Basics of Mechanical Engineering-3

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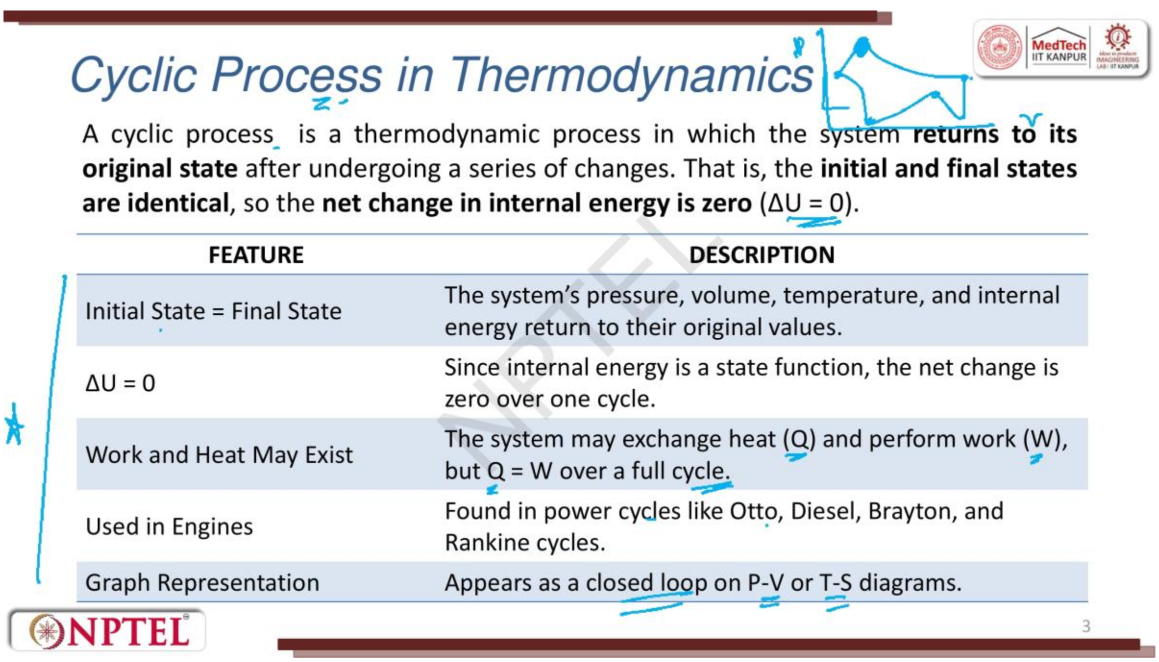
Week 01

Lecture 05: Thermodynamic Processes (Part 2 of 2)

Welcome to the second part of Thermodynamic Equilibrium, Process, and Thermometry. In this lecture, we will be seeing the continuation of some more cycles. I am sure now you will have a lot of clarity when you see an automobile going past you on the road. Let it be a two-wheeler, let it be a four-wheeler, let it be an AC. So, you will be fascinated, and you will understand the fundamentals—for all these things, the PV diagram and TS diagram of various cycles will be key.

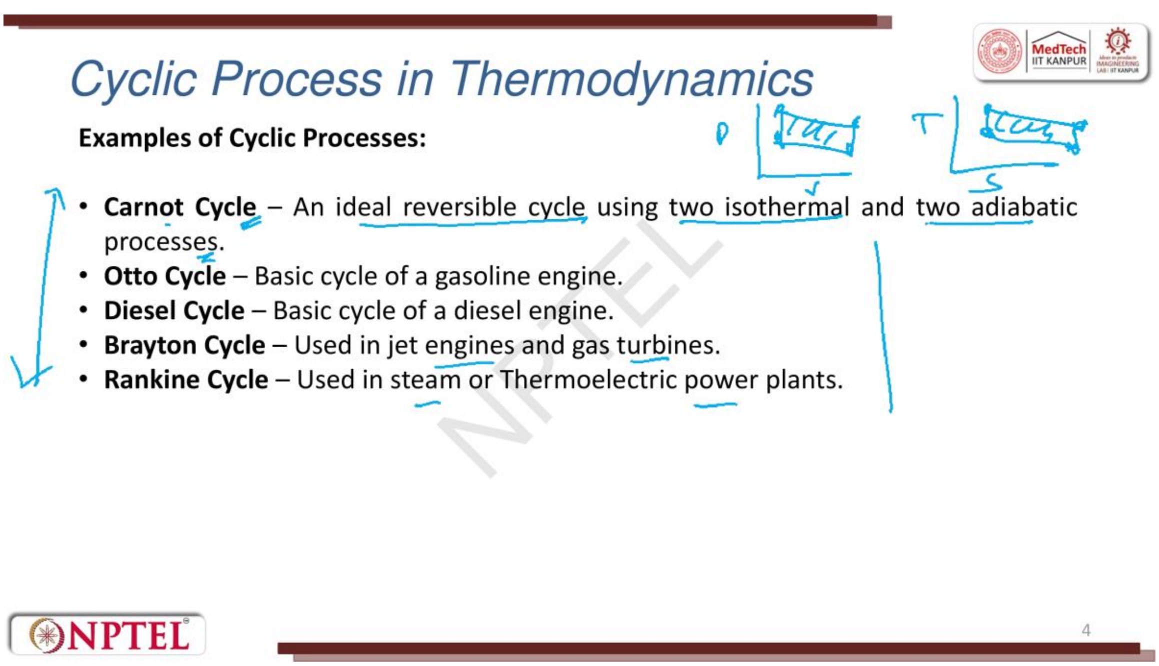


Now, let us try to look into the Cyclic Process. There are only two types of processes, right? One is called Compression. The other one is called Expansion. You will have a combination of compression and expansion such that you try to form a cycle.

A cyclic process is a thermodynamic process in which the system returns to its original state. You start from here, go here, then go somewhere here, then go somewhere here, then go somewhere here, then go somewhere here, and then you come back. So, the cyclic process is a thermodynamic process in which the system returns to its original state—start here and end here—after undergoing a series of changes. So, a series of changes in terms of pressure—this is volume, and this is P. The initial and final states are identical, so the net change in internal energy becomes zero. So, that is called a cyclic process.

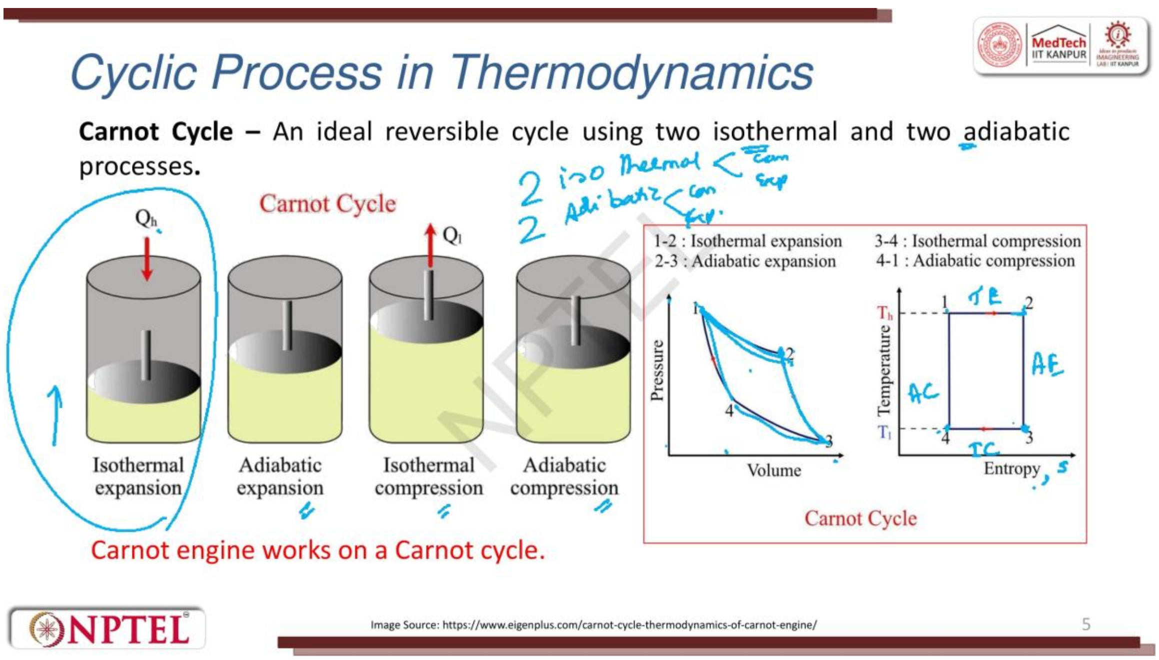
Initial state equal to final state. The system's pressure, volume, temperature, and internal energy returns to their original value is the initial state equal to final state. The delta U energy, since internal energy is a state function, the net change is 0 over 1 cycle. So, when you finish 1 cycle, the internal energy change is 0. Work and heat may exist.

The system may exchange heat (Q), work (W) but Q equal to W over a full cycle. Please understand heat will be there, work will be there, so that for a full cycle if you take it will be Q equal to W. Used in engines found in power cycle like Otto cycle, Diesel cycle, Brayton cycle and Rankine cycle. The graphical representation can be showed in terms of a closed loop curve over a PV diagram or a TS diagram. These things are very important.



Examples of a cyclic process. Carnot cycle. I told you very clearly. Now, you have a PV diagram, you have a TS diagram. So, you might have something like this, you might have something like this. Starting point, ending point will be the same, right.

And the other conditions will be followed like this. Delta U equals 0, W equals, sorry, Q equals W, and then you will have a representation. This is what a representation is. When we talk about it, the area under the curve is this, right? So, this is a cycle. And any system you take follows a cycle, right? From one state to the other state, and then to another state, it follows.



Carnot cycle: An ideal reversible cycle using two isothermal and two adiabatic processes is the Carnot cycle. The Carnot cycle is an ideal reversible cycle. What is reversible? We have already seen it.

The Carnot cycle is an ideal reversible cycle. When we talk about the Otto cycle, it is basically the cycle of a gasoline engine. The Diesel cycle is the basic cycle of a diesel engine. Brayton, in the previous one also, Brayton has to be a bayonet, I would have said. So, the Brayton cycle is used in jet engines and gas turbines.

The Rankine cycle is used in steam and thermoelectric power plants. So, you can see different types of cycles are used in different places. So, the Carnot cycle will be our first focus, which is a reversible cycle with two isotherms. Isotherm means temperature is constant. Isoadiabatic means Q is constant.

Q is equal to 0. So, let us try to see the Carnot cycle. Carnot cycle. The Carnot cycle has four stages. It is an ideal reversible cycle using two isotherms and two adiabatics.

Let us go back to the isotherm. What did we see here? Two isotherms. So, a diathermal wall is there, two isotherms and two adiabatics. You have a wall, so you see Q, right?

So, first what you do is, Q equal to isothermal expansion. So, the thing is expansion is happening. Then, it is following adiabatic expansion. What is adiabatic expansion? Adiabatic expansion, what did we study?

There is no heat is transferred from or to the system is adiabatic, right? So, adiabatic expansion and then you will have isothermal compression and adiabatic compression. So, this process will have two isothermal, two adiabatic and each of them will have compression, expansion, compression, expansion. So, when we do compression, you see Q, the Q is pressed, the Q is out. When we do expansion, the H is in.

So, the Carnot engine works on Carnot cycle. So, when we try to take a PV diagram, pressure volume diagram, from 1 to 2, it follows isothermal expansion. What is isothermal expansion? It follows this diagram. Piston is there, gas is there, now you see this.

So, it is isothermal from 1 to 2, following isothermal expansion. When it is expanded, then from 2 to 3, it will be adiabatic compression. From 2 to 3, it is adiabatic expansion. When I say expansion, the volume increases. So, first is isothermal expansion; 2 to 3 is adiabatic expansion.

So, first expansion, second expansion. Now, from 3 to 4 is isothermal compression, so the volume is reduced. When the volume is reduced, the pressure increases. Then, it is adiabatic compression, so the cycle is closed. So, if you look at this PV diagram, 1 to 2 is isothermal expansion, then 2 to 3 is adiabatic expansion, 3 to 4 is isothermal compression, then 4 to 1 is adiabatic compression.

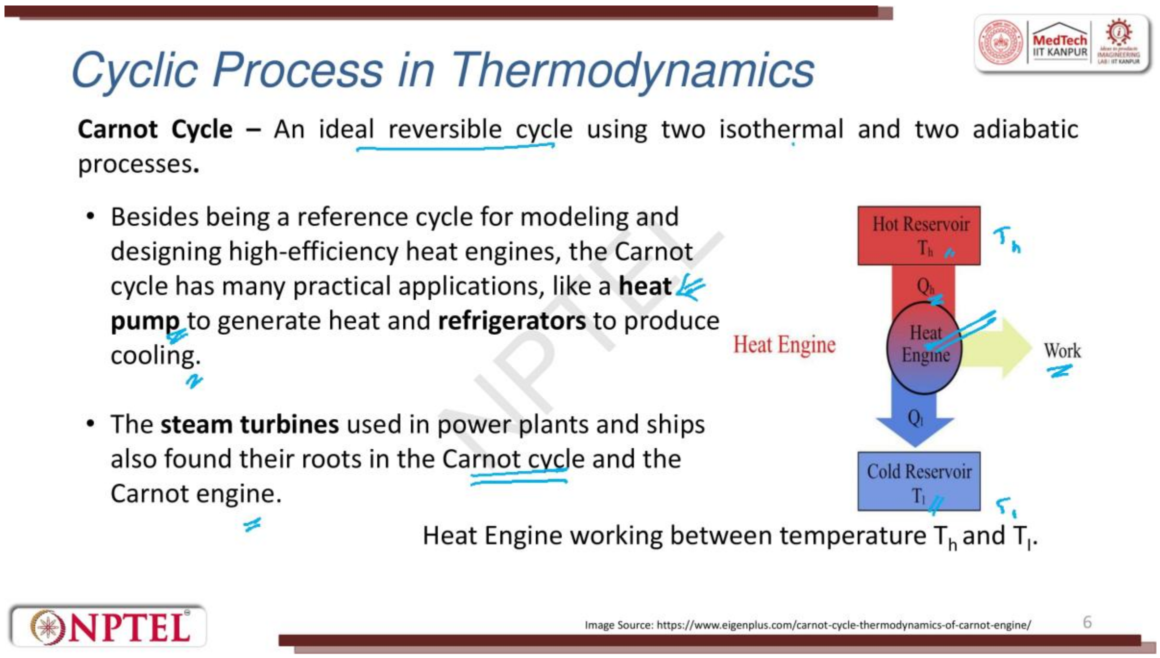
So, when you do adiabatic compression, there will be volume reduction and pressure increase. So, when we try to plot the similar thing with a TS diagram, yes. So, now what happens? If you try to move from 1 to 2, what happens is it is isothermal expansion. So, the temperature is almost constant.

Then, from there, 2 to 3, when we do adiabatic expansion, you see there is a reduction in temperature because from 2 to 3, entropy is constant. Temperature is falling because you have gone for a 2 to 3 expansion. So, entropy is constant. But there is an expansion in the volume. Then, from 3 to 4, what we do is we try to do compression, which is isothermal compression.

Isothermal compression means the temperature is constant. So, the entropy is reduced. And then, what you do is we try to do adiabatic compression, which is 4 to 1. There is an increase in temperature. Isothermal, then it is an increase in temperature.

Now, you see this follows a cycle. The TS diagram tries to talk about 1 to 2 isothermal expansion, adiabatic expansion, then it is isothermal compression, adiabatic compression. So, this tries to explain what a cycle is and how a Carnot cycle works. So, let us try to take a cyclic process in thermodynamics, which is the Carnot cycle. So, the Carnot cycle we are trying to consider is an ideal reversible cycle. An ideal reversible cycle uses two isothermal and two adiabatic processes.

So, you will have a hot reservoir which is Th, and then you have a cold reservoir. So, you can try to have Th, then T1, or you can try to have T initial or T room temperature. So, then what happens? There is work done. So, when the heat transfers T, then there is Q, which is Qh (very high), then this is a heat engine, and then Q low happens. So, from here you try to tap and then run an engine, right? An ideal reversible cycle with two isothermal and two adiabatic processes.



Besides being a reference cycle for modeling and designing high-efficiency heat engines, the Carnot cycle has many practical applications, like heat pumps, which are used to generate heat, and refrigerators, which produce cooling. So, a heat pump is one of the biggest examples where we use a Carnot cycle. The steam turbines used in power plants and ships also find their roots in the Carnot cycle and Carnot engine. The steam which is used in power plants—why, what do we do?

Water tries to increase the temperature, and it gets converted from liquid to vapor. Now, this vapor—what we do is we mix it up, and we have steam. So, that steam is allowed to hit the turbine. So now, based upon the steam that is there, the turbine rotates. The turbine is attached to a shaft, and henceforth it generates electricity.

Cyclic Process in Thermodynamics

Otto Cycle – Basic cycle of a gasoline engine.

The air-standard Otto cycle is the idealized cycle for spark-ignition internal combustion engines. This cycle is shown above on *P–V* and *T-s* diagrams. The *spark-ignition engine* is modeled with this Otto cycle.

The Otto cycle 1 → 2 → 3 → 4 consists of following four processes:

Process 1 → 2:
Reversible adiabatic compression of air;
Process 2 → 3:
Heat addition at constant volume;
Process 3 → 4:
Reversible adiabatic expansion of air;
Process 4 → 1:
Heat rejection at constant volume.

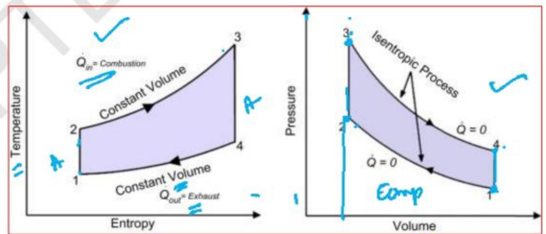


Image Source: https://www.sciencedirect.com/topics/-engineering/otto-cycle

So, let us now try to see an Otto cycle. The Otto cycle is the basic cycle of a gasoline engine. The basic cycle of a gasoline engine. The air-standard Otto cycle is the idealized cycle for spark ignition. So, in your petrol engine, what happens is you will have air. You will mix the air with petrol. Then, you try to atomize it, and then you try to push it into a cylinder where you have a spark plug, where you have a spark plug.

So, the air-standard Otto cycle is the idealized cycle for spark-ignition internal combustion engines. This cycle is shown in PV and TS diagrams. The spark-ignition engine is a model of the Otto cycle. So, the process starts from 1. Let us try to take a PV diagram.

It starts from 1. It goes to 2. Then, it goes to 3, 3 to 4, 4 to 1. So, in the first process, volume. So, volume is reduced.

So, it is a compression cycle. Then from here, it is trying to reduce the volume is constant and the pressure is increased. From 2 to 3, the pressure is increased. Then, from 3 to 4, the volume is expanded. So, it is expansion happening.

Then, from 4 to 1, there is a pressure drop. So here, we will try to see 1 to 2 is a reversible adiabatic compression of air. Volume reduction, compression. Volume expansion, volume enlargement, it is expansion. So, that is straightforward.

So, it is adiabatic compression where Q dot is equal to 0. Then, in 2 to 3, it is a constant volume. I told you that there is no change in volume, but there is an increase in pressure. So, heat addition to constant volume happens. So, once it happens, then what happens is the pressure increases.

Volume is constant. So, the volume is constant. Now, you are trying to add more energy. So, what happens? The piston expands.

So, the piston is in the bottom stage. So, it is a confined area. You are applying heat. So then, the pressure increases. So, 2 to 3: heat addition at constant volume.

So, there is a pressure increase. Then, from 3 to 4, you have an expansion. Volume increases. Adiabatic expansion of air. And then, 4 to 1 is the heat rejection at constant volume.

So, if you go to the TS diagram, you can try to see 1 to 2, which is an adiabatic compression. Then, 2 to 3 is a constant volume process, because here you see it is a constant volume process. From 3 to 4, it is an expansion process which is adiabatic. So, this is adiabatic, and this is also adiabatic. Then, from 4 to 1, there is heat rejection happening, but it is a constant volume process.

So, this is heat out through exhaust and heat in during combustion. So, if you see here, our typical cycle, which is used in the petrol engine, follows the Otto cycle. So, there are two compressions and two expansions. These are the two things which are used. And whatever we try to represent, we will try to represent it by a PV diagram and by a TS diagram.

Cyclic Process in Thermodynamics

Diesel Cycle – Basic cycle of a diesel engine.

The Diesel cycle is a thermodynamic process that is commonly used in diesel engines for internal combustion. It operates on the principle of constant pressure combustion and consists of four distinct processes: intake, compression, combustion, and exhaust.

- Process 1-2:
  Reversible Adiabatic Compression Process
- Process 2-3:
  Constant Pressure Heat addition
- Process 3-4:
  Reversible Adiabatic Expansion Process
- Process 4-1:
  Constant volume Heat rejection

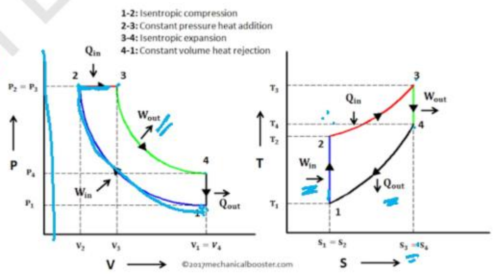


Image Source: https://mechanicalbooster.com/2017/10/diesel-cycle.html

Diesel cycle, a cyclic process in thermodynamics. Now, we will try to see a Diesel cycle. Diesel cycle, a basic cycle of a diesel engine. The diesel engine is a thermodynamic process that is commonly used in diesel engines for internal combustion. It operates on the principle of constant pressure combustion and consists of four distinct processes: intake, compression, combustion, and exhaust.

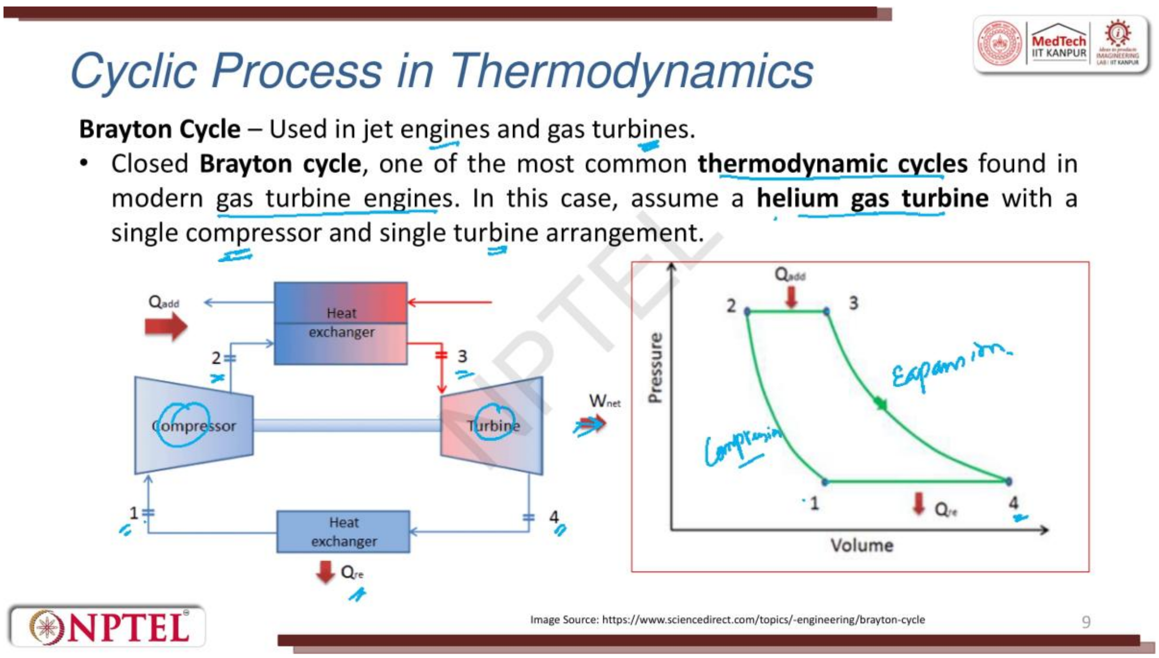
Again, let us go with the PV diagram. So, you have a PV diagram, then you have a TS diagram. The PV diagram will try to explain the four processes involved with a piston cylinder. The first cycle will be intake, then compression, then combustion, and finally exhaust. So, the process 1 to 2 in a Diesel cycle.

So, 1 to 2, it follows; 1 to 2 is this process. It follows adiabatic compression. So, adiabatic compression means there is a reduction in volume. Now, 2 to 3 is the heat addition that occurs. So, the volume slightly increases, but the pressure remains constant.

Then, from 3 to 4, there is work output; from this to this, from 3 to 4, there is an adiabatic expansion process. Then, from 4 to 1, there is a heat rejection process. So, this is very clear from a PV diagram. 1 to 2 is compression. 2 to 3 is slight expansion.

Then, 3 to 4 is a complete expansion. 4 to 1 is a heat out where there is a constant volume. So, when we try to go for a TS diagram, you can try to see 1 to 2 is adiabatic compression where the work is given in. 2 to 3 is heat in. You can see heat in.

Then 3 to 4 is the work out. 4 to 1 is the heat rejection. So, here it is TS. S is entropy, T is temperature. So, 1 to 2 there is an increase in temperature, 2 to 3 again there is an increase in temperature, 3 to 4 there is a decrease in temperature but the volume is, the entropy is constant and 4 to 1 the entropy is reduced. The temperature is also reduced. This talks about diesel. So, when you see a truck, it always follows a Diesel cycle.



Now, let us see Brayton cycle. Till now we have been seeing Carnot cycle, Otto cycle and then Diesel cycle. The most fundamental one is the Carnot cycle. It is an ideal reversible cycle. Next, we saw the Otto cycle, then we saw the Diesel cycle. Later, you will see when you say constant pressure increase, decrease, compression happening—how is this happening? You will have to have one more device.

So, you will see in petrol engines, in the Otto cycle, you will always have a spark plug. Now, let us start looking into the Brayton cycle. Where is it used? It is used in jet engines and gas turbines. You saw steam turbines; in a similar way, you also have gas turbines.

So, the closed Brayton cycle is one of the most common thermodynamic cycles found in modern gas turbine engines. In this case, assume a helium gas turbine with a single compressor and single turbine arrangement. Single compressor, single turbine. The compressor is used to compress the volume. For example: from 4 to 1, there is compression happening.

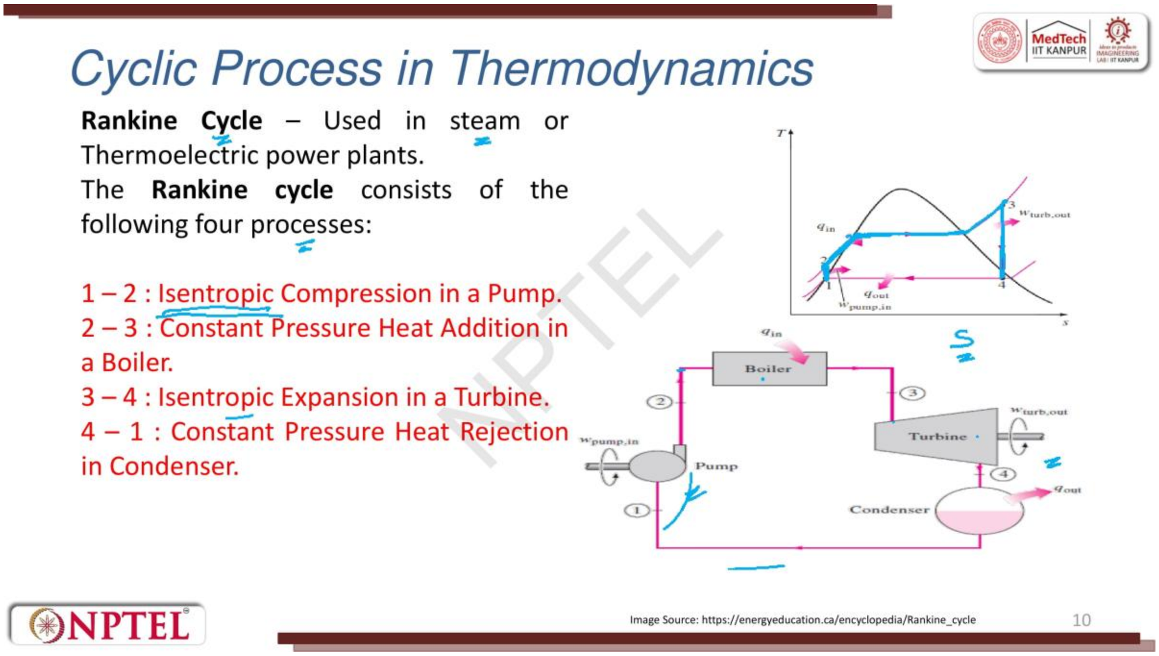
So, now what from the compressor is sent to a heat exchanger. What is a heat exchanger? Where there is an exchange of heat, which is like you have Q in and Q out. So, this goes into a heat exchanger, then once it is inside the heat exchanger, it goes directly to a turbine. In a turbine, you will have a blade through which highly pressurized and very hot gas passes.

What happens is, it hits the turbine blade, and the turbine starts rotating. Once the turbine starts rotating, I take work out. The moment the gas passes through the turbine and has done its work, then slowly what will happen is, it will lose its pressure, it will lose its temperature, and then come down. When it is coming down, you have to further extract heat out, then we try to extract Q, and whatever is finally left gets into. So, basically, if you see, it gets heated here. It gets cooled here by and large. It gets cooled here, or you do not have to use a cooler.

So, you can try to take the residual heat and take it to the compressor. In the next compression cycle, the temperature residue can be used to an advantage. So, the Brayton cycle is a very, very important and common thermodynamic cycle. Now, let us look into the PV diagram. PV diagram 1 to 2.

So, 1 to 2 is you see there is a compression happening in the medium. So, 1 to 2 there is a compression. Once there is a compression there is a pressure increase. Now ,in heat exchanger, so what you do is you try to add heat to it. So, you try to add heat to it and then slowly allow some amount of expansion to happen.

From 2 to 3, there is a heat which is getting added and there is a small relaxation of the volume. So, 2 to 3 is a place where you add Q and from 3 to 4 you can see there is a volume expansion, compression expansion. So, in this portion there is a volume expansion which comes to 4. Now, at 4 what you do is, again you try to push it into compression cycle 4 to 1. So, now 4 is there. Now, when you go, it gets into the compressor. So, volume reduction, volume reduction, volume expansion and again a volume expansion. Clear?



So, the next cycle is Rankine cycle. So, I will leave you an assignment. You have seen the PV diagram. Can you try to draw a TS diagram for the Brayton cycle? If you are not able to do it, don't worry. In the tutorial hour, we will have a discussion and then explain the TS diagram for the Brayton cycle. Now, let us move to the next cycle, which is called the Rankine cycle.

The Rankine cycle is used in steam power plants or thermoelectric power plants. Thermoelectric means where heat is generated by electricity, as in thermoelectric power plants. The Rankine cycle also has four processes. So, in the Rankine cycle, you will have a pump and a turbine. From a turbine, you always extract work output.

So, you will have a pump. What happens in 1 to 2 is isentropic. Isentropic compression happens in a pump. 1 to 2 is isentropic compression. Afterwards, there is constant-pressure heat addition in a boiler.

So, there is a boiler where heat is being added. Now, it undergoes isentropic expansion when it hits the turbine. When it exits the turbine, it has completed the expansion process, right? And then, from the gas turbine, it enters a condenser, where the heat is removed. The remainder is connected back to the pump.

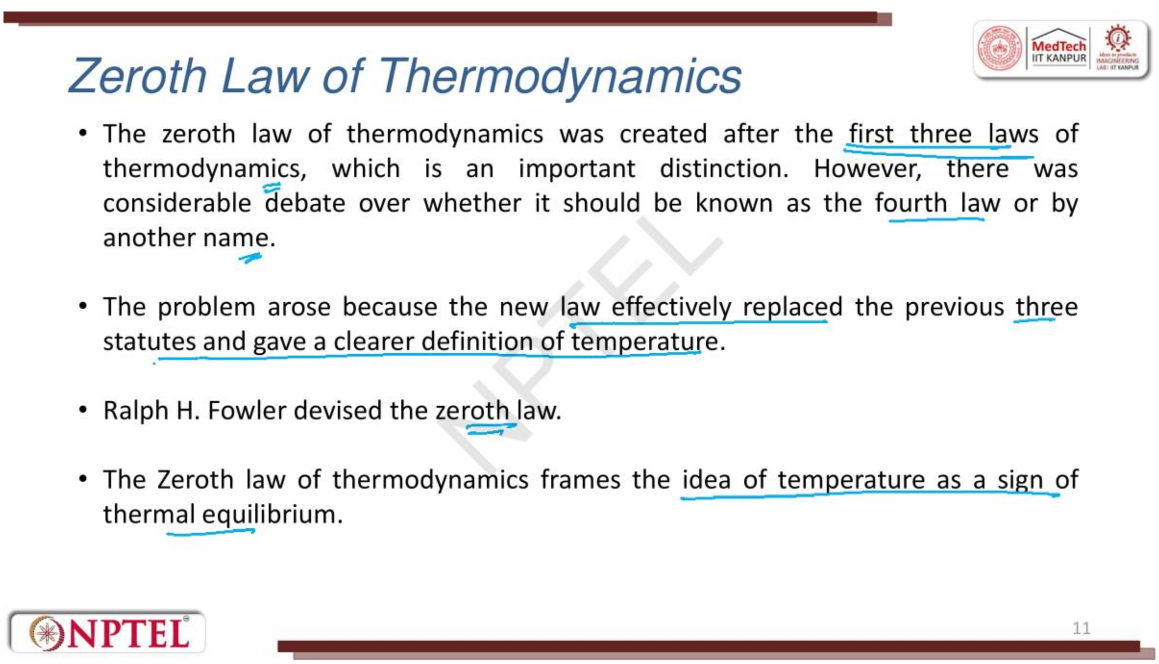
So, if you observe a Rankine cycle and plot a TS diagram, the assignment for this cycle will be to draw a PV diagram. So, isentropic. So, 1 to 2 is T, which is temperature. So, isentropic means constant entropy but increasing temperature, right? After that, from 2 to 3, you apply the boiler.

That means heat is pushed inside. So, the temperature will increase. And then what happens? There is an increase in entropy, right? And this entropy approaches the curve.

And then it tries to expand to 3. At 3, we try to extract work. 3 to 4, we try to extract work. And in condenser, we try to reduce the entropy and the temperature is constantly maintained. So, it is isentropic 1 to 2, 3 to 4 is compression and expansion.

We saw Carnot engine, Otto cycle. Diesel cycle, Brayton and Rankine. These five are good enough for the level we are having an exposure. Of course, there are hybrid cycles and then there are also tailor-made cycles for different applications. If you see here, we have considered a petrol engine, we have considered a diesel engine, a gas turbine and we have also considered a boiler.

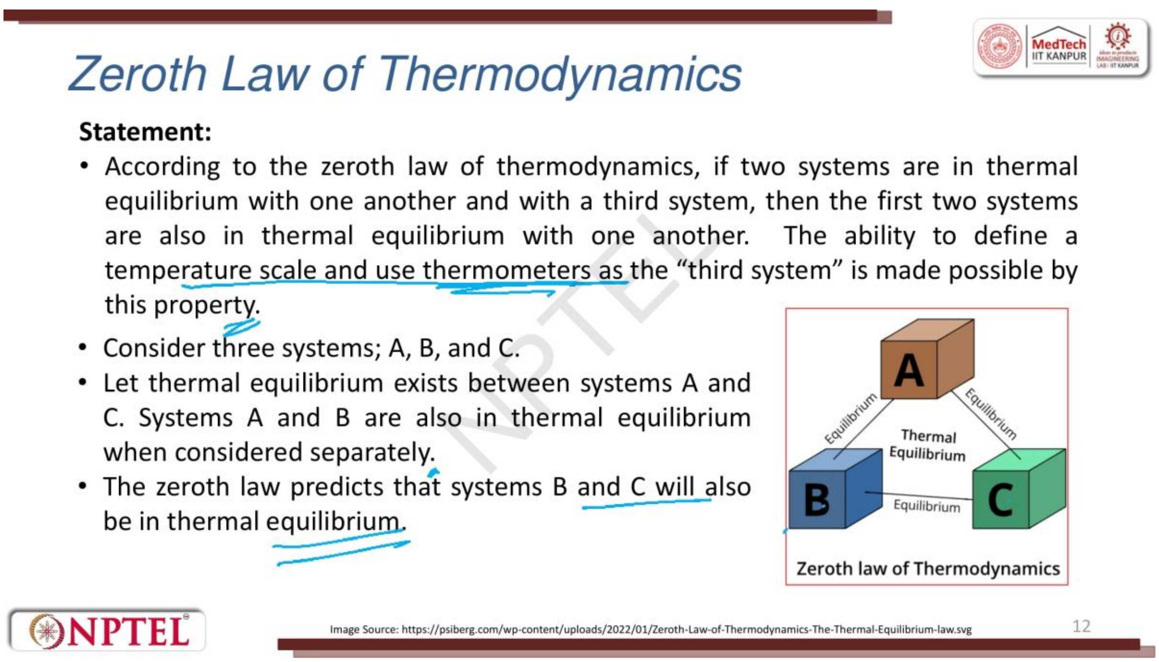
A steam turbine, right. So, all the four we have considered. So, the assignment for you will be for the Brayton cycle, you will draw the TS diagram and for the Rankine cycle, you will try to draw the PV diagram, okay.



Zeroth Law of Thermodynamics. The zeroth law of thermodynamics was created after the first three laws of thermodynamics. That means the first law, second law, and third law came. But then they realized, okay, something was missing. So, let us go ahead and define it as the zeroth law. So, that is how the zeroth law came into thermodynamics. The zeroth law of thermodynamics was created after the first three laws of thermodynamics, which is an important distinction.

You should understand—we have already seen in the previous lecture—what the zeroth law is. In a very crude, simple, colloquial fashion, we have seen the zeroth law, first law, second law, and third law. However, there was considerable debate over whether it should be known as the fourth law or any other name. Why not fourth? Then, people had a strong deliberation.

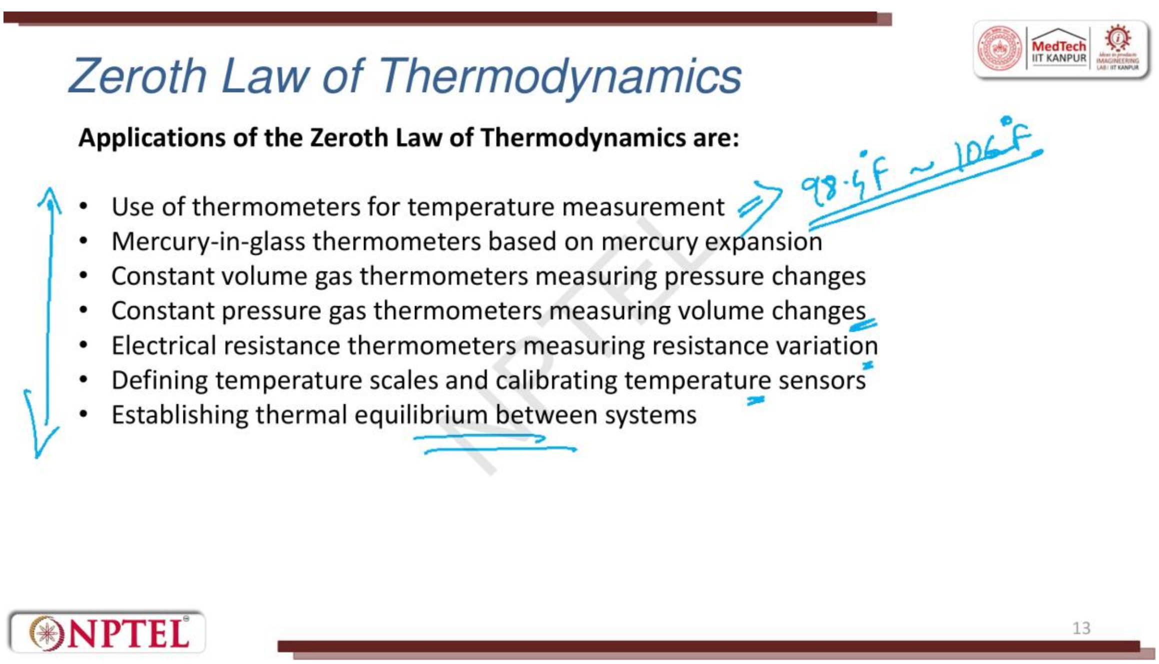
The problem arose because the new law effectively replaced the previous three statutes and gave a clear definition for temperature. So, that's why Ralph H. Fowler devised the zeroth law. The zeroth law of thermodynamics frames the idea of temperature as a sign of thermal equilibrium. That is what the zeroth law is. Okay.



What is the statement of the zeroth law? According to the zeroth law of thermodynamics, if two systems are in thermal equilibrium—B and C are in thermal equilibrium with one another and with a third system, AC thermal equilibrium, AB thermal equilibrium—then the first two systems are also in thermal equilibrium with one another. The ability to define the temperature scale and the use of a thermometer as the third system is made possible by this property.

So, in the zeroth law, when two systems are in equilibrium—B and C are in equilibrium with one another and with a third system A—then the first two systems are said to be in thermal equilibrium with one another. Consider three systems A, B, and C. Let thermal equilibrium exist between system A and C. System A and B are also in thermal equilibrium when considered separately, AC and AB.

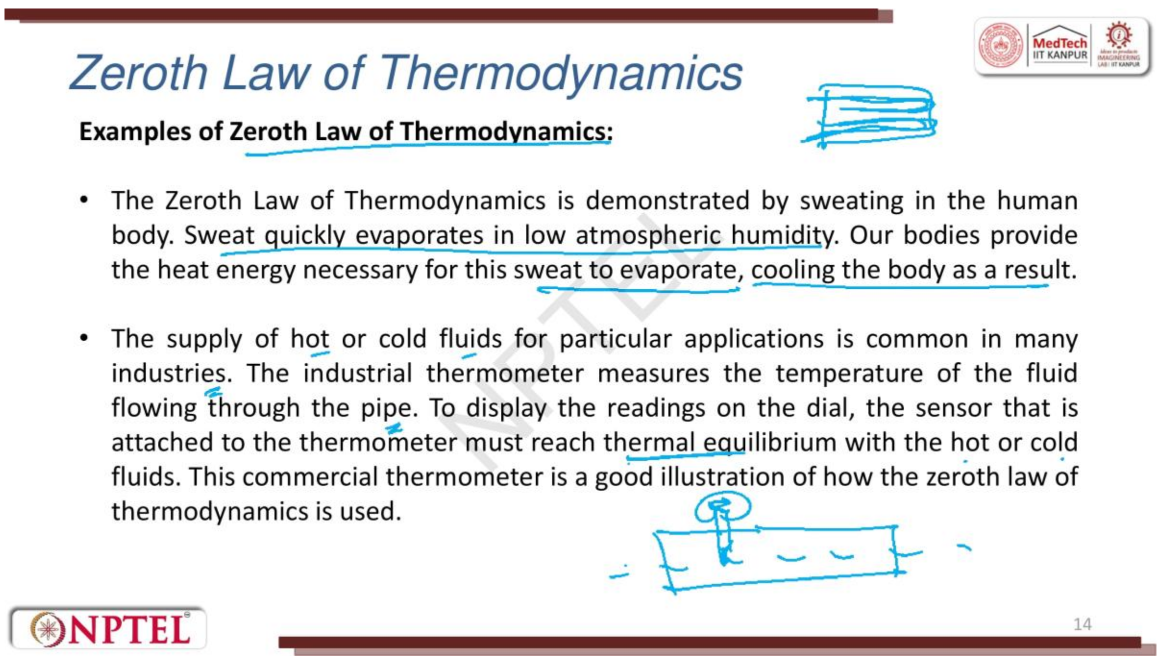
The zeroth law predicts that the system BC will also be in thermal equilibrium. This law, the zeroth law, gave the inception for the temperature scale and the use of a thermometer. That's the beauty of this law.



So, the application of the Zeroth law of thermodynamics includes the use of a thermometer for temperature measurement, Mercury-in-glass thermometer based on mercury expansion.

Constant-volume gas thermometer measuring pressure changes. Then, you will have a constant-pressure gas thermometer measuring the volume change. Electrical resistance thermometer measuring resistance variation. These are the zeroth law applications. I repeat, the zeroth law states that if two systems are in equilibrium with one another—AC, AB—and with a third system, then the first two systems are also in thermal equilibrium with each other.

That is what it is. Based on this came all these applications. The thermometer, which is used for measuring, always ranges from 98.4 degrees Fahrenheit to 106 degrees Fahrenheit, right? So, all that came into existence because of the zeroth law.



Some more examples of the zeroth law of thermodynamics. The zeroth law of thermodynamics is demonstrated by sweating in the human body. You run, you sweat, right? Sweat quickly evaporates in low atmospheric humidity. Have you seen it? Low atmospheric humidity.

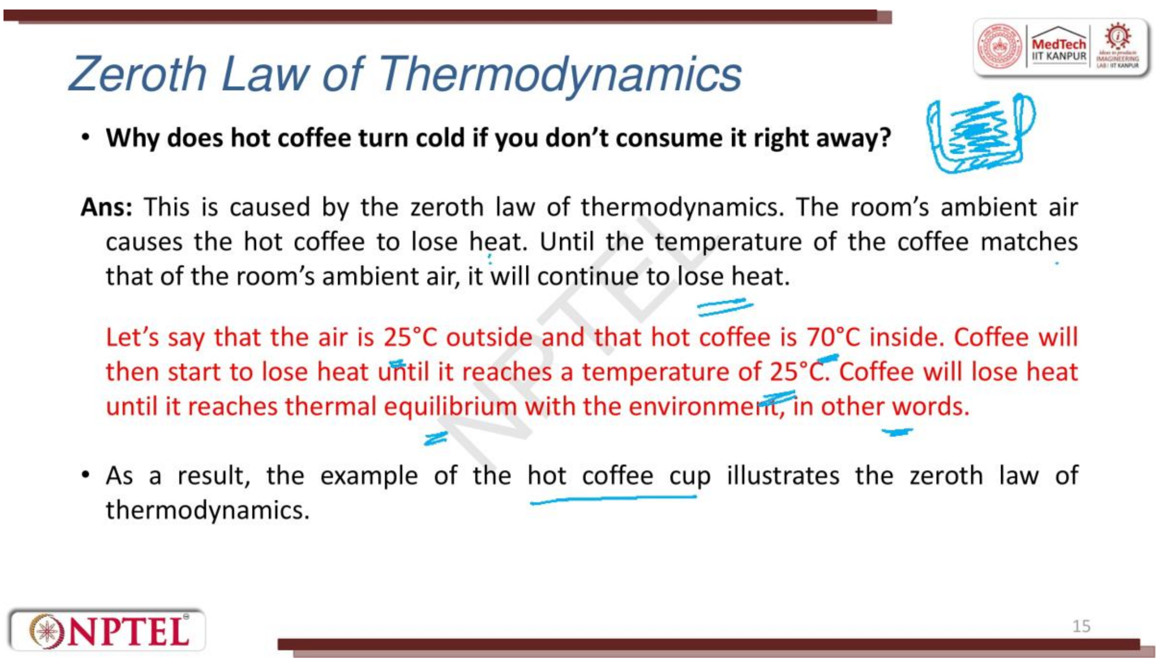
When do you have low atmospheric humidity? When you are up the hill or down the hill. Please think about it. Our body provides the heat energy necessary for this sweat to evaporate, cooling the body as a result. That is because of the zeroth law.

If somebody asks, tell me the phenomenon: what happens when you sweat and when the sweat evaporates? So then, you should say it follows the zeroth law principle of thermodynamics, right? The supply of a hot or cold fluid for a particular application is common in many industries. A hot fluid—where do you use it? Suppose you have some sweets inside a container, or let us take steam cooking.

You have rice kept inside, and then the rice has to cook. So you pass hot air or steam around the oven. So, that keeps the temperature high. And that maintains the temperature of the rice. So, you use the hot fluid to do it.

The same applies to cold fluid. For example, when you are using AC and it is used as a heater, cold fluid for a particular application is common in many industries. The industrial thermometer measures the temperature of the fluid flowing through a pipe. So, there is a pipe. So, there is a fluid. So, through this, there is water going, and there is a thermometer which is there to measure the temperature.

The industry thermometer measures the temperature of the fluid flowing through the pipe. To display the reading on the dial, so there is a dial. The sensor that is attached to the thermometer must reach a thermal equilibrium with hot or cold fluid. First, it has to reach to a equilibrium and then what it will do is it will try to increase. This commercial thermometer is a good illustration of how the zeroth law of thermodynamics is used.



So, some more example. Why does hot coffee turn cold? If you don't consume it right away, you take a ceramic bowl and then you fill it up with coffee. Over a period of time this coffee gets cold. Why? Because this is an insulating media. Have you thought about it? This is an insulating media, ceramic cup, it insulates, right? It does not allow heat to go. This is caused by zeroth law of thermodynamics.

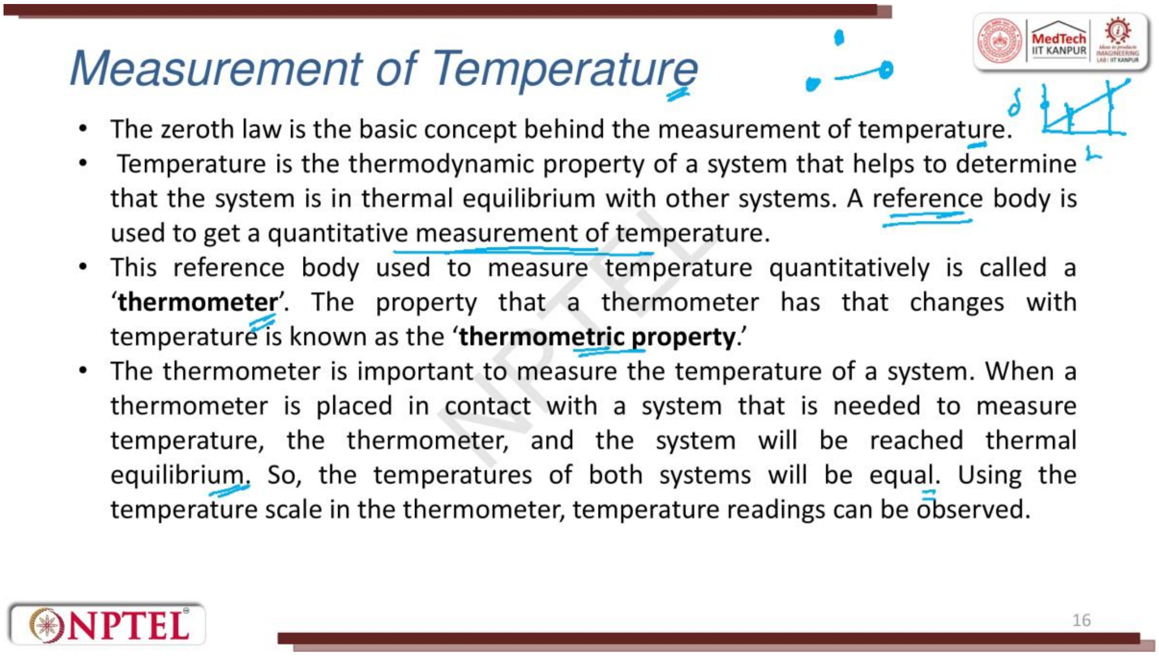
The room's ambient temperature causes the coffee to lose the heat. Until the temperature of the coffee matches the room's ambient air, it will continue to lose heat. Because of this nature, your coffee gets colder. Let us say that the air is 25 degrees Celsius outside the atmosphere, AC is running 25 degrees Celsius and the coffee temperature is 70 degrees Celsius. Why?

100 is a boiling point of water. Milk will have more amount of water. So, you can't go for 100 degrees. It should be around about 70, 80 degrees. And mind my friends, when you try to drink a coffee, 70 degrees, all your tissues should be burnt, right?

So, it is 70 degrees Celsius. So, you should have a feel for it. So, what happens is, when you try to sip, the liquid quantity is very low. It spreads over a large area of your tongue and your tongue again has a lower temperature. So, there is a heat loss.

Clear? So, the hot coffee is 70 degrees Celsius. The coffee will start to lose its heat until the temperature reaches 25 degrees Celsius. The coffee will lose until it reaches thermal equilibrium with the environment. In other words, it gets cooled.

As a result, the example of a hot coffee cup getting cold is because of the zeroth law of thermodynamics. Are you able to now understand and appreciate the zeroth law? I repeat once again. So, when two systems are in thermal equilibrium with one another and with a third system, then the first two systems are also in thermal equilibrium with one another. So, this is the law, and these are the examples.



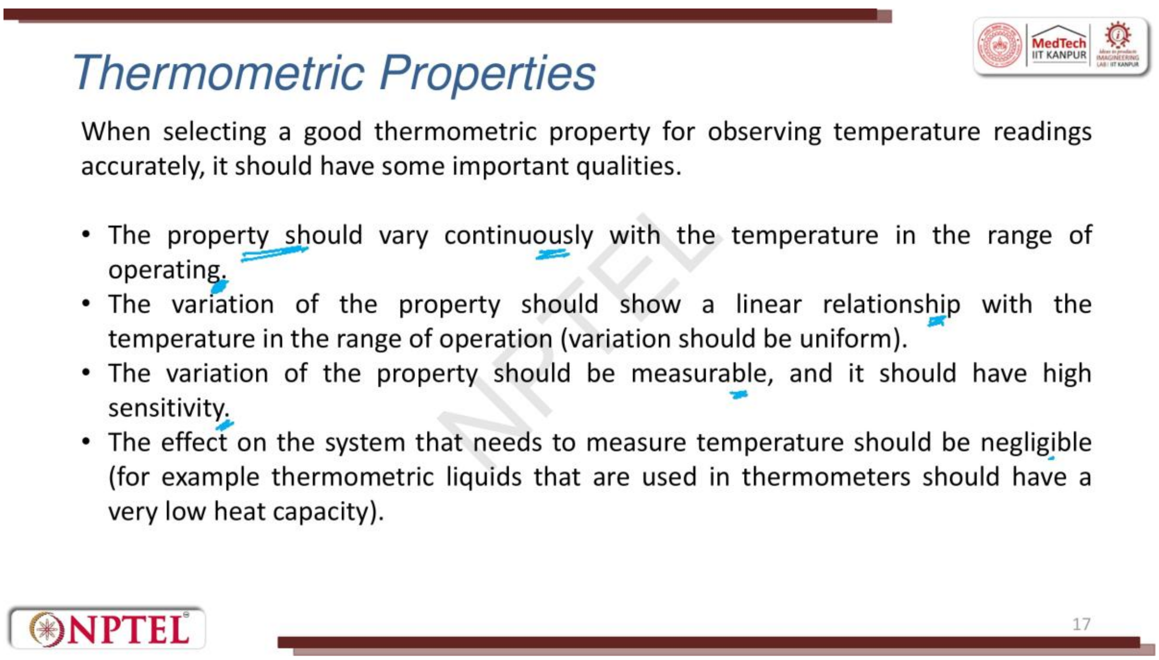
So, Measurement of Temperature. So, I said no application of the zeroth law is the measurement of temperature. So, the zeroth law is the basic concept behind the measurement of temperature. Temperature is a thermodynamic property of a system that helps to determine whether the system is in thermal equilibrium with another. There has to be a reference body.

A reference body is used to get the quantitative measurement of temperature. So, what we are trying to say is, here is a body, and here is a temperature-measuring device. So, you try to hit at it, you try to measure the temperature, but before even doing it, you will have one more reference. So, that reference body is used to quantitatively help in measuring what the temperature here is. Without this reference, you cannot do it.

Because this reference will try to say. For example: if you try to see a spring balance what you do is, you try to measure the displacement with respect to load. So, you get a straight line. So, afterwards what you say is, from this portion to this portion you do a calibration and then you try to get this values. So, the next time whatever I do is, I measure only the displacement, I will try to say what is the load which we have applied. In the same way what we do is, a reference body is used to get the quantitative measurement of temperature.

The reference body used to measure the temperature quantitatively. It is called as thermometer. The reference body is used to get a quantitative measurement of temperature. The property of the thermometer has that changes with temperature is called as thermometric property. A thermometer is important to measure the temperature of a system.

When the thermometer is placed in contact with a system that is needed to measure the temperature, the thermometer and the system will reach a thermal equilibrium. So, the temperature of both the systems will be equal. Using the temperature scale in a thermometer, temperature reading can be observed.



What are Thermometric Properties? I used the word thermometric property. So, now, let us understand what is thermometric property. When selecting a good thermometric property for observing temperature reading accurately, it should have some of the points or qualities. The property should vary continuously with temperature in the range of operating. The variation of the property should show a linear relationship with the temperature in the range of operation. The variation of the property should be measurable and it should have very high sensitivity, right?

So, what are we trying to say is, high sensitivity means if you are trying to measure 1 degree Celsius, your sensitivity of the equipment should be 0.1 or the reading graduation should be 0.1. For example: You take a scale of 1 centimeter, you will be able to see 111 millimeter. So, that is the shortest least count. So, the variation of the property should be measured and should have high sensitivity. The effect on the system that needs to measure the temperature should be negligible. The thermometer should not put an influence on the system. So, that is, what we are trying to say.

Thermometric Properties

Table: Thermometric properties used in thermometers

Thermometer	Thermometric property
Thermocouple	Electromotive force
Electrical resistance thermometer	Resistance
liquid-in-glass thermometer	Expansion of liquid (change in length)
Constant pressure gas thermometer	Volume
Constant volume gas thermometer	Pressure
Bimetallic strip thermometer	Bending due to differential thermal expansion

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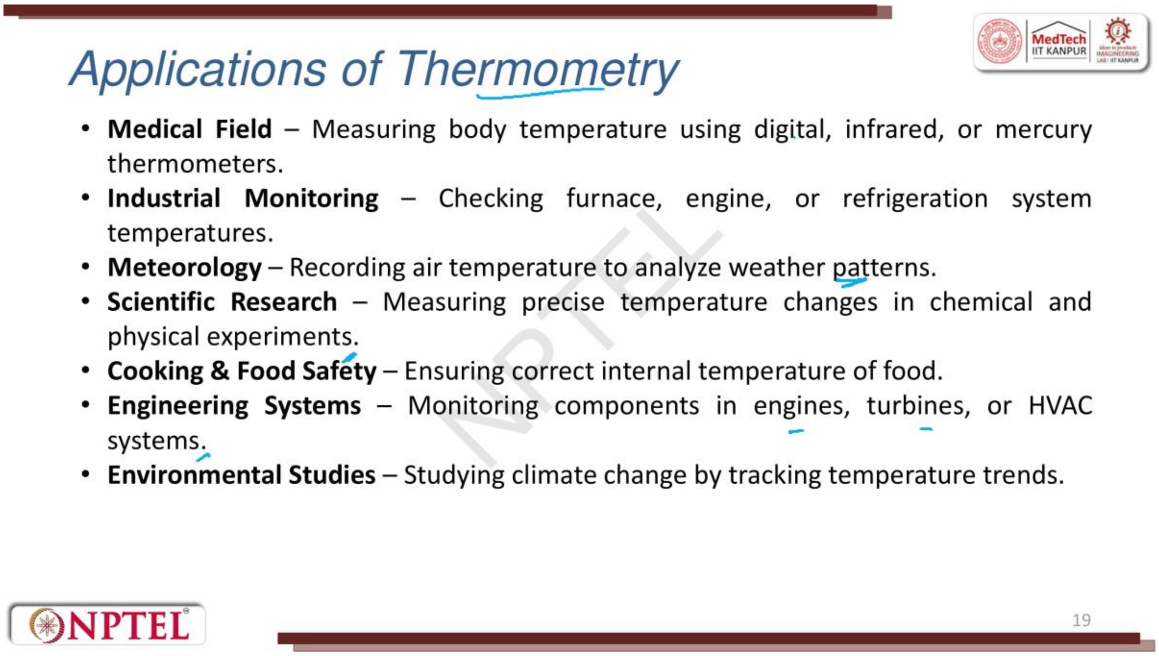
So, what are the different Thermometric Properties used in thermometer? We have thermometry is thermocouple. So, it works on electromagnetic force, then you have electromagnetic force. Then, you have electrical resistance thermometer, where in which it works on the principle of resistance, then we have liquid in glass thermometer, the thermometer what you put in your mouth, expansion of the liquid changes in the length. So, you see here mercury bulb will be there, then this will expand and linearly and go and then here you see the graduations.

Constant pressure gas thermometer, so you will have a volume. Constant volume gas thermometer, it works on pressure. Then, bimetallic strip thermometer, all your MCBs, what you use in your house when the electricity trips off, we always try to use a bimetallic strip thermometer. So, what happens is, you have two dissimilar materials which can be used. Bend due to the deflection of thermal expansion.

So, basically, use the thermal expansion principle, and then this deflects and switches off. So, when you draw more current, the bimetallic strip tries to knock off the wire connection. So, here are some of the thermometers, and here are the thermometric properties which are used for measurement.



So, what are the applications of Thermometry? Medical field: It is used to measure body temperature using digital infrared or mercury thermometers.

So, infrared is when you use a gun to measure it. During COVID, we used that because you could not touch. Digital is when you can use mercury, which is there, and then that can be, rather than a linear scale, it can be a digital scale. Industrial monitoring: For example, checking furnace, engine, or refrigeration system temperature is used. Sometimes it is also used in your car to measure the temperature. Metrology: It records air temperature to analyze weather patterns.

So, we use metrology, and we also use thermometry. Then, scientific research measures precise temperature changes in chemical and physical experiments. Then, cooking and food safety: Ensuring correct internal temperature for food. You will always be done with cooking and food safety. For example: When you put a pizza into the oven, there is always a temperature-controlled parameter there.

So, ensures correct internal temperature of the food comes in. For example: Microwave, also you can try to maintain the temperature time you can vary. Then, engineering systems: Monitoring the components of engine turbine HVAC systems we use a thermometry. Then, environmental studying climate change by tracking temperature trends we study. The environmental studies based on it.

Common Temperature Scales

Scale	Symbol	Freezing Point of Water	Boiling Point of Water
Celsius	°C	0°C	100°C
Fahrenheit	°F	32°F	212°F
Kelvin	K	273.15 K	373.15 K
Rankine	°R or °Ra	491.67 °R	671.67 °R

99°F to 106°F

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So, there are different Scales of Measurement? This is very important. So, Celsius is always expressed in degree Celsius, freezing point of water is 0, boiling point is 100 degree Celsius. When we talk about Fahrenheit, it is degree F. So, the freezing point of water is 32 degree Fahrenheit, the boiling point of water is 212 degree Fahrenheit, right. Your human body when you have a fever, it is around about 99 degree Fahrenheit to 106 degree Fahrenheit, this is the max. When we talk in terms of Kelvin, it is K, right. So, Kelvin is when you talk about 0 degree Celsius it is 273.15 Kelvin.

When we talk about 100 degree Celsius it is 373.15 Kelvin. So, Rankine, which is otherwise called as degree R or degree Ra, which is 0 degree Celsius is going to be 491.67 Rankine, and when it is 100 degree Celsius it is going to be 671.67 degree Rankine. Generally, we try to avoid Rankine. We use all these three scales and symbols as degree Celsius, Fahrenheit and Kelvin. You can see that there is a correlation.

So, from this correlation, you can try to find out what the formula is. When you want to convert Celsius to Fahrenheit, Fahrenheit to Kelvin, or Kelvin to Celsius, you can try to find out a formula.

Temperature Scales Conversion

$$\frac{F-32}{180}=\frac{C}{100}=\frac{K-273}{100}=\frac{R}{80}$$

Where;
F = Temperature in Fahrenheit Scale
C = Temperature in Celsius Scale
K = Temperature in Kelvin Scale
R = Temperature in Réaumur Scale

So, now, let us look at the scale conversion. As I told you, the R scale is seldom used. So, if you want to avoid it or if you feel that it is not required, that's okay. But these three systems are very important. You would have studied them in your school days also, but—Let us recollect it:

$$\frac{F-32}{180}=\frac{C}{100}=\frac{K-273}{100}=\frac{R}{80}$$

So, if you do this, then you can try to have a conversion factor. So, you can try to play with it. So, you can try to figure out how to convert Fahrenheit to Celsius, Celsius to Kelvin, and then you can derive the answer.

To Recapitulate

- What are the different types of Thermal Equilibriums?
- What do you understand by Reversible and Irreversible Processes in terms of Thermodynamics?
- Discuss the Reversible and Irreversible Thermodynamic Processes with their Graphical representations.
- How do we differentiate Reversible and Irreversible Proceses?
- Name and illustrate the Cyclic Thermodynamics Processes.
- State the Zeroth Law of Thermodynamics. Also list its applications with suitable examples.
- How do we measure Temperature?
- What is Thermometry? Where is it applied?
- Which are the commonly used Temperature Scales. State their Inter-Conversion formulae.

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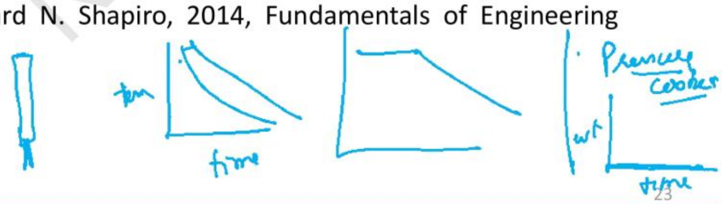

So, to conclude this lecture, what did we see in the two lectures? The first part is: what are the different types of thermal equilibrium we saw? Then, we saw what a reversible process and an irreversible process are. We discussed reversible and irreversible thermodynamic processes with their graphical representations, A to B and B to A. Then, we differentiated between reversible and irreversible processes.

Then, we saw four different types of cycles: the Rankine cycle. If you want to go by sequence: the Carnot cycle, Otto cycle, Diesel cycle, then we saw the Brayton cycle, and lastly, the Rankine cycle. So, we saw those cycles. Then, we went into the basics of the zeroth law. We saw what the zeroth law is, how we measure temperature using the zeroth law, what thermometry is, and the different types of temperature scales used in real-time and their state of conversion. So, these are the topics we covered in two lectures, and I am sure you have gained more insight into this process.

We are not going deeper into thermodynamics because it is the basics of mechanical engineering. So, we are superficially covering all the basic knowledge about these cycles. So, these are the books we have used for references. Now, let me give you some assignments, right? So, the first assignment is going to be: take a red-hot rod.

Basically, take a cold rod, heat it in the burner of your kitchen—but do it with care—and then see how the temperature reduces over time. If you have a physical thermometer to touch and measure, fine. If not, you can try to say, 'Oh, reddish-red hot,' 'blue is green,' 'greenish-blue,' whatever it is, and then you can say 'room temperature.' So, you can see how it reduces. Does it reduce in an exponential way? Does it reduce in a linear way?

Does it follow a bilinear fashion? You have to understand that. Please do this exercise. Then, you will understand the importance of temperature. The next thing is think about it.

I am using a flat surface. There is a flat surface. This flat surface is trying to have a very high temperature on its surface. There is a very high surface. Assuming that this is a tile when the tile is approaching from moon back to earth. So, there is lot of heat going to be generated.

Now, my question is which will be the best temperature measuring device to get the overall temperature of this tile? And, I would like to have the contour of this tile heat rejection, understood. So, that means to say, from 10 kilometers it is coming down to earth. So, it is dropping from there, it is a tile, it is a surface.

It is a tile, which is coming from here. So, now, I am asking you please measure the temperature. And, also try to tell me whether the temperature of the flat plate is all along constant or is there any variation? And, if there is variation, how will be the variation? You cannot measure it, but you can speculate and see.

The third interesting thing I wanted to tell you is to try taking a pressure cooker in your kitchen, fill it with water, and start heating it. Note down the response of the pressure cooker with respect to time. At some point, the heat will rise and convert the water into steam. Because it is a constant volume, the steam will keep increasing. At some point, the weight or mass you put on top will be lifted.

I would like you to plot the activities. When will the weight be lifted with respect to time, and what phenomena are happening in real time regarding the weight lift? Of course, you cannot see inside the cooker, but you can sense it through the sound it generates. When you boil milk, you also hear that 'bulak bulak bulak' sound, right? That means there is nucleation. Heat comes, convection happens, nucleation occurs, and then it tries to escape.

Then, the temperature rises. So, friends, I request you all to do these experiments yourselves. Think and then try to tell us the outcomes of these observations. The assignment I gave for TS and PV for the Brayton cycle and Rankine cycle will be discussed during the tutorial. Please draw it.

If you are having a problem, you will get it clarified during the tutorial.

Thank you very much.