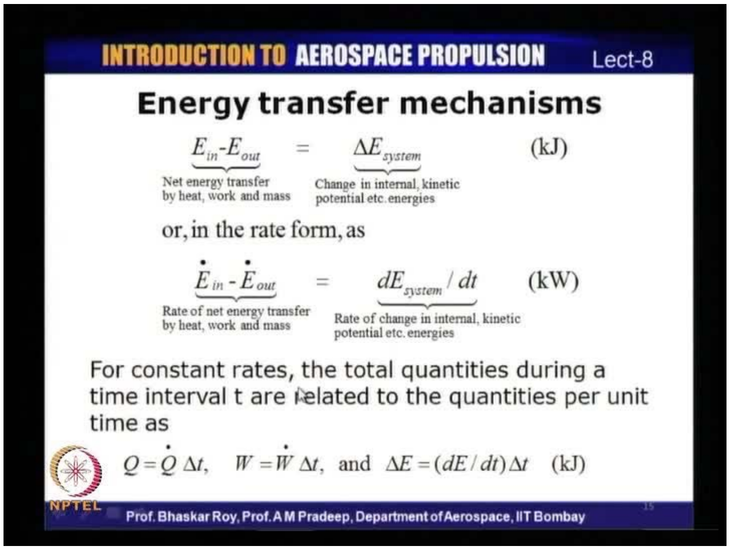

If you were to express the previous expression E in minus E out, which could be net energy transfer, it could be by either heat, work or if it is an open system by mass, is equal to delta E of the system, which could be reflected in terms of change in internal energy, kinetic energy, potential energy, etcetera.

We can also express this in the form of rate. That is, in the rate form, the rate of net energy transfer by heat, work or mass, E in, which is… There is also usually rates that are expressed by a dot at the top of the symbol. So, E in dot means rate of energy in minus E out dot, which means rate of energy out is equal to dE system by dt; that is, rate of change of internal, kinetic, potential energy, etcetera. If the rates were constant, then the net heat transfer or work done or energy can simply be found by multiplying the rate by the corresponding time interval. That is, Q will be equal to Q dot times delta t, W should be equal to W dot times delta t and delta E is equal to dE by dt times delta t. This is how you find the net work or heat or energy if you know the rates and the time interval during which these interactions were taking place.

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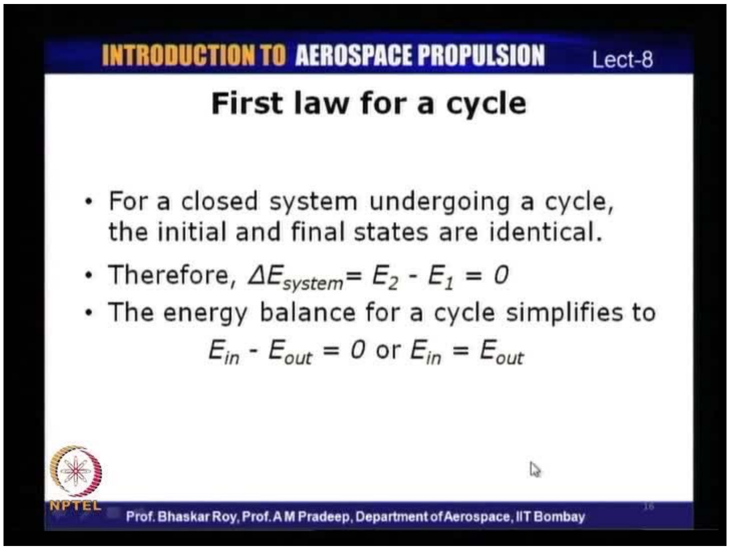

What we shall look at next is - how do you apply the first law of thermodynamics for a cycle? We were discussing about Joules experiment, which was a cyclic processes, wherein work was done on the system. Then subsequently, heat was transferred from the system causing the system to come back to its initial state. Therefore, that qualifies as a cyclic process. So, Joule had proved that for such processes, delta W is proportional to delta Q. So, that is the first law for a cyclic process means.

If you look at a closed system, which is undergoing a cycle, the initial and the final states are the same. We are already aware that for a cyclic process, the cyclic integral of a property should be 0, which means since energy is a property of a system, cyclic integral of that should be 0. So, if we were to consider E 1 and E 2 as the initial and final states, they should be same. Therefore, delta E of a system will be equal to E 2 minus E 1, which is 0 because E 2 and E 1 are same as a system has come back to its initial state after the process. So, delta E of a cyclic process will be equal to 0. If delta E was 0 for a closed system, if you apply the first law of thermodynamics, what we shall see is delta W and delta Q will be the same. This is because delta E is equal to 0. That is what is explained in this slide here (Refer Slide Time: 37:02).

Now, for closed system, which is undergoing a cycle, we know that initial and final states are identical. Therefore, delta E of the system is equal to E 2 minus E 1, which is

0. So, for energy balance, it simplifies that E in minus E out is 0 or it means that E in is equal to E out. So, energy in and energy out are the same.

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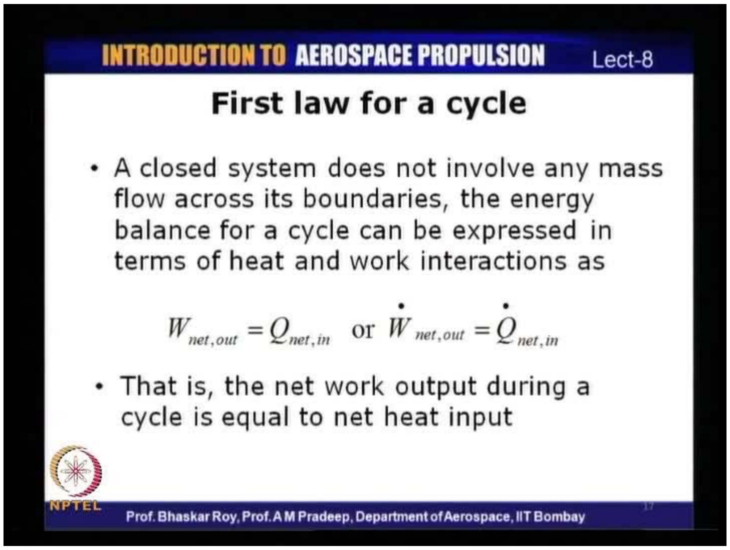

If we extend the first law of thermodynamics, then if it is a closed system, which does not obviously involve in a mass flow across system boundaries. The energy balance for this cyclic process can simply be expressed in terms of heat and work interactions. That is, W net out is equal to Q net in or in the form of rate, W net out dot is equal to Q net in dot. That is, rate of work output should be equal to rate of heat transfer input. So, this is the first law of thermodynamics as applied to a cycle.

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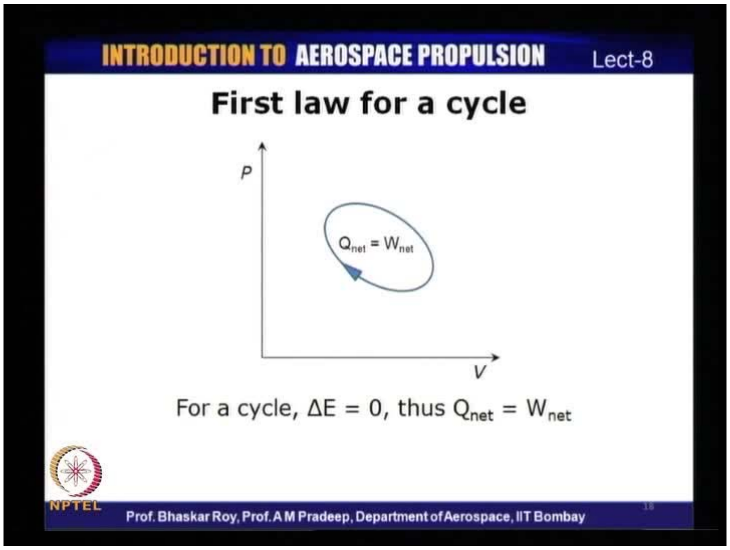

We have explained in terms of an illustration here. Here we have a cyclic process, which means that the system was initially at a state here. At the end of the process, it comes back to its initial state. So, as per the first law, since delta E is equal to 0 for a cyclic process, the net heat transfer during this cyclic process should be equal to the net work done during the cyclic process. So, this is the first law as applied to a cycle that W net is equal to Q net. We shall now look at how you can calculate or determine or apply the first law of the thermodynamics for system, which is undergoing a change of state. This means that it is not undergoing a cyclic process, but it is just undergoing a process wherein there is a change of state. Therefore, the initial and final state will be different. So, in this process, obviously delta E will not be 0 because there is a change of the system.

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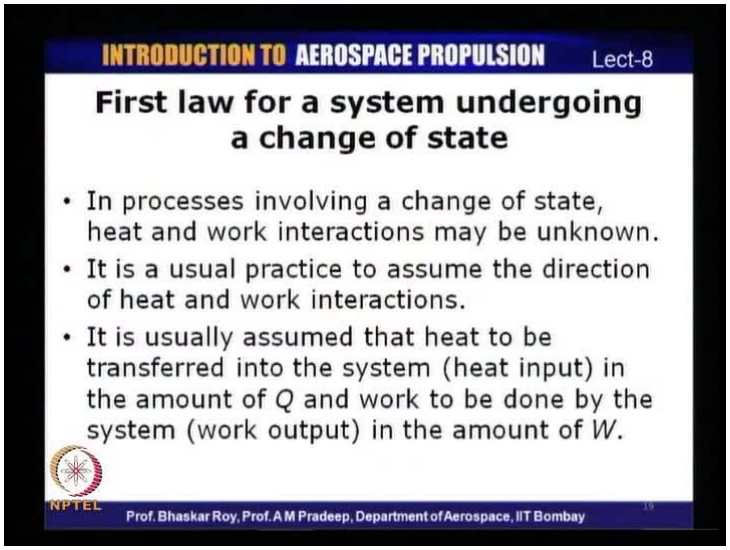

We shall see how we can apply the first law for a system, which is undergoing a change of state. In processes, which involved a change of state, you could have involved scenario, where the heat and work interactions are unknown. That is, you do not know whether heat transferred to the system or from the system or work is done by the system or to the system. So, normally what we do is to assume the directions of heat and work interactions.

The normal practice is that we usually assume that heat is transferred into the system or usually there is heat input into the system and there is work output from the system. So, this is just a normal practice. It is not compulsory that all systems will definitely have such a property. There could be systems, where there is heat transfer or heat output and there is work input. However, in general, it is a normal practice to assume that heat is transferred into the system in the amount Q and work is done by the system by amount W.

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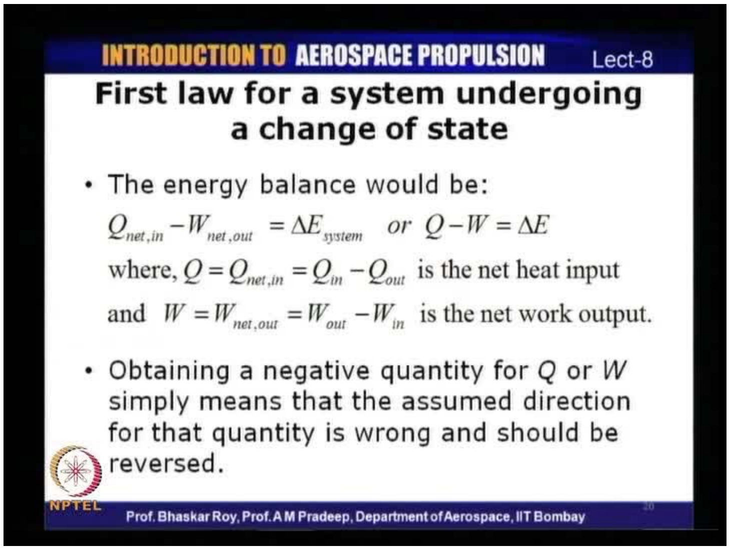

If that were the case, then if you apply the first law of thermodynamics, we get Q net in because heat is transferred into the system minus W net out work done by the system is equal to delta E of the system. In other words, Q minus W is equal to delta E. Here Q is Q net in, which means Q in minus Q out, which corresponds to the net heat input and W is the W net out, which is W out minus W in that is the net work output of the system.

If in a particular example or in some problem, which you are trying to solve, if you apply this particular sign convention and end up getting negative quantity of Q or W, it means that the assumed direction for that quantity was not correct and it has to be reversed. Magnitudes would not change, just that you may get a negative sign when you try to solve a problem. However, that only means that the assumption was initially incorrect and it should be just reversed.

For a system, which is undergoing a change of state, the first law of thermodynamics comes to Q minus W is delta E. That is, difference between the net heat transfer and the net work done will manifest itself as the net energy change of the system. That is, Q minus W will be equal to delta E. So, the first law of thermodynamics boils down to Q minus W is equal to delta E, which means that the difference between the net heat transfer and the net work output will be showing up as the net energy of the systems. That is what Q minus W is equal to delta E means. So, that is the first law of thermodynamics as applied to a system, which is undergoing a change of state.

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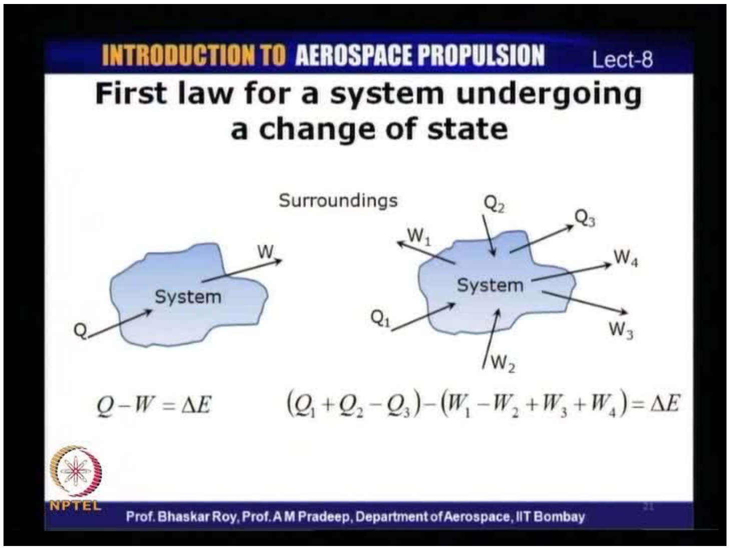

If we look at a system, which has multiple inputs and multiple outputs in the sense that there are multiple modes of heat transfer and multiple forms of work interactions, then let us look at what would be the first law for a system. Remember: you can actually sum up the net heat transfers and net work outputs. Therefore, get delta E. On the left-hand side is a system, which is undergoing a change of state. There is some heat transfer into the system and the system does some work out. Therefore, the first law states that Q minus W will be equal to delta E of the system.

What if you had multiple number of Q and multiple number of W? That is, there are multiple modes of heat transfers either to the system or from the system. If there are multiple modes of either work done on the system or by the system, then it is adding up all these quantities. So, in this case, we have heat transfer in the form of Q 1 to the system, Q 2 to the system and Q 3 from the system. Q 3 is heat transfer from the system. Similarly, we have W 1, which is work done by the system, W 2 is work done on the system, W 3 is work done again by the system and W 4 is also work done by the system. If you were to apply the sign conventions, which we had discussed in the last lecture, then heat transfer to the system is usually taken as positive and heat transfer from the system is negative. Similarly, work done by the system is positive and work done on the system is negative.

If you apply that particular sign convention, you get Q 1 plus Q 2 because both of these are heat transfer to the system. Minus Q 3 because Q 3 is heat transfer from the system; minus W 1 which is work done by the system and therefore, positive; minus W 2, which is work done on the system and hence negative. W 3 and W 4 are positive because they are work done by the system. So, this net effect is equal to delta E. So, here we have net heat transfer and net work done is equal to net change in energy of the system. This is how you would apply first law for a system that has multiple energy interactions.

Let us summarize first law expressed in different forms and different ways for closed systems

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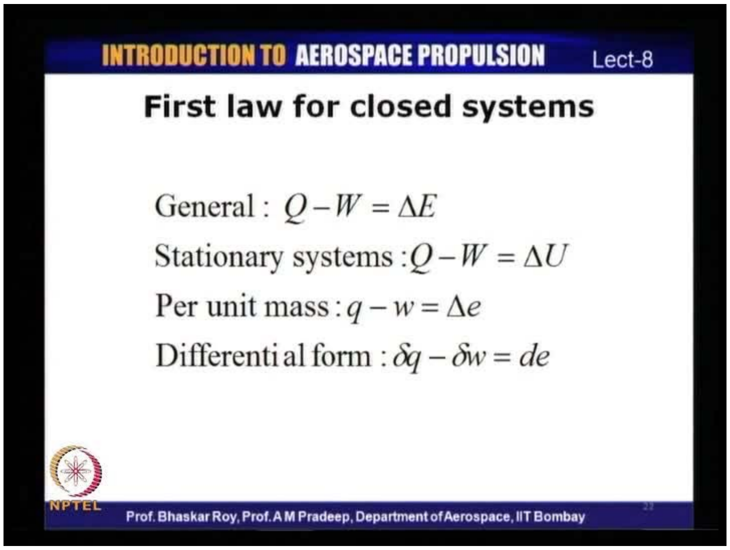

We have seen that in general, you can express Q minus W as delta E for a stationary system because delta kinetic energy, delta potential energy is 0. Q minus W is delta U. Per unit mass, it becomes q minus w in small letters is equal to delta small e. In differential form, small delta q minus small delta w is equal to de. So, this is how you would express first law in general for closed systems. If it is a cyclic process, the right-hand side naturally becomes 0 because there is no net change in energy of the system. Therefore, that right-hand side becomes 0 and therefore, Q will be equal to W for cyclic processes for closed systems.

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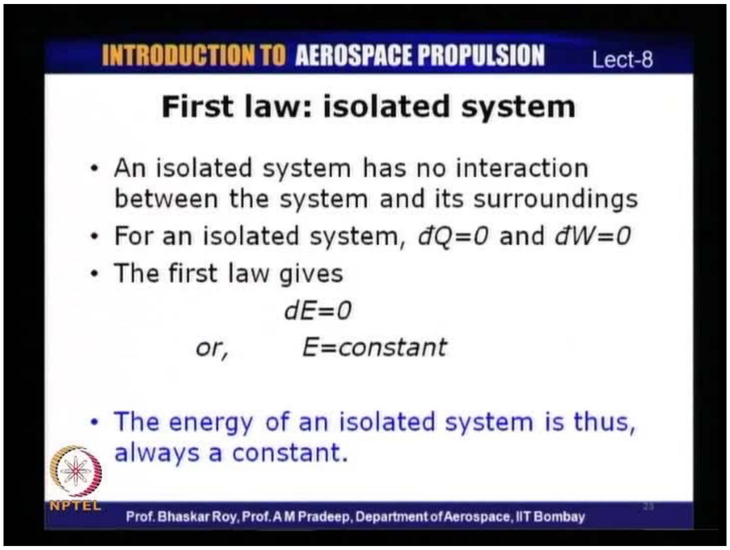

What if the system is isolated? For an isolated system because there is no interaction between the system and its surroundings, there is absolutely no energy interaction between the system and the surroundings. Delta Q is 0 because it is adiabatic. Delta W is also equal to 0 because it is isolated. Therefore, first law gives dE should be equal to 0 or E should be equal to constant. That means the energy of an isolated system is always constant. So, if a system is isolated, that means that it has no energy interaction between the system and the surroundings. The net energy of the system is the same or the energy of the system does not change because there is no way the system can interact with surroundings. Since it cannot interact with surroundings, there cannot be any energy interaction. Therefore, as per the first law, energy of that particular system will be a constant. Therefore, energy of an isolated system is always a constant.

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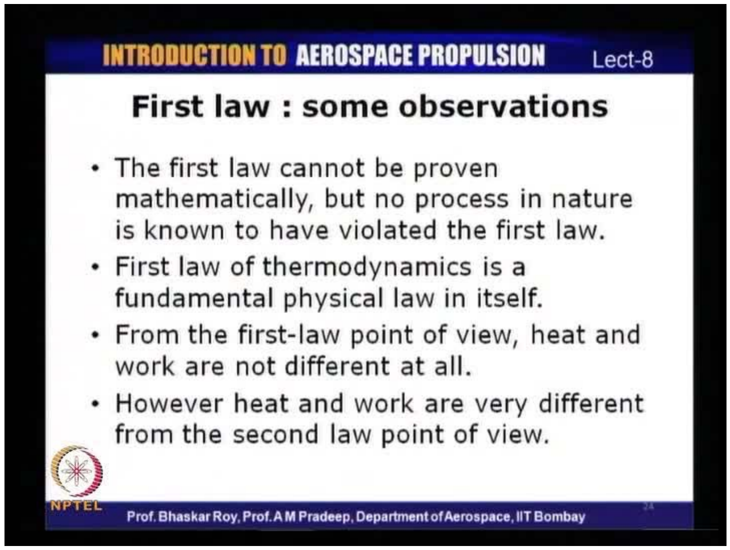

Now there are some interesting observations based on the first law. First law is something, which you cannot mathematically prove. However, just that there are no processes in nature, which have known to have violated; we consider that the first law is a sufficient proof in itself. That is, first law cannot be violated because there have not been any proof of violations of the first law of thermodynamics. Therefore, it is not necessary to prove first law mathematically. This is because of the fact that there are no processes, which can actually violate. First law itself is a proof in it that first law does exist and it is a fundamental law. First law of thermodynamics is a very fundamental law and physical law in itself. The fact that first law is something, which you cannot mathematically prove or that it cannot be derived from any other law qualifies first law to be what is known as a fundamental law of nature like Newton's laws of nature. You cannot really prove Newton's law from some other law. Therefore, that is why Newton laws are fundamental laws of the nature. Similarly first law of thermodynamics is also fundamental law of nature.

As per first law of thermodynamics, we have seen that heat and work interactions are identical. First law does not distinguish between heat and work, but it only considers heat and work as two different forms of energy interaction. However, what we shall see later on in few lecture from now is that as per the second law, there is definitely a great difference between heat and work. That will become clear as we understand the second law of thermodynamics, but as per first law there is absolutely no difference between heat and work; they are simply two different forms of energy interactions. What we shall see now are some interesting aspect of first law of thermodynamics that as we have seen, it is a fundamental law and you cannot really violate the first law of thermodynamics.

However, over the years, there have been several such concepts or proposals by different so-called inventers, who have come up with device, which violate the first law of thermodynamics. Therefore, no such device has actually been proved to be working. If they are actually working, they would be violating the first law of thermodynamics. However, there are so many such devices, which have been proposed over the years. So many inventers have kind of filed patents for their so-called inventions, which violate a fundamental law of nature.

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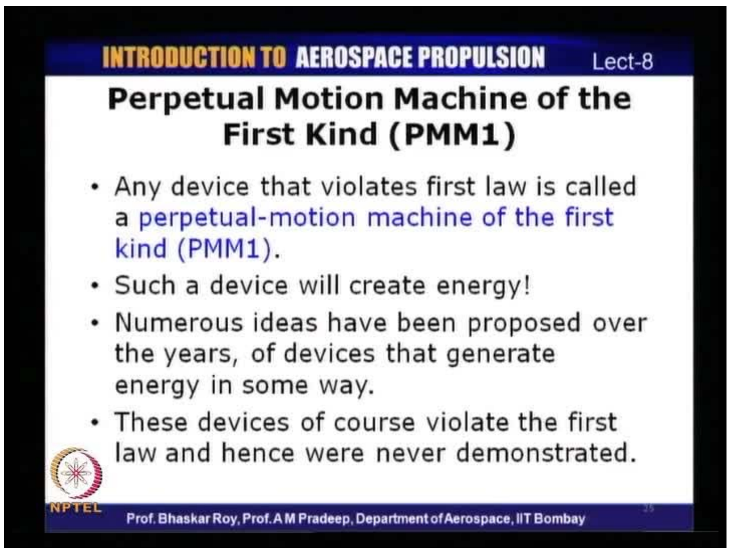

Those devices, which violate the first law of thermodynamics are known as perpetual motion machines of the first kind. Such a device obviously will create energy. Therefore, such devices cannot exist. Therefore, these devices were never actually demonstrated. These were just concepts, which were proposed, but they were never demonstrated.

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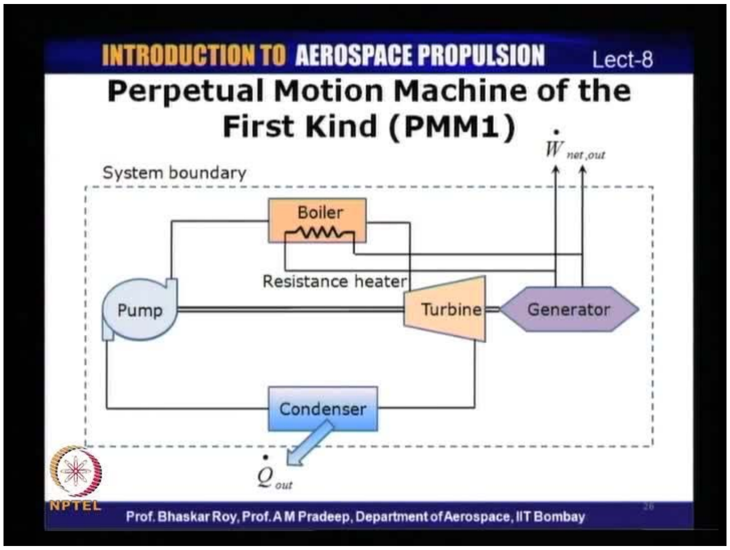

Let us look at one interesting example here. Here we have an example, where the inventors so-called inventor proposes that we have a power generating unit, where instead of a boiler in a conventional boiler, you add fuel and generate energy. Here the inventor claims that you can use a resistance heater by using part of the power, which is generated by the generator to heat up water to generate steam, which can be expanded in a turbine. This turbine raises both the pump as well as the generator and the exhaust from the turbine goes through a condenser, which condenses water. Then, it is pumped into the boiler back. So, you can see from the condenser that there is heat transfer out of the system and this is the system boundary.

Obviously, the generator generates electrical work output. So, the inventor claims that once you start this device, it can run forever without having to use any fuel. So, it looks like very interesting innovative concept, which will solve the energy crisis forever. This is because you do not need any fuel to run such a system. However, if you look at it from fundamental thermodynamics point of view, it violates the first law of thermodynamics. Why does it violate? It violates because it generates a network output, which is Q dot out and W net out without any energy input. So, there is no energy input into the system, but it always generates work output. Therefore, it is obviously violating the first law of thermodynamics and such a device can never exist and can never work. This is the reason why such a concept has never been proven. Though there were proposals and so-called inventions, they have never been demonstrated. So, such devices are known as perpetual motion machines of the first kind of PMM1.

There are also devices, which are converse of PMM1. That is, those devices, which will consume work output without any heat transfer from the system. Such devices are known as converse of PMM1, but they are also perpetual motion machines of the first kind.

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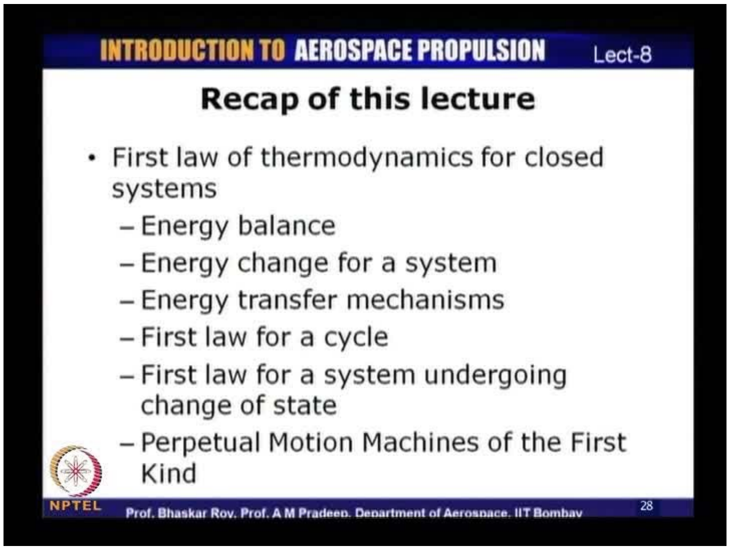

Let me quickly recap what we had looked at in this lecture. We had discussed the first law of thermodynamics for closed systems; we discussed about energy balance, energy change of a system and also the energy transfer mechanisms for a system in general. Then, we applied the first law of a thermodynamics for a cycle and then first law of a system undergoing a change of state. Towards the end of the lecture, we discussed about the perpetual motion machines of the first kind, which are device that violate the first law of thermodynamics.

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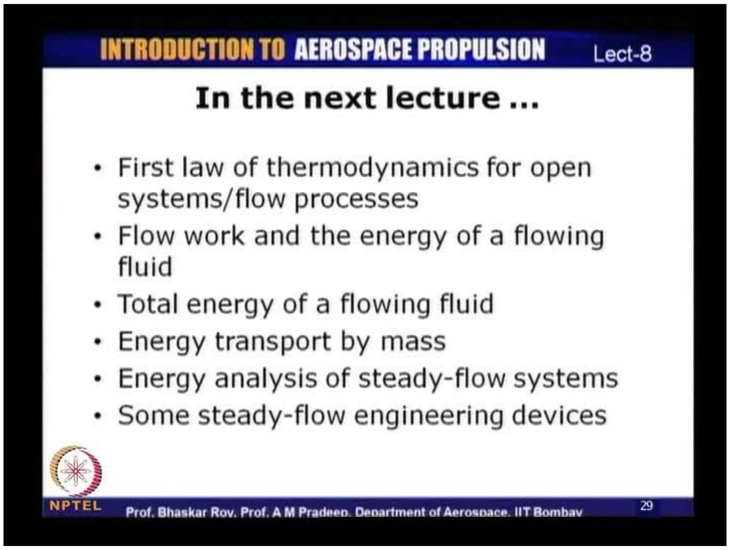

In the next lecture, what we shall discuss is the first law of thermodynamics applied for open systems or flow processes. We shall discuss about flow work and energy of a flowing fluid, the total energy associated with the flowing fluid and how is energy transferred or transported through mass. Then, we shall carryout energy analysis for steady-flow systems or steady-flow processes. It is also known as steady-flow energy equation. Then, we shall apply the steady-flow energy equation for certain engineering devices, which involved steady-flow processes. So, that brings us to the end of this lecture. In the next lecture, we shall take up first law for open systems.