Introduction to Aerospace Propulsion

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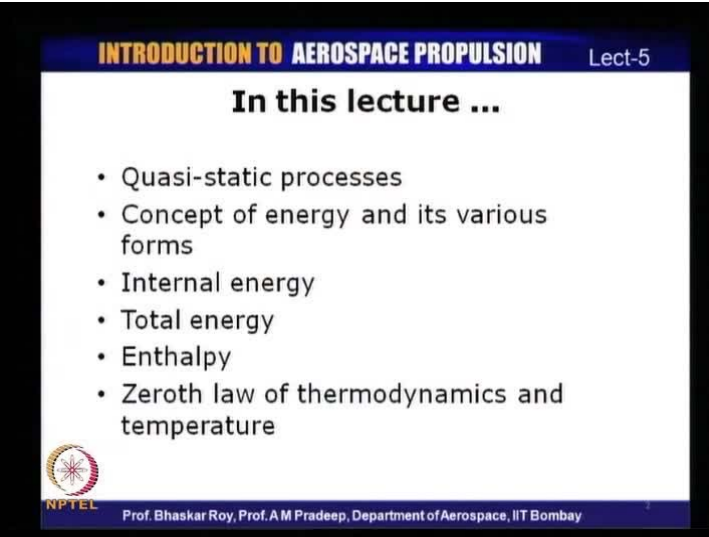
Indian Institute of Technology, Bombay

Module No. # 01

Lecture No. # 05

Quasi-Static Processes, Zeroth Law of Thermodynamics and Temperature, Concept of Energy and its Various Forms, Internal Energy, Enthalpy

Hello and welcome to lecture 5 of the lecture series on Introduction to Aerospace Propulsion. In the previous lecture, I think we had covered up some of the very basic aspects and terminology associated with thermodynamics. We shall continue our journey further into understanding thermodynamic principles and basics of thermodynamics in this lecture and in future lectures.

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Now, in this lecture, what we are going to cover are basically to look at some of the other aspects of fundamental thermodynamics. We shall start our lecture with understanding what are known as quasi-static processes. Subsequently, we shall understand the concept of energy and different forms of energy.

We shall understand a very important term associated with energy known as internal energy; what is meant by internal energy and what constitutes internal energy. We shall then look at total energy and how do you calculate total energy for a particular system. We shall then understand the concept; what is known as enthalpy? Enthalpy happens to be a combination property; that is, it is a sum total of two or more different types of properties.

Towards the end of this lecture, we shall understand – what is known as the zeroth law of thermodynamics, significance of zeroth law of thermodynamics, and the outcome of the zeroth law of thermodynamics. As we shall see later on, the outcome of zeroth law of thermodynamics is temperature. So, temperature measurement has the basis in zeroth law of thermodynamics. Let us first look at what are quasi-static processes.

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When we understand or analyze a particular system thermodynamically, we would like the process to proceed in a manner such that the system remains infinitesimally close to an equilibrium state at all times. Such processes are known as quasi-static processes or sometimes also referred to as quasi-equilibrium processes.

This process, in this case, proceeds slow enough to allow the system to adjust itself internally so that properties in one part of the system do not change any faster than those in other parts. That is, doing a quasi-static process, we would have change in properties, which are same throughout the system. That is, you do not have a different set of properties in one part of the system and another set of properties in another part of the system. So, quasi-static process proceeds at an infinitesimally slow pace so that properties in one part of the system are the same as that of the other part of the system.

Now, let us look at what are quasi-static processes in terms of examples.

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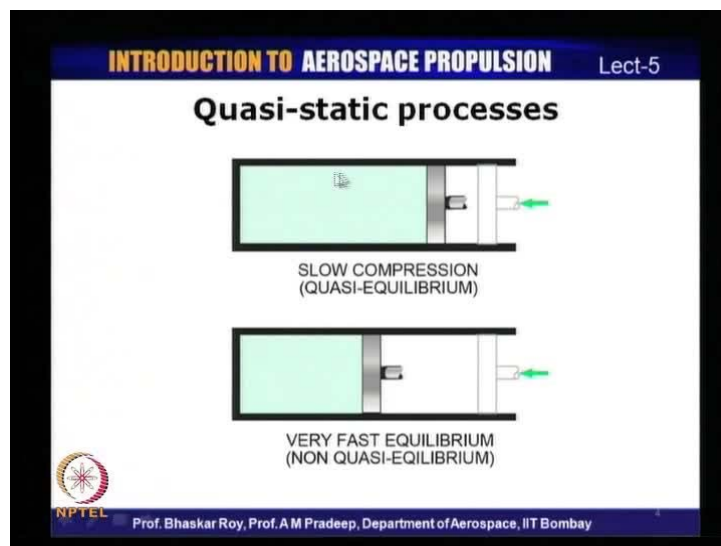
Now the first example, which is shown here is that of a piston cylinder assembly. The first picture that you see here shows a Slow Compression process. A Slow Compression process is one wherein the piston moves at an infinitesimally slow rate so that the system remains in equilibrium at all times. This qualifies to be known as a quasi-static or a quasi-equilibrium process.

Now, the second process on the other hand shows that the piston has moved a much greater distance as in the previous case. So, this really does not qualify to be a quasi-static process because the system has proceeded in a very fast rate. Therefore, properties in one part of the system will not be the same as the other parts of the system. So, it is not really quasi-equilibrium or a quasi-static process.

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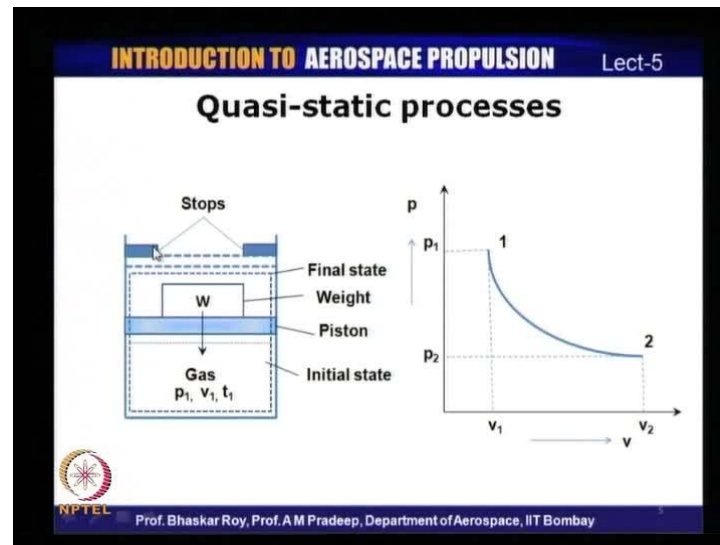
Now, let us look at another example again of a piston and cylinder assembly. In the first example that we shall see here, we would like to compress the gas, which is held within this piston and cylinder assembly. So, what we do is that initially, let us say the piston was at this location. Then, as you drop a weight on the piston, the piston and cylinder assembly moves down. So, the piston and cylinder assembly moves down causing the gas to be compressed.

If you look at it the other way around, if the system was in its initial state at p 1, v 1 and t 1, which is at a higher pressure, lower volume and a different temperature. This was because, there was weight placed over the piston. Now, as you remove the weight from the piston, the piston moves up because the gas which was compressed, will now get expanded. Therefore, the system will finally, reach a state, which is referred to as state 2, the final state, which has a lower pressure and a higher specific volume.
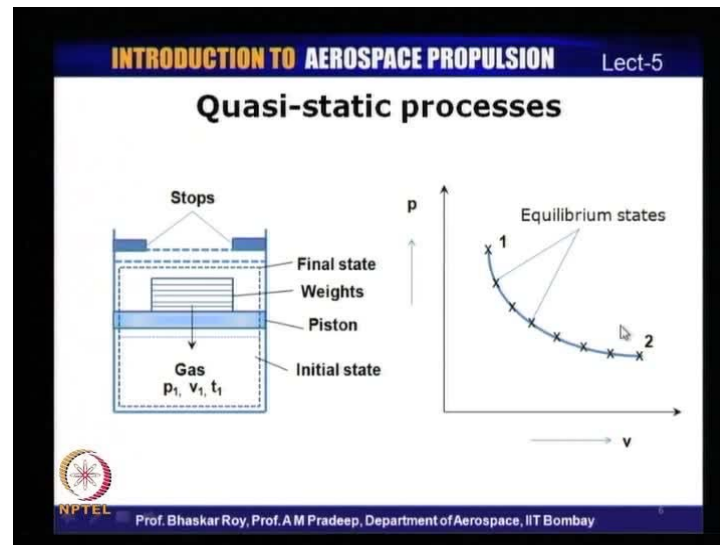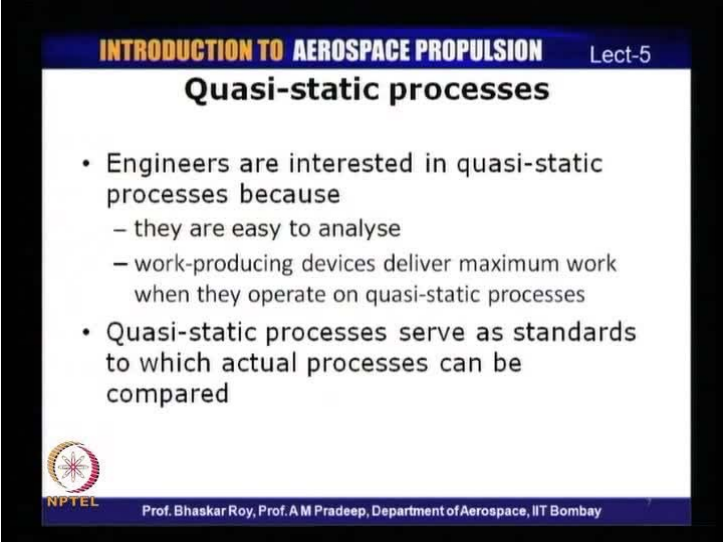
Now, if you were to analyze the system thermodynamically, what we would like to do is the following. So, instead of one single weight, we would like to have infinitesimally small weights, which are placed one over the other. The total weight of these individual weights will be equal to the larger weight, which we had seen in the previous slide. So, if you remove each of these weights one by one and because these are infinitesimally small weights, the system proceeds from one state to another state through a series of equilibrium states.

These equilibrium states have been denoted here by this cross symbols. Each of them are referring to states, which are in equilibrium. The reason is that we have an infinitesimally small weight, which is removed from the piston causing the piston to move by an infinitesimally small amount. If your system were to proceed in this manner, this is referred to as a quasi-static process.

In thermodynamics, we shall be analyzing different processes, which are assumed to have taken place quasi-statically or in quasi-equilibrium. This is important because as we shall see little later, that quasi-static processes can also be classified as reversible processes and so on. Therefore, it is important for us to ensure that the process proceeds in a quasi-static manner. So, most of the processes that we shall be analyzing in thermodynamics are assumed to be taking place quasi-statically.

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Why are we interested in quasi-static processes? As engineers, we are all interested in quasi-static processes: Firstly because they are easy to analyze; Secondly if you are looking at work-producing devices or power generating devices, these devices generate maximum work when they are operating on quasi-static processes. Therefore, as engineers, we will be able to define a process, which has taken place quasi-statically. This particular process will serve as a standard when you would like to compare actual process with reference to a quasi-static process. This is the reason why we are all interested in quasi-static processes. This is because firstly that helps us in easier analysis of a particular process as well as such processes will serve as a standard for comparing other processes or actual processes with it.

What we shall see now is: what are the different forms of energy and what are the implications of these different forms of energy. Now, as we are all probably aware, energy can exist in different forms. You could have energy in the form of thermal energy, mechanical energy, kinetic energy, potential energy and so on.

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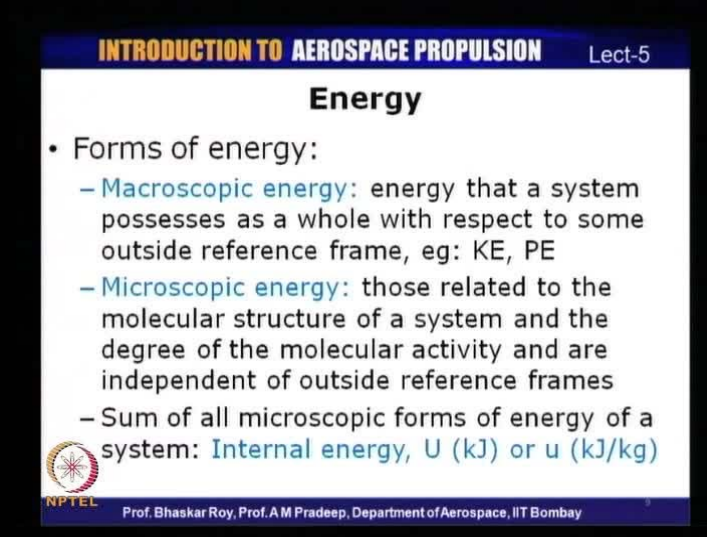
You would have already come across many such forms of energy or terms associated with energy. The sum total of all these forms of energy like mechanical, kinetic energy, potential energy, electric, magnetic, chemical, nuclear and so on. All of them put together is referred to as the total energy of a system, which is usually denoted by symbol E. Specific energy, which is symbol small e is equal to total energy per unit mass.

In thermodynamics, we usually do not provide any information about the absolute value of total energy. Thermodynamics only deals with the change of total energy and it does not really matter what is the absolute value of energy. We are interested in change of energy from one value to another. So, we would always be dealing with changes in energy rather than the absolute value of the energy.

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What are the different forms of the energy? Energy can exist in different forms. These can be classified broadly as macroscopic energy and microscopic energy. Macroscopic energy refers to the energy that a system would possess as a whole with reference to some outside frame of reference. Examples of macroscopic energy are kinetic energy and potential energy. These are the energies that a system can possess with reference to some frame of reference. Microscopic energy on the other hand is related to the molecular structure of a system and the degree of molecular activity. This is basically independent of the outside frame of reference. So, microscopic energy is the energy content at the molecular level and they do not really depend upon with what frame of reference you are looking at.

The sum total of all the microscopic forms of energy of a system is referred to as the internal energy of a system. Internal energy is usually denoted by symbol U, which is for internal energy and small u, which is for specific internal energy; that is, internal energy per unit mass.

Now, to illustrate this example to this point further: As I was mentioning, macroscopic energy refers to the energy that a system contains has a whole and it is with reference to some frame of reference. Examples of macroscopic energy are kinetic energy and potential energy. The example that I am going to show is about one simple example of the macroscopic energy associated with let us say a car, which is climbing up a hill.

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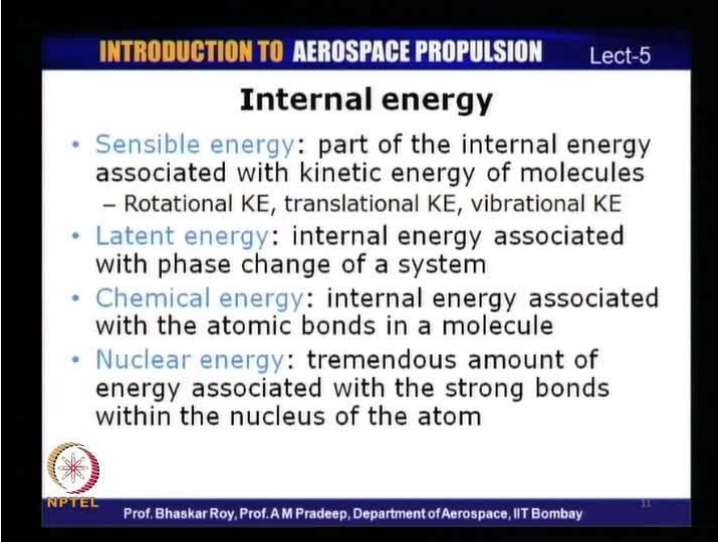
As we know that this particular car that is shown here by this cartoon has some amount of potential energy and kinetic energy. These energy will change as the car moves up the slope because its potential energy changes. If its speed also changes, then that changes the kinetic energy of this particular system. So, the system we are considering here consists of the car and what is around it is the surrounding. So, the macroscopic energy of this system, which is in terms of its kinetic and potential energy will keep changing as the car moves.

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Now, as I mentioned, internal energy on the other hand is the sum total of all the microscopic forms of energy. What are the different microscopic forms of energy? These are referred to as the sensible energy, latent energy, chemical energy and nuclear energy.

Sensible energy refers to that part of the internal energy, which is associated with kinetic energy of the molecules. As we have seen earlier, macroscopic energy looks at kinetic energy of the system as a whole and not at the molecular level. Sensible energy is the energy, which is associated with kinetic energy of individual molecules. These are again of different types. You could have rotational kinetic energy, translational kinetic energy, vibrational kinetic energy and so on. These are again associated with the molecular level of the system.

Latent energy on the other hand is the internal energy, which is associated with phase change of a system; that is, if the system changes from solid to liquid or solid to gas or vice versa. The energy that is associated with this particular phase change is referred to as the latent energy.

Chemical energy refers to the internal energy, which keeps the molecules bonded together to themselves. So, internal energy associated with the atomic bonds of a molecule is referred to as the chemical energy. This is the energy that is released or absorbed when either bonds are broken in a chemical reaction or new bonds are formed during a chemical reaction process.

Nuclear energy refers to the amount of energy that is associated with the strong bonds within the nucleus of an atom. This energy is tremendous as you are perhaps aware that nuclear fission or fusion reaction produces tremendous amounts of energy. That is because the energy associated with the bonds within the nucleus of an atom is very tremendous. Therefore, the nuclear energy refers to that particular energy, which is associated with the bonds within the nucleus of an atom.

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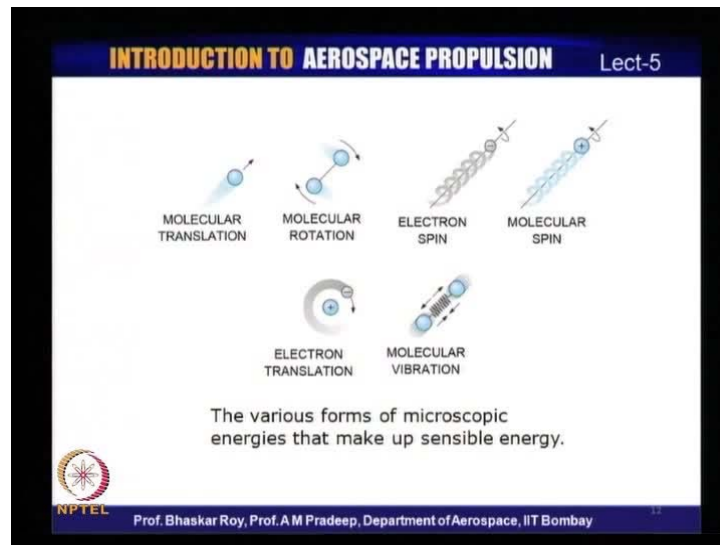
Now, we will explain this by examples, which are shown here or showing the different forms of microscopic energy, which form the sensible energy. I mentioned that sensible energy refers to the energy, which is associated with kinetic energy of individual molecules.

Examples of such kinetic energy associated with molecules are the molecular translation; that is, motion of the molecules. Molecular rotation or the electron spin or the molecular spin or it could be electron translation; that is movement of the electrons around the nucleus. You could also have new molecular vibration. So, all these individual forms of microscopic energy form what is known as the sensible energy. This sensible energy refers to or gives us an idea about the amount of energy, which is associated with kinetic energy of individual molecules.

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The other forms of energy are the latent energy, chemical and nuclear energy. Internal energy is the sum total of all these forms of microscopic energy. We will keep referring to internal energy because that plays a very significant role in thermodynamic analysis of systems. This internal energy basically refers to the sum total of the sensible energy, the latent energy, chemical energy and the nuclear energy. So, every system has certain amount of internal energy associated with it. Basically, that is comprising of these individual energies, which are at the molecular level. Or, sum total of all these microscopic forms of energy constitute the internal energy of a system.

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Now, if we were to look at the advantages of microscopic forms of energy or macroscopic forms of energy, macroscopic kinetic energy basically refer to an organized form of energy. Microscopic kinetic energy is the organized form of energy and it is more useful than the disorganized forms of kinetic energy of molecules.

There is an example, which is shown here. We can see what is shown here is that of a dam wherein water is discharged into a turbine, which generates a power output. So, what is shown here is the turbine wheel, which is placed here at the exit of the dam or if the turbine wheel is placed inside the reservoir. This reservoir of the dam contains a lot of energy associated with it because of the molecular motion or kinetic energy of these molecules. So, there is a lot of energy associated with it, but it is the disorganized form of energy. As you can see, all the molecules are oriented randomly. Therefore, this organized form of energy would not help us in any way because it does not generate any work output.

If the turbine wheel was to be placed inside the reservoir even though the reservoir has a lot of microscopic kinetic energy of the molecule, it does not generate any work output because it is disorganized form of energy. On the other hand, if you were to place the turbine wheel at the exit of the dam, this disorganized form of energy gets converted to organized form of energy. That is, you get the macroscopic kinetic energy of this water, which is coming out of the dam, which is conversion of the microscopic form into macroscopic form. This macroscopic kinetic energy is what you can convert to useful work outputs. So, you get useful work output from the system because of the macroscopic kinetic energy. The macroscopic kinetic energy is the organized form of energy as we had seen is in this example. Therefore, it produces useful work output as compared to the disorganized microscopic kinetic energy of the molecules. As engineers, we are always interested in the macroscopic form of energy because that gives us the useful work output.

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Now, let us look at how we can calculate kinetic energy, potential energy and the total energy associated with a system. Earlier, you probably have already understood some of the aspects of kinetic energy. So, kinetic energy is the product of mass and its square of the velocity divided by 2. So, mV square by 2 is the kinetic energy of a system. Kinetic energy per unit mass is V square by 2. That is usually referred to kilo joules per kilo gram on a unit mass basis.

Potential energy on the other hand is the product of mass, acceleration due to gravity and the elevation from the reference. Here z refers to the elevation of the system from the reference. So, product of mass, acceleration due to gravity and z gives you the potential energy of a system in kilo joules. On a unit mass basis, potential energy is equal to g times z, which is product of acceleration due to gravity and elevation from the reference in kilo joules per kilo gram.

If you were to calculate the total energy associated with system, if you assume the absence of any magnetic electric and surface tension effects, then the total energy of a system consists of kinetic energy, potential energy and the internal energies. So, total energy, E is equal to U plus KE plus PE, which is equal to U plus mV square by 2; that is, the kinetic energy plus mgz, which is the potential energy. The same equation on a unit mass basis; that is, energy per unit mass is equal to internal energy per unit mass; that is, small u plus kinetic energy and potential energy; both on unit mass basis. So, that is equal to u plus V square by 2 plus gz in kilo joules per kilo gram. So, this is equal to the total energy of a system.

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Usually, we come across closed systems whose velocity and elevation of its center of gravity would remain constant during a process. Such systems are referred to as stationary systems. If a system is stationary, then there is no change in kinetic energy of a system and also there is no change in potential energy of a system. So, the change in total energy of such a system will be equal to the change in internal energy of a system. This is because there is no change in its kinetic energy as it is stationary and there is no change in its potential energy because its elevation from the reference is not changed. So, the change in the total energy of a stationary system will be equal to the change in its internal energy.

What we shall see next is a property, which is known as a combination property. That is, a property, which is a combination of two or more different properties is referred to as a combination property. One such property, which is very important in thermodynamic analysis and which we shall refer to several times during this course is known as enthalpy.

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Enthalpy is a combination property, which is a combination of internal energy, u and product of pressure and specific volume, pv. So, the combination of u and pv is very often encountered in the analysis of open systems or in control volumes.

Enthalpy is usually denoted by the symbol h. h is equal to u plus Pv. On a small letter scale, it is per unit mass; that is, small h is equal to small u plus Pv in kilo joules per kilo gram. If it is not per unit mass, then total enthalpy is denoted by capital H, which is equal to capital U plus PV in kilo joules.

Also, enthalpy is often referred to as heat content. In many text books, you would see that enthalpy is often referred to as heat content of a particular system. A process during which the enthalpy remains a constant is known as an isenthalpic process.

If you recall during the previous lecture, I had mentioned towards end of the lecture that if during a process enthalpy remains constant, it is known as isenthalpic process. At that point, we were not sure what enthalpy means. As I have just mentioned, enthalpy is a combination property; it is the sum of the internal energy and the product pv. So, enthalpy forms a very important role in analysis of systems of engineering importance. For example, if you are analyzing an aircraft engine, which we shall do little later, enthalpy will form a very important property in thermodynamic analysis of such engineering systems.

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Now, let me give an example here that explains the importance of enthalpy. Here we are looking at a control volume, which is denoted by these dotted lines. Because there is mass influx into the system and a flux from the system, this is an open system. It is also referred to as a control volume.

The flow enters the control volume with certain internal energy u 1 and certain pressure p 1 and v 1. It leaves the system with an internal energy u 2 and pressure p 2 and v 2. So, enthalpy of the system changes from h 1 at inlet, which is equal to u 1 plus p 1 v 1 to h 2 at the outlet wherein h 2 is equal to u 2 plus p 2 v 2. So, there is a change in enthalpy of this particular system. Thermodynamic analysis of this system will involve understanding change in enthalpy of this particular system. We shall be using this concept of enthalpy during several process analysis, which we shall be doing during this course.

What we shall look at next is a very important law; a very fundamental law of thermodynamics, which is zeroth law of thermodynamics.

Zeroth law of thermodynamics states that if two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other. So, this is zeroth law of thermodynamics. It serves as a basis for validity of temperature measurement, which we shall see little later.

Replacing the third body with a thermometer, we can restate the zeroth law as two bodies are in thermal equilibrium if they have the same temperature reading even if they are not in contact. That means that if there are two bodies, both of them show the same temperature reading. Even if they are not in contact, they are said to be in thermal equilibrium because each of them is individually in thermal equilibrium with the thermometer. Therefore, thermometer helps us in measuring temperature because it establishes a thermal equilibrium within itself as well as with the system.

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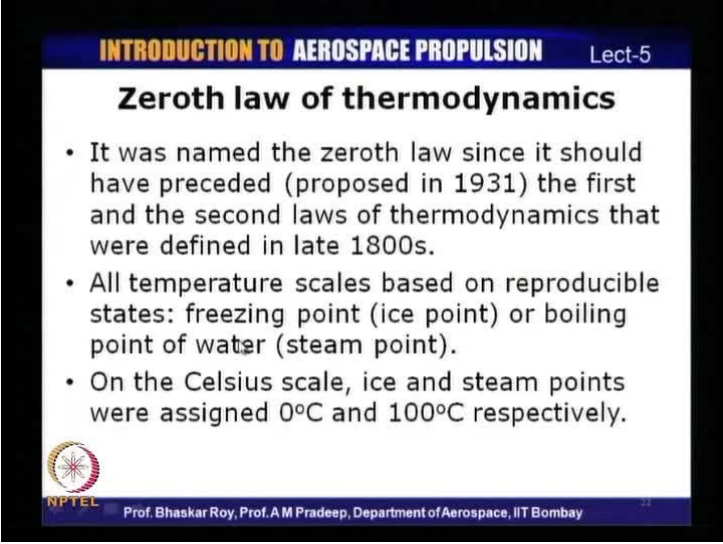
So, zeroth law of thermodynamics forms the basis for temperature measurement. Now, let me explain this point further. What is shown here are three different bodies denoted by A, B and C.

Let us say the temperature of these bodies are: T A for body A, T B for body B and T C for the body C. Now, let us say body A and C are in thermal equilibrium. That means T A is equal to T C. Body B and C are in thermal equilibrium; that is, T B is equal to T C. Because A is in equilibrium with C and B is in equilibrium with C, as per zeroth law or as a consequence of the zeroth law, A should also be in thermal equilibrium with a body B. That means T A should be equal to T B. So, zeroth law helps us in explaining thermal equilibrium between these three bodies.

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There is a reason why this particular law is referred to as the zeroth law. This zeroth law was proposed only in 1931, whereas the first and second laws of thermodynamics were defined much earlier in the late 1800s. This is called zeroth law because it is much more fundamental law than the first and second laws of thermodynamics and it should have actually preceded the first and second laws of thermodynamics. However, since we already had a first and a second law of thermodynamics, this particular law was renamed as the zeroth law of thermodynamics.

All the temperature scales that we see in existence today are based on certain reproducible states. Like, it could be the freezing point, which is the also referred to as the ice point or it could be the boiling point of water, which is the steam point.

On the celsius scale, which I am sure you all are familiar with; we usually measure temperature in celsius even though that is not the SI unit of temperature. On the celsius scale, ice and steam points were assigned 0 degrees and 100 degree celsius respectively. So, these were the temperatures, which were defined when celsius scale was formed long ago.

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In thermodynamics, we would like to have a temperature scale, which is not dependent on properties of a particular substance. For example, in the celsius scale, it depends upon properties of water, which was ice point and steam point. Whereas, in thermodynamics, we would not like to have such a scenario; we would not want to have a temperature scale, which depends upon the property of a particular substance that requires us to maintain a certain pressure and other properties of that particular system. So, we would like to have a scale, which is independent of properties of one particular substance. So, the thermodynamics temperature scale is also referred to as the kelvin scale.

We shall understand kelvin scale in detail little later. The lowest temperature on the kelvin scale is 0 kelvin; as we shall see little later in the third law of thermodynamics, which states that the temperatures below 0 kelvin is not possible or not feasible. So, thermodynamic temperature scale is the scale, which is independent of any particular property of a substance and one such property we shall see little later.
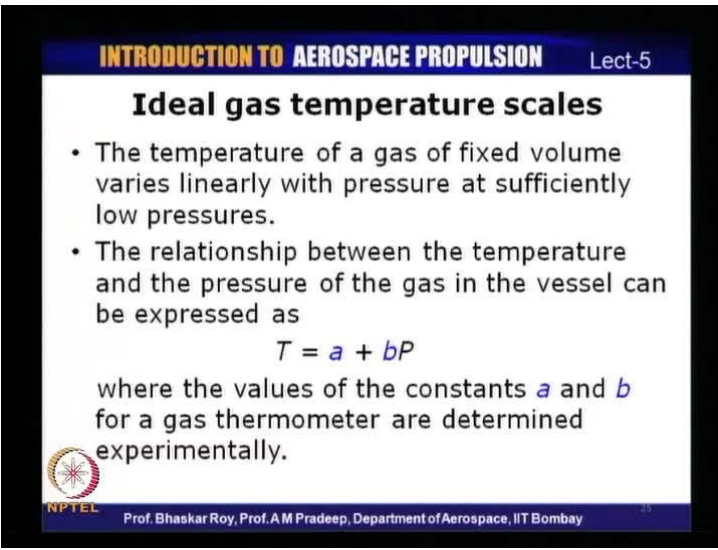
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There is a temperature scale, which is quite identical to the kelvin scale. This is known as the ideal gas temperature scale. This ideal gas temperature scale involves a constant volume thermometer, which is filled with a gas, which could be either hydrogen or helium. It is based on the principle that at low pressures, temperature of a gas is proportional to its pressure at constant volume. So, this forms the basis of the measurement of temperature using the constant volume temperature. That is, at low pressures, temperature of a gas will be proportional to its pressure if the volume is held constant.

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In an ideal gas, temperature scale what we see is that the temperature of a gas in a fixed volume varies linearly with pressure and that occurs at low pressures. So, the relationship between the temperature and pressure can be expressed as temperature T is equal to a plus b times P, where a and b are constants. These constants are determined experimentally for a particular gas thermometer. If you were to find these values a and b, you can estimate temperature of a system if you know the pressure at a particular instant. So, constant volume gas scale involves measurement of pressure of a particular gas and then inferring temperature from this measured pressure. So, it is necessary for us to find the values of these constants a and b, which are determined experimentally. Once you know a and b and also the pressure, you can infer temperature from these parameters a plus bP.

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If you were to determine the constants a and b, then you need to measure the pressure of the gas at two reproducible points. For example, ice point and the steam point, which I had explained earlier are two reproducible states of water. That is, as we know, ice point has a temperature of 0 degree celsius and steam point is 100 degree celsius for water. So, if you were to measure pressure of a gas at two different reproducible states and then assign suitable values of temperatures to these two values, it is possible for us to find these constants a and b. So, if you have just two measurements, then you are able to find these constants a and b. Once a and b are known, the unknown parameter is the temperature. So, temperature will be equal to a plus b times P. Since a and b are known

and the pressure is known for this particular instant, you can find temperature from the simple equation T is equal to a plus bP.

This is the basic principle behind the ideal gas temperature scale, which is a constant volume thermometer. Now, if you were to assign those two values that I had measured mentioned earlier equal to 0 degree celsius and 100 degree celsius, then the temperature scale that we get is identical to the celsius scale. In celsius scale, the two reference points are the ice point and the steam points.

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Now, if this were to be the case; that is, if you were to have 0 and 100 as the fixed points, then it is possible that for a, which is equal to 0; if you were to assume that the absolute pressure is equal to 0, then the temperature that we shall get from the scale will be equal to minus 273.15 degree celsius. This temperature is regardless of the type and the amount of gas in the vessel of the gas thermometer. This means that it is possible for us to find a point where in a is equal to 0, you can assume a is equal to 0. This means that the pressure is 0 and the corresponding temperature there would be minus 273.15 degree celsius. As we shall see in the example later on, this is independent of the nature of the gas in the vessel and the quantity of the gas in the thermometer.

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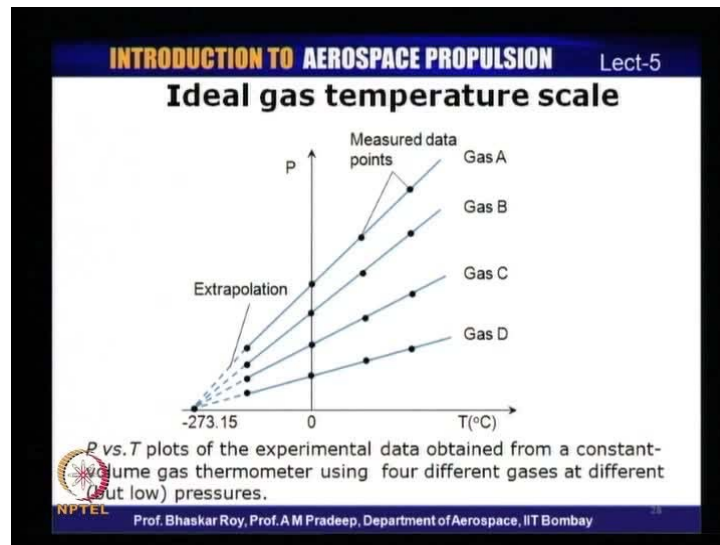
Let me explain this point little further using this example. What is plotted here are pressure on the y axis and temperature in degree celsius on the x axis.

Let us say the gas thermometer has different gases: gas A, B, C and D. We have fixed two or more measurement data points. However, we just need two points: one is the 0 degree celsius; that is the ice point and another is 100 degree celsius; that is the steam point.

For this particular gas (Refer Slide Time: 35:24), we have maintained ice point at 0 and then we find the corresponding pressure. Then, we also maintain the same thermometer at the steam point and find the corresponding pressure at that particular temperature. If we were to join these two points and extrapolate this line, the point where it meets on the x axis is minus 273.15.

If you repeat this experiment for several other gases, what we shall see is that all these gases will finally, merge towards this particular point: minus 273.15. This means that this particular temperature scale is independent of the type of gas that is used. That is a big advantage for us because in thermodynamic temperature scale, you would not want a scale, which is dependent on properties of a particular substance. So, here is a scale, which is independent of the type of gas, which is used in this particular scale. So, this ideal gas temperature scale is one which is independent of the type of gas that is used.

The example here shows four different gases and you measure temperature well. You measure pressure for two different temperatures, which can be fixed or which can be reproduced. If you were to use 0 degree celsius and 100 degree celsius as the reference points, then this scale is very similar to that of a celsius scale. So, what we do in this ideal gas temperature scale is to measure pressure at two temperatures, which can be reproduced at 0 degrees and let us say - this steam point 100 degrees. Once you get two measurement data points, you can join those two lines and extrapolate it. What we shall see is that extrapolation of these lines will take us to one particular temperature, which is minus 273.15.

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The significance of this temperature that we get of minus 273.15 is that this is the lowest temperature that you can get using a gas thermometer. We can call this as an absolute gas temperature scale because we have assigned a value of 0. If you assign a value of 0 to the constant a, then the temperature that you get will be minus 273.15 degree celsius. This is very convenient for us because in this case, we need to only specify the temperature at one point to define an absolute gas temperature scale. So, temperature will now be equal to b times P. If you just know b and you measure pressure, you can actually calculate temperature from there.

Now, the standard fixed point for temperature scale has been agreed upon as the triple point of water. Triple point of water is the temperature at which all the three phases of

water; that is, solid, liquid and gas phase coexist. That is, you would have system, which has ice, water as well as water vapour; all the three of them coexist in equilibrium. This occurs at a temperature of 0.01 degree celsius or 273.16 kelvin.

If you recall, I had mention earlier that the kelvin scale begins at a temperature of 0 kelvin. So, this is the lowest temperature that is possible to be achieved. As we shall see later on that at 0 kelvin temperature, which is also known as the absolute 0, the entropy of a system becomes 0. What is entropy will be clear in the later lectures. From the entropy principle also, we shall able to derive the kelvin scale, which we shall do later on. 0 kelvin is equal to minus 273.15 degree celsius. So, 0 kelvin on the kelvin scale is corresponding to minus 273.15 degree celsius on the celsius scale.

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The absolute gas temperature scale is not a thermodynamic temperature scale because there are couple of problems associated with this particular temperature scale. One of the problems occurs at very low temperatures. So, as you reduce the temperatures to very low values, there could be condensation of the gas occurring within the constant volume gas thermometer. Condensation can change the pressure and another aspect within the constant volume gas thermometer. So, this is one of the problems that at very low temperatures, there could be condensation of the gas. The other problem occurs at very high temperatures. What happens at very high temperatures is that the gas could

dissociate and probably ionize. Both of which can change the properties of the gas. So, dissociation and ionization can occur at high temperatures.

This absolute gas temperature scale or thermometer is valid only for a certain range of pressures and temperatures. At low pressures, there is problem of condensation and at high pressures, it may cause ionization and dissociation of the gas within the thermometer. So, it is important to understand that the absolute gas temperature scale is not really a thermodynamic temperature scale because thermodynamic temperature scale requires us to start at 0 kelvin. As you know that 0 kelvin is the lowest temperature that is possible, but if you were to use the absolute gas temperatures scale at such low temperatures, it will definitely cause condensation of the gas within the volume.

As we had seen in the example earlier, we were extrapolating the graph to achieve this minus 273.15 degree celsius. However, if you were to actually do that for any particular real gas, then you would notice that particular gas is condensing. Condensation of the gas is definitely not good because that can change the properties within the control volume. Therefore, equation T is equal to a plus bP will no longer be valid. However, absolute gas temperature scale definitely has its significance in the range of temperatures in which it can be safely used. So, there is certain range of temperature in which you can use the absolute gas temperature scale. In that range, the absolute gas temperature scale works well and without any problem, whereas for defining an absolute temperature scale, it requires certain modifications and change of definitions. This we shall see when we understand the concept of entropy, third law of thermodynamics and the consequent development of the kelvin scale during that.

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Let me recap what we had looked at in this lecture. What we had understood were certain basic parameters associated with thermodynamics and the quasi-static processes. We started our lecture with understanding what quasi-static processes are. Quasi-static processes are those wherein the process is assumed to occur or progress at infinitesimally slow rates so that the system is in equilibrium with itself at each instant of time.

After quasi-static processes, we looked at the concept of energy and the different forms of energy. We understood that energy can exist in microscopic form or in macroscopic form. Useful work output from a system can be obtained if the form of energy is in macroscopic in nature. Microscopic energy on the other hand does not really give us any useful work output because it is a disorganized form of energy. The sum total of all the microscopic forms of energy is known as the internal energy. Total energy of a system constitutes the sum total of the internal energy plus the kinetic energy and the potential energy of a system.

Subsequently, we looked at the concept of enthalpy. Enthalpy is a combination property, which is the sum of internal energy u plus Pv. This plays a very significant role in the thermodynamic analysis of several engineering systems; especially, those dealing with open systems or control volumes. Many of the engineering systems are indeed control volume systems and therefore, enthalpy plays a significant role in its analysis.

Towards the end of the lecture, we looked at the zeroth law of thermodynamics. As an outcome of zeroth law of thermodynamics, we understood: how we can develop a temperature scale; how you can define temperature of a system if you understand the concept of zeroth law of thermodynamics; how you can define a an absolute gas temperature scale and approximate the absolute gas temperature scale within ideal gas temperature scale. We also understood that there are certain limitations with an ideal gas temperature scale especially at very low temperatures and at very high temperatures. However, in spite of these limits, we can still use an ideal gas temperature scale for a certain range of temperatures. So, this is what we had looked at in this lecture.

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In the next lecture that is, lecture 6, what we shall look at specific heat. We shall define specific heats of a system. We will see that there are two types of specific heats: specific heat at constant pressure and specific heat at constant volume.

We shall understand what is meant by heat transfer and the different types of heat transfer. We shall also look at work, the thermodynamic definition or thermodynamic meaning of work, and what are the different types of a work that are possible. What we shall see in the next lecture is that heat and work are two different forms of energy interaction that a system can have with its surroundings. So, we shall look at these aspects in the next lecture that would be lecture 6.