

Basics of Mechanical Engineering-3

Prof. J. Ramkumar

Prof. Amandeep Singh Oberoi

Department of Mechanical Engineering

Indian Institute of Technology, Kanpur

Week 01

Lecture 02: Thermodynamic System

Welcome to the second part of Introduction to Thermodynamics. In the first lecture, we saw some fundamentals. We will continue to see some more fundamentals in this lecture.

Thermodynamic System



- Thermodynamic systems are “regions in space whose **thermodynamic properties are of interest**”.
- It is the part of the universe that is separated from the surrounding by real or hypothetical **boundaries**.
- The surrounding contains everything other than the **system**, including other thermodynamic systems.

In simple terms:

Universe = System + Surrounding

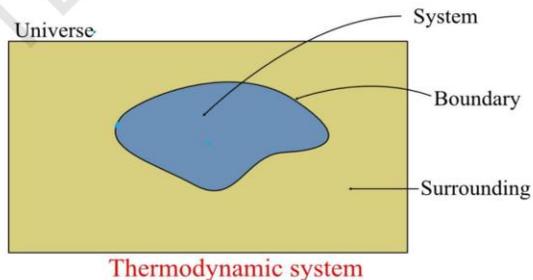
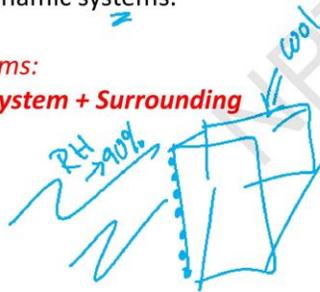
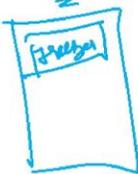


Image Source: <https://www.eigenplus.com/types-of-thermodynamic-system-definition-examples/>

3

Let us understand what a Thermodynamic System is. A system means it is a large box, right? For you, in an analogy sense, a system means something like an AC unit. It is a system, right? So, a Thermodynamic System will have many ingredients in it. So, let us see what they are. Thermodynamic systems are regions in space whose thermodynamic properties are of interest.

If I am going to talk about a building, Inside a building, I am going to place a refrigerator in a corner. My interest is only in the refrigerator corner. So, then what do I do? I try to talk about the thermodynamic properties in the area of interest.

So, when you try to expand, you can try to take a larger room, like an AC room. That is also okay. It is a part of the universe that is separated from the surroundings by real or hypothetical boundaries. So, you can see here, this is a system. This system is separated from the universe by a boundary.

So, that is the limitation you see. So, surrounded by real or hypothetical boundaries. For example, if I have a refrigerator, then this box becomes a boundary to the rest of it. And why is it important? Let me tell you.

Suppose, let us assume this portion is a cold portion. And then you have air coming from outside. This air has a relative humidity of maybe 90%. That means there is a lot of water in the surrounding air. When it touches the cool system, it tries to condense and form droplets.

This phenomenon you will try to see when you take a glass tumbler, fill it with cold water, and observe around the boundary. You will see droplets of water condensing. So, this boundary is very important. If you insulate the boundary, you get different performance. If you do not insulate the boundary, there are losses. So, these thermal losses will lead to energy inefficiency.

So, the boundary is also very important. So, it is the part of the universe separated from the surroundings by either real or hypothetical boundaries. The surroundings contain everything other than the system, including other thermodynamic systems. For example, in a refrigerator, you focus only on the freezer. If our focus is the freezer, then everything outside the freezer boundary is called the surroundings. So, in simple terms, the universe equals the system plus the surroundings.

Thermodynamic System

1



- The nature of its wall characterizes any thermodynamic system. These walls can be purely hypothetical when describing them as permeable to all matter, radiation and energies. Or it can be real, which is made of some matter.

The boundary of any thermodynamic system can be classified into two types, based on their ability to move:

- 1 **Fixed boundary** *When the system's boundary can not move and remains rigid.*
- 2 **Movable boundary** *When the boundary of the system can move.*

Other than the above classification, the boundaries can also be of these two types:

- 1 **Real boundary**: A tangible separating wall that separates the system from the surrounding.
- 2 **Imaginary boundary**: There is no real separation between the system and surroundings; there is just a hypothetical wall separating the system from surroundings.



4

The nature of its wall characterizes any thermodynamic system. You can insulate it or leave it open. These walls can be purely hypothetical when described as permeable to all matter, radiation, and energy, or they can be real, made of some material. For example, you can fix thermocol around the glass to insulate it.

The boundaries of any thermodynamic system can be classified into fixed boundaries and moving boundaries. Fixed boundaries and moving boundaries are very important because later, when you go for higher-end computations or higher-level courses, they will always discuss fixed boundaries and moving boundaries. So, when the system boundaries cannot move and remain rigid, they are called fixed boundaries. For example, a freezer has fixed dimensions. So, the freezer is a fixed boundary.

A movable boundary is when the boundary of the system can move. For example, if you have a car traveling at a certain speed, assuming there is a hot body surrounding the car, the car is moving very fast. So now it becomes a moving boundary. So, these two cases are completely different. For example, you try to take a hot rod.

You keep it in its current condition. You will observe when the red-hot rod becomes cool. The other way around, you just sweep it or move it through free air. You will see the hot rod will cool down very fast. Now what you do is take the hot rod and immerse it inside an ice pack.

You will see what the performance is. And the last thing is, you try to do it while moving and try to do it on a cold winter day. You will see what the performance is. So, the moving boundary creates a completely different phenomenon. Other than the above classification, there are two more classifications.

So, they are nothing but real boundary and imaginary boundary. A tangible separation wall that separates the system from the surroundings is a real boundary. So, fixed boundary, moving boundary condition, then real boundary condition and imaginary condition. Why is this imaginary boundary very important? Because you cannot simulate the complete system.

So, what do we do? We try to take a small unit cell, simulate that unit cell, and then find out what the response is. So, what do we do there? We try to use an imaginary boundary condition. There is no real separation between the system and the surroundings. There is just a hypothetical wall separating the system from the surroundings. You have a body, so now what is happening?

You are there and then you have a boundary, right? You have a boundary. So, that is how the thermal imaging works. When you try to see, use a thermal imaging, our body radiates heat, right? When it radiates heat, when you try to take an image, you will see a boundary which is there, which can radiate heat.

You will see a red hot boundary around me. So, that is real. Imaginary is you are trying to introduce something and where in which you can try to put a boundary condition. You can try to say, okay, the heat is getting dissipated at some rate, you can try to say. So, these are four very important things you should understand.

So, there are different types of thermodynamic systems. So, here with the thermodynamic system, so we saw. This is a system so universe is nothing but system plus the surrounding. Now, what are we trying to do? We are only first trying to understand what is this boundary.

Types of Thermodynamic System



- Thermodynamic systems are the regions in space that are separated by boundaries.
- And the nature of these boundaries defined how mass and energy transfer across the thermodynamic systems and boundaries.

Every thermodynamic system in the universe can be classified into three types:

1. Open system:

If the thermodynamic system can exchange both matter and energy with its surrounding.

2. Closed system:

If the thermodynamic system can exchange only energy with its surrounding.

3. Isolated system:

If the thermodynamic system can neither exchange matter nor energy with its surrounding.



Now, we will try to look at the system itself. There are three different Types of Systems. So, the thermodynamic systems are the region in space that are separated by boundaries which we have clearly established. Again here boundaries four different types. And the nature of these boundaries define how mass and energy transfer across the thermodynamic system and the boundary happens.

The boundary, because this fellow is the separation between the system and the surrounding. So now, the nature of the boundary defines how mass and energy transfer, heat and mass transfer, mass and energy transfer happens between the system and the surrounding. Every thermodynamic system in the universe can be classified into three types. Open Type, Closed Type and Isolated Type. Predominantly, you can have subsystems in it, right? Open system, if the thermodynamic system can exchange both matter and energy with its surrounding, then it is called as a open system.

We will see the example in the next slide. What is a closed system? Closed system means the thermodynamic system can exchange only energy with its surrounding. That is closed. Open system is both matter and energy.

Closed system is only energy. And the isolated system is there can neither be a transfer of matter nor energy is called as isolated systems. Why are the three important? Because when you are trying to work on very low temperatures, we always look forward for an

isolated system. We always look forward because now there are a lot of reactions which happen at very low temperatures.

There is martensite, when you do heat transfer, there is a big heat treatment process which is happening. When you go below the room temperature, you go down sub-zero, you go there and you try to do heat treatment. It tries to help in freezing the microstructure. So, we go for 90% isolated system. So, there are three different types of system, open system, closed system and isolated system.

Types of Thermodynamic System



Type of system	Matter Interaction	Energy Interaction
Open system	Yes ✓	Yes ✓
Closed system	No ✓	Yes ✓
Isolated system	No ✗	No ✗

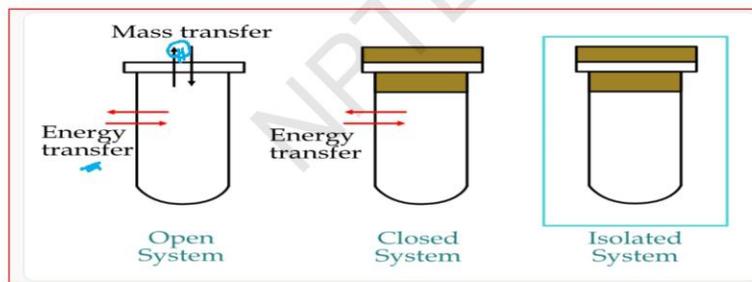


Image Source: <https://www.eigenplus.com/types-of-thermodynamic-system-definition-examples/> 6

So, we will try to see the example. If you try to see that system, open system, closed system, isolate, then matter interaction, yes, and in closed system, no, and isolation also, no. So, in the open system, when you talk about energy, yes, and in closed system, we talk about energy, yes, and isolated system, both are no. This and this are no. So, what is the mass transfer, what is energy transfer?

Mass transfer is—suppose, let us assume you have a cooker, a Prestige cooker or a pressure cooker. When there is a weight sitting on top of it, the pressure goes very high, there is a push that happens, and then there is mass that is moved. So, that is mass transfer. So, energy transfer is the higher temperature to lower temperature, where there is a transfer of energy happening.

Open System ✓

- In an open system, **matter** and **energy** can transfer between the system and the surroundings. For such systems, the boundary that separates the system and surroundings allows matter and energy to pass through it.
- Open system is also termed as **control volume analysis**.
- **For example**, in tea in a cup, the vapors of heat can go outside the cup and the heat is transferred through its boundaries.
- Another example is the human body; we are an open system because we take energy in the form of radiation and also exchange heat with our surrounding through our skin. And to survive, we eat, i.e., the matter enters and exits our body.



So, an open system is one where matter and energy can transfer between the system and the surroundings. For example, take a tawa or a pan. You apply energy and you put matter. So, for such systems, the boundaries that separate the system and the surroundings allow matter and energy to pass through. For example, tea in a cup—where vapor and heat escape outside the cup, and heat is transferred through its boundaries—is a typical example of an open-loop system. So, a tawa, whatever you use, is also an example of an open-loop system.

Another example is the human body. We are an open system because we take energy in the form of radiation and also exchange heat with our surroundings through our skin. To survive, we eat—matter enters and exits our body. These are very crude examples, but just for your understanding, I have given two examples for an open system: one is a teacup, and the other is the human body. So, the human body radiates. That is why we always insist that when you are sleeping at night, you should try to maintain a temperature of 24 or 25 degrees Celsius. Because our body operates at 32 to 34 degrees Celsius, if the room temperature is 18 degrees Celsius, then so much work has to happen through the skin, and that will make you tired.

So, in order to have a cool setting, we are expected to set the AC temperature to 24. That is what the Government of India has also given under the energy initiative schemes, okay. Because we take energy in the form of radiation and also exchange heat with our

surroundings through our skin, right. So, your temperature is high. The external temperature in an AC room, 18 degrees, is very low. So, you start rejecting heat, okay.

Control Volume and Control Surface



- A large engineering problems involve mass flow in and out of a system and therefore, are modeled as control volumes.
- **Control volume** refers to a definite volume on which attention is focused for energy analysis.
- **Examples:** Nozzles, Diffusers, Turbines, Compressors, Heat Exchanger, De-superheater, Throttling valves, I.C engine etc.

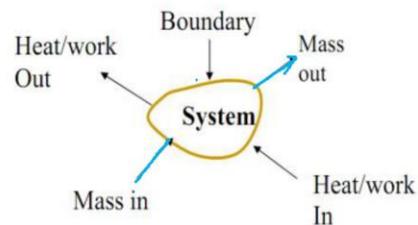


Image Source: <https://www.eigenplus.com/types-of-thermodynamic-system-definition-examples/>

8

A Controlled Volume and a Controlled Surface. A large engineering problem involves mass flow in and out of the system and is therefore modeled as controlled volumes. Any engineering system will always try to be modeled as a controlled volume system. A controlled volume refers to a defined volume on which attention is focused for energy analysis. So, you have a system. You have a system. There is a boundary. There is a mass in. There is a mass out.

Then there is a heat in. There is a heat out. So, this is a system. So, we try to call it as controlled volume. What are the examples? Example is nozzle diffuser. Nozzle is focusing. You have something coming up. So, you try to focus through the nozzle, increase the pressure. The area is small, the volume is constant, so you pressurize it, so you get a higher pressure air or water coming out.

Diffuser is vice versa. Turbines, compressor, heat exchanger, these super heaters and then throttle valves, IC engines, all these things follow controlled volume. What is controlled surface?

Control Volume and Control Surface



- **Control Surface:** The closed surface that surrounds the control volume is called Control surface.
- **Mass as well as energy crosses the control surface.**
- **Control surface can be real or imaginary.**

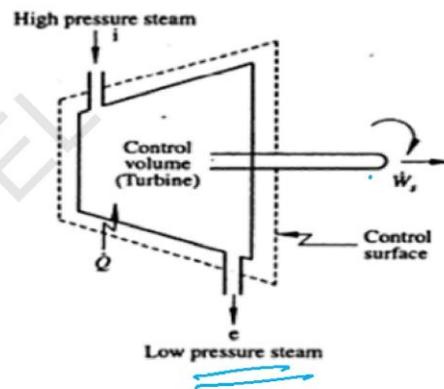


Image Source: <https://www.eigenplus.com/types-of-thermodynamic-system-definition-examples/> 9

The closed surface that surrounds the control volume is called as the controlled surface. So, you have a control volume, a turbine is there and then you try to close it. So, then there is a Q which goes there. So, then it tries to do a work and C comes out of it. So, control surface; The closed surface that surrounds the control volume is called as the control surface. Mass as well as energy crosses the controlled surface. Please keep that in mind.

So, turbine generally we will see little later. Turbine is what happens is you try to push a high pressure. That is what a nozzle is used, high pressure steam is pushed. So, then there is a turbine blade. So, that tries to rotate because the pressure is very high as and when the work is done the pressures fall down. So, then it is what it exceeds out is called as low pressure steam. So, high pressure steam it rotates. If the pressure or the steam the weights of the water which comes inside is very high, then the amount of energy which can be transferred to the turbine is very high.

So, accordingly the shafts will rotate very high. So, you generate electricity or you generate whatever it is accordingly, right. The control surface can be real or imaginary. Control volume and control surface. Now, let us go into Closed System. Where are we coming? So, open system, we saw a tawa. You saw a pan. So, this pan can be dosa pan or it can be pan for frying. Everything it can be there. So, that is what it is, or it can be a cup of coffee. It is a open system.

Closed System

- A closed system can only exchange **energy** with the surroundings and can not transfer matter through its boundaries. For such a system, the **mass of the system remains constant**. And the boundary is real, but it can be movable or rigid.



- **For example**, when the cap is present in the water bottle, it behaves like a closed system.
- A system can also change its type with time.
- For example, in the case of car or bike engines, when fuel enters into the piston-cylinder arrangement, we can say that the piston-cylinder arrangement is an open system. But the same system becomes a closed system when the piston is moving in forwarding and backward stroke.

Now, let us see Closed System. Closed system can only exchange energy with the surrounding and cannot transfer matter to its boundary. So, you have a pan. Put a lid on the pan.

A closed system can only exchange energy with the surrounding and cannot transfer matter through its boundaries. For such a system, the mass of the system remains constant. And the boundary is real, but it can be movable or rigid. The boundary is real in a closed system. For example, when a cap is present in the water bottle, it behaves like a closed loop system.

Or you try to buy a Starbucks coffee where you put a lid. It's a closed-loop system. Here also, you can try to take it to the analogy of an open loop, but an open system, but just give an example of a closed system. So, a system can also change its type with time. A system can also change its type with time.

So, open system, closed system. For example, in the case of a car or a bike engine, when fuel enters into the piston-cylinder arrangement, we can say that the piston-cylinder arrangement is an open system. But the same system becomes a closed system when the piston is moving in a forward or backward direction. Very important. Please try to see the difference between an open system and a closed system.

When the fuel enters into the piston-cylinder arrangement, we can say the piston-cylinder arrangement is an open system. What is an open system? An open system means it is here. There is a matter interaction. There is an energy interaction.

But the same system becomes a closed system when the piston moves in forward and backward strokes. So, what is a closed loop? Go back. A closed loop has no matter interaction, but energy interaction, yes. So, a system can move from open to closed, or closed to open.

Isolated System

- Isolated systems are those systems in which neither matter nor energy can transfer from the system. For these systems, the total energy remains constant.
- For example, the universe is the most common example, where the energy remains constant.**
- Thermos-flask can also be considered an isolated system if it is completely insulated.

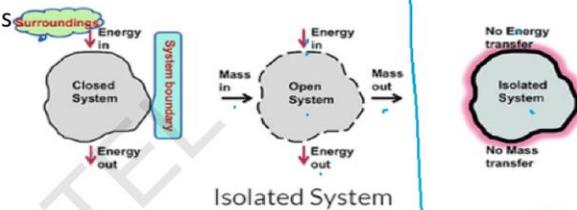


Image Source: <https://www.eigenplus.com/types-of-thermodynamic-system-definition-examples/> 11

What are isolated systems? Isolated systems are those in which neither matter nor energy transfer happens. For these systems, the total energy always remains constant—a closed loop system: energy in, energy out. So, this is a system boundary. So, you can see here: mass in, mass out, energy in, energy out—this is an open system.

Here, in the closed loop system, there is no energy transfer or mass transfer happening, but it is still a system. For example, the universe is the most common example where energy always remains constant. Now, you can clearly distinguish between an open system and an isolated system. Mass in, mass out, energy in, energy out. No energy transfer, no mass transfer—that is an isolated system.

Isolated System: Thermo Flask



Thermos flask is an Isolated system.

- It is a type of insulating storage vessel that keeps a hotter or cooler item at its respective temperature for a long time.
So, the Thermos flask is an Isolated system.

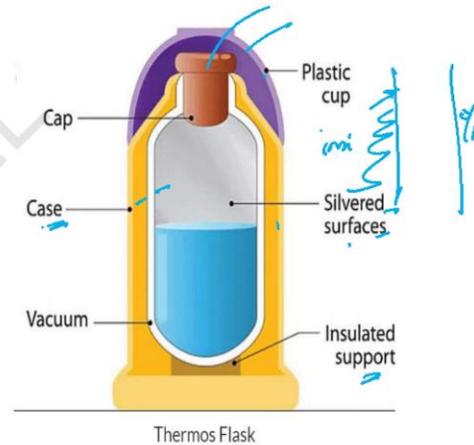


Image Source: <https://www.eigenplus.com/types-of-thermodynamic-system-definition-examples/> 12

A thermo flask can be considered an isolated system if it is completely insulated. So, if you pour water inside a thermoflask and keep it for long or put ice in it and keep it for long, it is considered an isolated system. Whereas, when you try to put the same ice in a glass tumbler, it becomes an open system. So, isolated system: thermoflask. A thermoflask is an isolated system.

It is a type of insulated storage vessel. It keeps hotter or colder items at their respective temperatures for a longer time. So, you can see here the thermoflask, whatever thermoflask we use, will have a cover on top, then you will have a cap. So, this cap and the cover help ensure that there is no heat loss. Then, there is a glass, right? The glass that is there is called a silvered surface.

So, inside the silvered surface, you pour the content, whatever it is—coffee, tea, or whatever. This silvered surface is again placed in a case. So, you doubly ensure that from the silver case, there is a lot of reflection happening, and nothing goes out. And if anything does go out, there is an insulating case that prevents it. Between the silvered surface, you also have two layers. One layer and the second layer, right?

So, this is something like these two walls. So, this is inside; this is outside. So, between these, they also try to create a vacuum so that there is not much heat loss. So, there is a vacuum. That is what we call a vacuum, and then we also have an insulating support so that it is a little above the base. So, this is a completely isolated system.

So, there is no mass transfer, and there is no energy transfer. It is a type of insulating storage vessel that keeps hotter or colder items at their respective temperatures for a longer time. So, it is an isolated system. If you keep the lid open—this lid and this lid open—then it becomes an open-loop system. So, think about it. Can you make it a closed-loop system? Just think about it.

Thermodynamic Properties



- Any observable characteristics required to describe the conditions or state of a system is known as Thermodynamic property of a system.
- Specific property = Extensive property/mass.**
- Examples:**
 - Specific volume (v) = Volume (V)/mass(m)
 - Specific enthalpy (h) = Enthalpy(H)/mass(m)
 - Specific entropy (s) = Entropy(S)/mass(m)

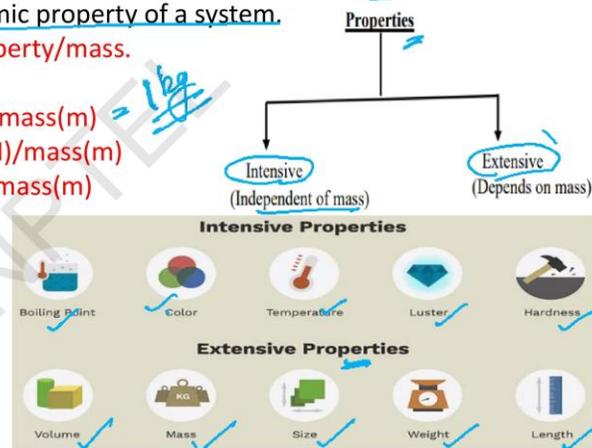


Image Source: <https://www.eigenplus.com/types-of-thermodynamic-properties-definition-examples/>

13

Now, let us get into Thermodynamic Properties. Any measurable characteristics required to describe the condition or state of the system are known as thermodynamic properties of a system. So, there are two things.

The observable characteristics required to determine the condition—hot, cold, condition, or state of the system—are known as thermodynamic properties of the system. So, we use some of the properties.

Extensive Properties



Extensive properties do depend on the amount of matter that is present.
An extensive property is considered additive for subsystems.

Examples of extensive properties include:

- Volume
- Mass
- Size
- Weight
- Length
- Energy

$$\begin{array}{ccccccc} v/m & ; & v/s & ; & v/wt & ; & v/L & ; & v/E \\ w/L & & w/E & & w/m & & & & \end{array}$$

- The ratio between two extensive properties is an intensive property. For example, mass and volume are extensive properties, but their ratio (density) is an intensive property of matter.



A specific property is nothing but an Extensive Property divided by mass; that is called a specific property. Some of the examples are: specific property—when you replace it with volume, enthalpy, or entropy. So, every time it will be divided by whatever the property is, divided by mass. That is what we have said.

So, specific volume means it is volume divided by mass. So, you try to keep 1 kg of something, like ice. You keep 1 kg fixed. So, then you can try to have a different volume. The same applies to enthalpy.

The same applies to entropy. So, henceforth, you should keep in mind: V represents volume, H represents enthalpy, and S represents entropy. So, small 'v' means specific volume. A capital 'V' means volume. A capital 'H' means enthalpy, and a small 'h' means specific enthalpy. A capital 'S' means entropy, and a small 's' means specific entropy. So, you should keep this in mind when we use the convention. When we talk about properties, there are two types of properties for any given material.

Intensive Properties



Intensive properties are bulk properties, which means they do not depend on the amount of matter that is present.

Examples of intensive properties include:

- Boiling Point; Density; State of Matter; Color;
 - Odor; Melting Point; Temperature; Refractive Index;
 - Lustre; Hardness; Ductility; Malleability
- Each of these qualities remains the same for a substance no matter its quantity.

For example, Regardless of whether you have 2 or 2,000 liters of water, the boiling point will always remain 100 degrees Celsius.



One is called as intensive property. The other one is extensive property. Intensive properties are properties which are independent of mass. Independent of mass is intensive properties. Extensive properties are dependent on mass.

So, intensive properties are color, temperature, boiling point. They do not depend on the mass. The luster, the hardness, they do not depend on the mass. You can have a small item, you can have a large item. The hardness will be same.

You can have a boiling point. You have a small, you put 1 kg of wax or 10 kg of wax, the boiling point is the same. When you try to do extensive properties, these are nothing but volume, mass, size, weight, length. These are all extensive properties where it depends on the mass. Please try to understand Specific Properties, Intensive Properties and Extensive Properties.

Extensive properties do depend on the amount of matter that is present. An extensive property is considered additive for subsystems. Volume, mass, size, weight, length, energy. The ratio between two extensive properties is an intensive property. Volume by mass, volume by size, volume by weight, volume by length, energy.

Length by energy, length by weight. So, when we talk about it, two extensive properties when you try to take a ratio. So, volume by mass, volume by size, volume by weight,

volume by length, volume by energy. Or you can try to have weight by length, weight by energy, weight by mass. So, you can see that.

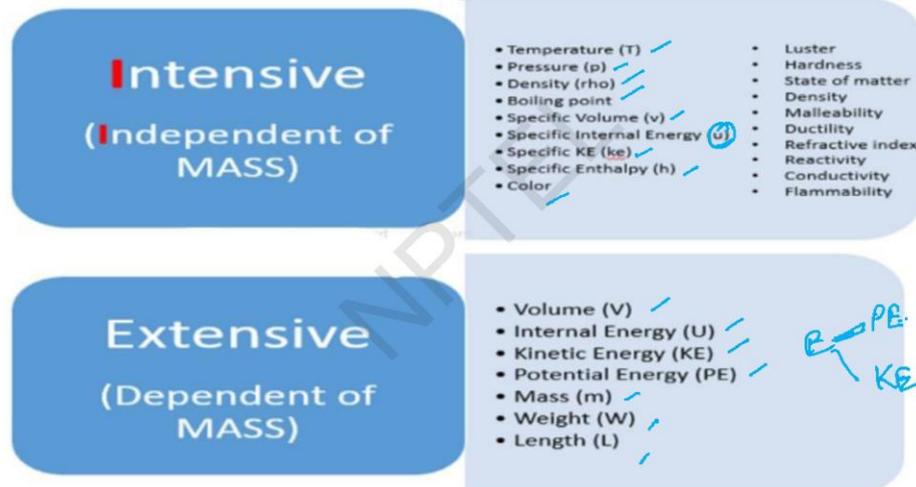
So, the ratio between two extensive properties is an intensive property. For example, mass and volume are extensive properties, but the ratio density is an intensive property. What is intensive? Which does not depend on the mass, independent of the mass. Intensive properties.

Intensive properties are bulk properties, which means they do not depend on the amount of matter present. For example, boiling point, odor, luster, density, melting point, hardness, state of matter, temperature, ductility, color, refractive index, malleability. All these things are intensive properties. The ductility of a given material. You can draw a wire.

Malleability means you can draw it into a sheet. That does not depend upon the mass. So, that is what intensive properties are. Let it be 2 liters. Let it be 20 liters.

Let it be 200 degrees Celsius. Let it be 100 degrees Celsius or 30 degrees Celsius. The boiling point will remain 100 degrees Celsius for a given item.

Intensive and Extensive Properties



Extensive v/s Intensive Property



Extensive Property	Intensive Property
Extensive properties are dependent on the mass of a system.	Intensive properties are independent of the mass of a system.
Extensive properties are additive. Its value for an overall system is the sum of its values for the parts into which the system is divided.	Intensive properties are not additive. Its value remains the same whether one considers the whole system or only a part of it.
Examples: Mass(m), volume(V), Energy(E), Enthalpy(H) etc	Examples: Pressure(P), Temperature(T), Density(ρ) etc
Uppercase letters are used for extensive properties except mass.	Lowercase letters are used for intensive properties except pressure(P) and temp.(T)



So, these are intensive and extensive properties. So, what are the overall properties? So, the most important ones are T, P, and rho. T is temperature, P is pressure, rho is density, boiling point, specific volume, specific internal energy is always represented by U, then you have specific kinetic energy KE, enthalpy as a small h, and color.

When we look into extensive properties, volume, internal energy, kinetic energy, potential energy—so energy has two things. One is PE, which we have seen already, and one is KE. So, energy, then you have potential energy, kinetic energy, mass, weight, and length. So, let us see the comparison between extensive property and intensive property. Why is it very important?

Because many times when a conversation happens, people try to mix up extensive with intensive properties. So, you should be very clear. When you solve the problem, you should also know we are trying to use this. Maybe in the examination hall, I would have given an extensive property, and you derive it to get an intensive property so that then you can try to solve the problem. So, extensive properties are dependent on the mass of the system.

They are additive. Their value for an overall system is the sum of their values for the parts into which the system is divided. The examples are mass, volume, energy, and

enthalpy. Uppercase letters are used for extensive properties except mass. When we go for intensive, these properties are independent of the mass of the system.

These properties are not additive. So, here it is additive, here it is not additive. Its value remains the same whether one considers the whole system or only a part of a system. Please understand these two properties are very very important for you. So, you try to take a total Dabba, inside you take one unit.

It is the same. So, it remains the same whether one considers the whole system or only a part of the system. Pressure, temperature, density are part of it. Lower casing are used to do intensive properties except pressure and temperature. Now, let us move into the other basic concepts.

Thermodynamic State, Path & Processes



State:

- It is the condition of a system as defined by the values of all its properties.
- It gives a complete description of the system.
- Any operation in which one or more properties of a system change is called change of state

Path and Process:

- The series of state through a system passes during a change of state is Path of the system
- If the path followed by the system during change of state is specified or defined completely, then it is called a process.

Thermodynamic state, Path and Processes. So, thermodynamic state is very important. Path and Process is very important when you look at cycles and other things. So, let us understand what is a state. It is the condition of a system as defined by the values of all its properties is called the state.

It gives a complete description of the system is the state. Any operation in which one or more properties of the system change is called as the change of state. From one to the other is called as change of state. For example, solid to liquid, change of state, right? So, it is the condition of a system as defined by the values of all its properties is the state.

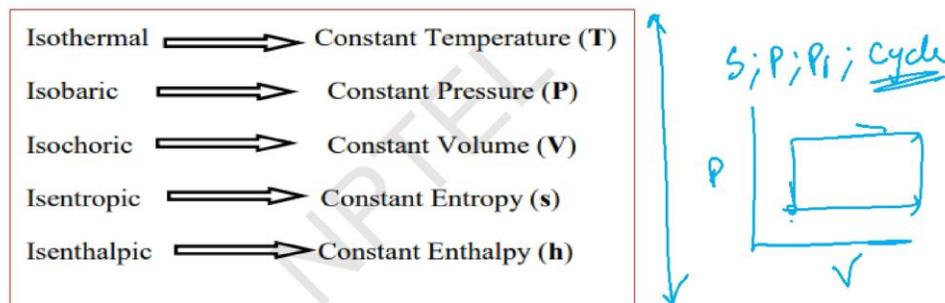
It gives a complete description of the system. Any operation in which one or more properties of a system changes is called as change of state. Path and process: A series of state through a system passes during a change of state is the path of system. If the path followed by the system during the change of state is specified or defined completely, then it is called as a process. So, for example, solid to liquid.

So, if the path followed by the system during the change of state is specified or if it is clearly defined, then it is called as a process. So, paths and process are linked. A series of state through a system passes during a change of state is path. So, you should clearly understand the difference between state, path and process because this will be used later while solving problems. We can allow one of the property to remain a constant during a process.

Thermodynamic Processes and Cycle



We can allow one of the properties to remain a constant during a process.



- **Cycle:** When a system in a given initial state undergoes a series of processes and returns to initial state at the end of process, then the system is said to have undergone a thermodynamic cycle.

Now, we are trying to look at process. Now, from a process we will go to cycle, so that we will see later. So, is that clear? Path, process. If the path followed by the system during change of state is constant or is specified, then it is called as process.

So, now we can allow one of the properties to remain constant during a process. For example, isothermal. One of the property you should understand. Constant during the process. What is the process? You have understood process here.

So, for a process you should understand the path, right? So, isothermal, when we say isothermal process, then that means to say there is a constant temperature. Isobaric means constant pressure. Isochoric means constant volume. Isoentropy means constant entropy.

Isoenthalpic means constant enthalpy. So, these are some of the most important properties you should understand. Isothermal, isobaric, isochoric, isentropic, isenthalpic. A cycle. So, now state is done, path is done, process is done. Now, we are trying to see a cycle.

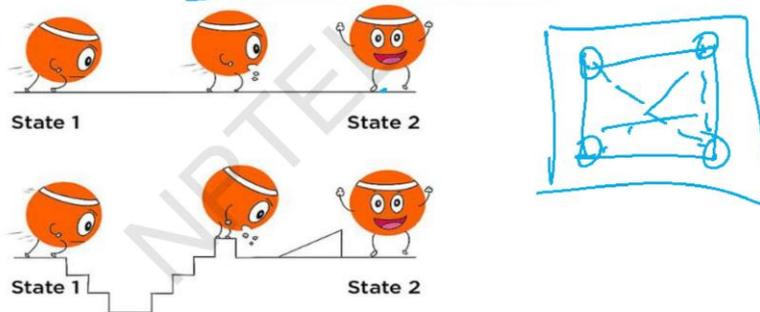
Cycle: When a system in a given initial state undergoes a series of processes and returns to the initial state at the end of the process, then the system is said to have undergone a thermodynamic cycle. For example, it starts from a solid, goes to a liquid, then from a liquid it goes to a gas, and at the end of the process, if it comes back to a solid, that is called a thermodynamic cycle, right?

Or you can have a cycle in a P-V diagram; you can have pressure and volume, and you can try to have something where the process goes this way, and comes back to the starting point. When the system in a given initial state undergoes a series of processes, what is a process? I am redefining. If a path followed by a system during a change of state is specified, then it is called a process, right? So, this is a cycle.

State and Path Function



i) State Function: A property whose value doesn't depend on the path taken to reach that specific value is known to as a state function or point function.



State functions are systems where only the start and end points matter rather than the path taken

State and Path Function. State function means a property whose value does not depend on the path taken to reach that specific value is known as a state function or a point function. From 1 to 2, from 1 to 2 it goes, right.

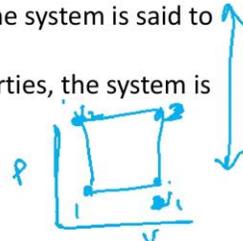
So, a property whose value does not depend on the path. This path taken to reach that specific value is known as a state function or a point function. So, it can go through stages like this, it can go through a staircase effect like this, it can fall up and down, it can lose energy, but finally, it is called a state function. A state function is a system where only the start and end points matter rather than the path. So, it is like your drilling experiment. You have a hole to be made here, a hole to be made here, a hole to be made here, and here.

So, you have to make four holes. So, it is least bothered how you go. You can go like this, this, this, this, or you can go like this, then from here you can go like this, then you can come like this and finish. So, the state function is a system where only the start and end matter; the in-between part does not matter. That is a state function.

State and Path Function

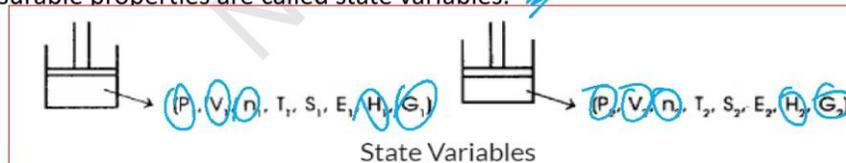


- When macroscopic properties of a system have definite values, the system is said to be in an indefinite state.
- Whenever there is a change in any one of the macroscopic properties, the system is said to change into a different state.
- Thus, the state of a system is fixed by its macroscopic properties.



State Variables

- The state or condition of a system is described by certain measurable properties & these measurable properties are called state variables.



Whenever there is a change in any one of the macroscopic properties, the system is said to change into a different state. Thus, the state of the system is fixed by its macroscopic properties.

Clear? This is very important. The State Variables: Let us understand what the different types of state variables are. The state or condition of a system is described by certain measurable properties, and these measurable properties can be defined as state variables. Whichever parameter you can measure is called a state variable.

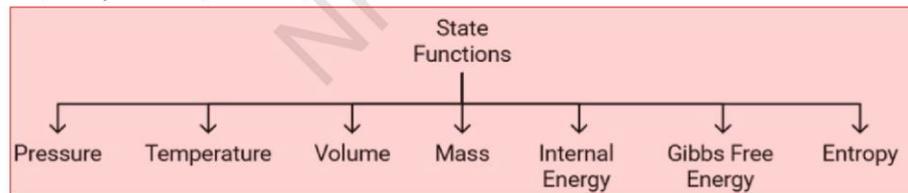
Pressure, volume, whatever temperature, enthalpy, all these things if you can measure it is there. So, it goes from P_1 to P_2 , V_1 to V_2 , n_1 to n_2 , G_1 to G_2 , H_1 to H_2 . So, you can see all these things. So, state variables: The state or the condition of a system is described by a certain measurable properties and these measurable properties are called as state variables. Because later when you try to work on PV diagram, basically when you try to take an IC engine, there is a play up between pressure and volume. So, then you will try to move your graph from one position to other position to other position to other position, you will try to move.

When you try to move, so then you will try to measure the state variables. So, what happens this is P_1 , this is 2, this is 3, this is maybe 3, you can say 1, this is 2, right. So, the pressure will be the same, the volume increases. So, $P_1 P_2 V_1 V_2$.

State Functions



- State variables or the thermodynamics parameters depend only upon the initial and final states of the system and are independent of how the change is brought are called state functions.
- **Note:** State function depends only on the initial & final state of the system. It does not depend on the path or how the process was carried out.
- Some common state functions are internal energy, enthalpy, entropy, free energy, pressure, temperature, volume, etc.



The state variables or the thermodynamic parameters depend not only on the initial and the final stage of the system and are independent how the change is brought are called as the state function.

So, now state variable: Measurable quantities are state variable and state functions are the independent, so are state variables or thermodynamic parameters depend only upon the initial. It is not only, it is depend only upon the initial and the final state of the system and are independent how the change is brought is called as a function.

Note, state function depends only on initial state and final state of the system. It does not depend on the path or how the process was carried out. So, some common state functions are internal energy, enthalpy, entropy, free energy, pressure, temperature, volume, etc., So, the state function is very clear. The definition for state functions is that they are independent of how the change is brought about and are called state functions.

State Functions



- **Pressure:** Pressure is a measure of the average force exerted by the constituent molecules per unit area on the container walls. Pressure does not depend on the path of the molecules and thus it is a state function.
- **Temperature:** Temperature is defined as the measure of the average kinetic energy of the atoms or molecules in the system. Temperature measures a property of a state of a system irrespective of how it got there and thus it is a state function.
- **Volume:** Volume is the amount of physical space occupied by a substance and it will not be dependent on the path followed. Thus, the volume is a state function
- **Mass:** The measure of the amount of matter in an object is known as mass and is usually measured in grams (g) or kilograms (kg). Mass measures the quantity of matter regardless of both its location in the universe and the gravitational force applied to it and thus it is a state function.

So, these are different types of state functions. So, pressure, denoted as P, is nothing but the force acting per unit area. It is a measure of the average force exerted by the constituent molecules per unit area on a container wall and is called pressure. The pressure does not depend on the path of the molecules; thus, it is a state function. What is a state function?

We have defined it here. A state function is independent of how the change is brought about. Temperature is defined as a measure of the average kinetic energy of the atoms or molecules in a system. Temperature measures a property of a state of a system, irrespective of how it got there, and thus it is called a state function. The temperature is 32 degrees Celsius.

It does not say I moved from 25 degrees Celsius to 32. No. So, that is what temperature is defined as: a measure of the average kinetic energy of the atoms or molecules in a system. Volume is the amount of physical space occupied by the substance and does not depend on the path followed. Thus, volume is a state function.

Mass, the measure of the amount of matter. Here, the space, here it is the amount of matter in an object is called the mass and is usually measured in grams or in kilograms. Mass, measures the quantity of the matter regardless of both its location in the universe and the gravitation force applied on it. Thus, it is called as a state function. I am trying to tell you what are all the state functions.

State Functions



- **Internal energy:** It can be defined as the sum of all kinds of energy associated with molecular motions. The internal energy of ideal gases is a function of temperature only (Joule's law) and the internal energy of real gases is a function of temperature, pressure, and volume. So it can be seen that since internal energy depends on quantities like P, T, V which are state functions, the internal energy is also a state function.
- **Gibb's free energy:** The enthalpy of the system at any point minus the product of the temperature times the entropy of the system is Gibb's free energy of the system $G=H-TS$. The Gibbs free energy of the system is a state function because it is defined in terms of thermodynamic properties that are state functions.
- **Entropy:** Entropy is the measure of imbalance in the system and it's totally independent of the path through which the system has achieved that state also it's unique to the current state of the system.

Then, it is internal energy. Internal energy is, it can be defined as a sum of all kinds of energy associated with the molecular motion. The internal energy of an ideal gas is a function of temperature only according to Joule's law. And, the internal energy of real gas

is a function of temperature, pressure and volume. So, it can be seen since internal energy depends on PVT which are a state function, the internal energy also is a state function.

So, we have seen PVTM, now we are seeing U, then we will see Gibbs free energy and then we will move to entropy and enthalpy. Gibbs free energy is the enthalpy of a system at any given point minus the product of the temperature times the entropy of the system is Gibbs free energy of a system. So, it is given as $G = H - TS$. So, it is given enthalpy of a system at any point minus the product of temperature and entropy of a system is nothing but Gibbs free energy of a system. The Gibbs free energy of a system is a state function because it defines the terms of thermodynamic property that are state function.

Entropy is a measure of imbalance in a system. It depends entirely on the path through which the system has achieved that state. It is also unique to the current state of the system. So, that is entropy. So, enthalpy, entropy.

Path Functions



Path Function depends on the initial as well as final state of a system and also depends on the path of the process followed.

Example: Heat and Work.

- Different paths give different values of the system.
- Path function requires multiple integrals and limits of integration to integrate the property.
- Depends on the specific process or path and work, Heat and other energy transfer forms.

After finishing the state functions, now let us examine path functions. A path function depends on the initial and final state of a system. It also depends on the path of the process that is followed. So, that is the path function. State function—I would just like to review.

So, you would have seen state functions: pressure, temperature, volume, mass, internal energy, enthalpy, entropy. You have seen all those things. Now, path function. So, what is an example? Examples of this are heat and work.

So, different paths give different values of the system. So, here I have written very clearly that it depends on the path of the process followed. So, a path function requires multiple integrals and limits of integration to integrate the property. I repeat, a path function requires multiple integrals. We are taking small, small steps and then doing it.

And limits of integration to integrate the property. It depends on the specific process or path and work. Heat and other forms of energy transfer. So, a path function looks into the initial, final, plus the path of the process. I hope you enjoyed this lecture.

Thank you very much.