

# Engineering Thermodynamics I

## Lecture 2

### Basic Concepts and Definition

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# ***Lecture learning outcomes:***

**At the end of this lecture, you will be able to:**

- i. Understand the concept of a system's thermodynamic **state**.
- ii. Explain the concept of **paths** between thermodynamic states and analyze different processes.
- iii. Differentiate the concepts of **reversible** and **irreversible processes**
- iv. Explain the significance of **pressure, temperature**, and other system properties.
- v. Use the **zeroth law of thermodynamics** to explain thermal equilibrium
- vi. Build a solid understanding that serves as a basis for exploring more complex thermodynamic laws and applications.

# Content

1. Thermodynamic State
2. Thermodynamic Path and Processes
3. Quasi-Static and Non-Quasi-Static Processes
4. Reversible and Irreversible Processes
5. Common Thermodynamic Properties
6. Zeroth Law of Thermodynamics

Summary

References

# 1. Thermodynamic State

- A thermodynamic state refers to the condition of a system at a specific point in time, described by its state properties, such as **pressure, temperature, volume,** and **composition** [1].
- These properties are **macroscopic** in nature and act as coordinates to describe the system.
- These properties **uniquely** define the state of the system when it's in **equilibrium**.
- The differences in thermodynamic states often depend on variations in the following properties.
  - Temperature difference
  - Pressure difference
  - Volume difference
  - Phase difference

# 1. Thermodynamic state

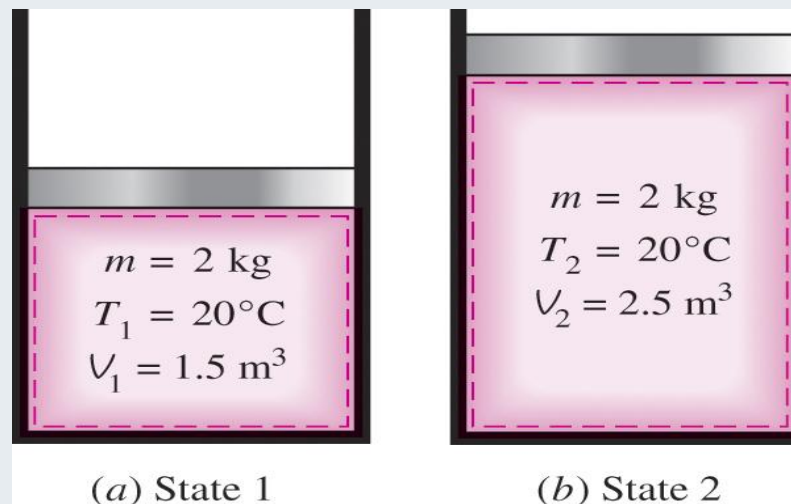
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- A substance can be at various **pressures & temperatures** or in various states.
- In a given state each property has **one value**.
- Thermodynamic state helps to illustrate changes or processes a system undergoes.
- Understanding thermodynamic states and how systems transition between them (thermodynamic processes) is essential in:
  - Engineering Design
  - Refrigeration and Heating
  - Material Science
  - Energy Systems
  - Chemical Reactions
  - Environmental Science

# 1. Thermodynamic state

Cont...

- A thermodynamic state is a **point function**. This means that the state of a system is defined by specific properties.
- **Point functions** are path-independent, focusing solely on the current conditions of the system rather than the process or path taken to arrive at that condition.



**Figure 1:** A system at two different states

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## The State Postulate

- The **state postulate** is a fundamental principle in thermodynamics, which states that the state of a thermodynamic system can be fully defined using a sufficient number of independent properties.
- For a single-phase system (such as a liquid or gas), typically **two independent properties** are enough to determine all other properties of the system, assuming the composition remains constant [2].

# 1. Thermodynamic state

Cont...

- The state of a simple compressible system in equilibrium is completely specified by **2** independent **intensive** properties [2].
- The state postulate is also known as **the two-property rule**. The state postulate requires that the two properties specified be independent to fix the state.



**Figure 2:** The state of Nitrogen is fixed by two independent intensive properties

[url:https://slideplayer.com/slide/9191840/27/images/16/The+State+Postulate+The+number+of+properties+required+to+fix+the+state+of+a+system+is+given+by+the+state+postulate+%3A.jpg](https://slideplayer.com/slide/9191840/27/images/16/The+State+Postulate+The+number+of+properties+required+to+fix+the+state+of+a+system+is+given+by+the+state+postulate+%3A.jpg)

## 2. Thermodynamics Path and Processes

- A **thermodynamic path** refers to the series of states that a thermodynamic system passes through during a process as it transitions from an initial state to a final state or from one equilibrium state to another [3].
- It describes how the system changes its properties, such as pressure, temperature, and volume, over time.
- A thermodynamic path is often represented visually on diagrams, like **Pressure-Volume (P-V)** or **Temperature-Entropy (T-S)** plots, to show the relationship between properties during the process.

## Path Function

- A **thermodynamic path function** is a property that depends on the **specific path or process** taken by a system during its transition from one state to another.
- Unlike state functions, which are independent of the path and depend solely on the system's current state, path functions are concerned with the **process** itself.

### Key Characteristics of Path Functions:

- They are not properties of the system's state, so they cannot be represented by a single point on a state diagram.
- Their values are calculated by integrating along the path taken during the process.
- They are process-dependent and are expressed as inexact differentials (denoted by symbols like  $\delta Q$  and  $\delta W$ ).

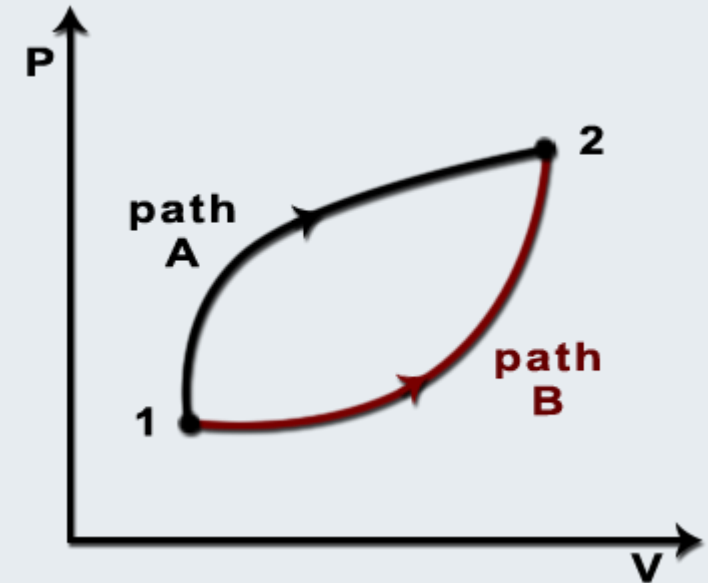
# 2. Thermodynamics Path and Processes

Cont...

## Examples of Path Functions

**Work (W):** The amount of work done by or on a system depends on the path taken (e.g., isothermal, adiabatic processes).

**Heat (Q):** The heat transferred into or out of a system depends on how the process occurs.



**Figure 3.** Thermodynamic Path

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# 2. Thermodynamics Path and Processes

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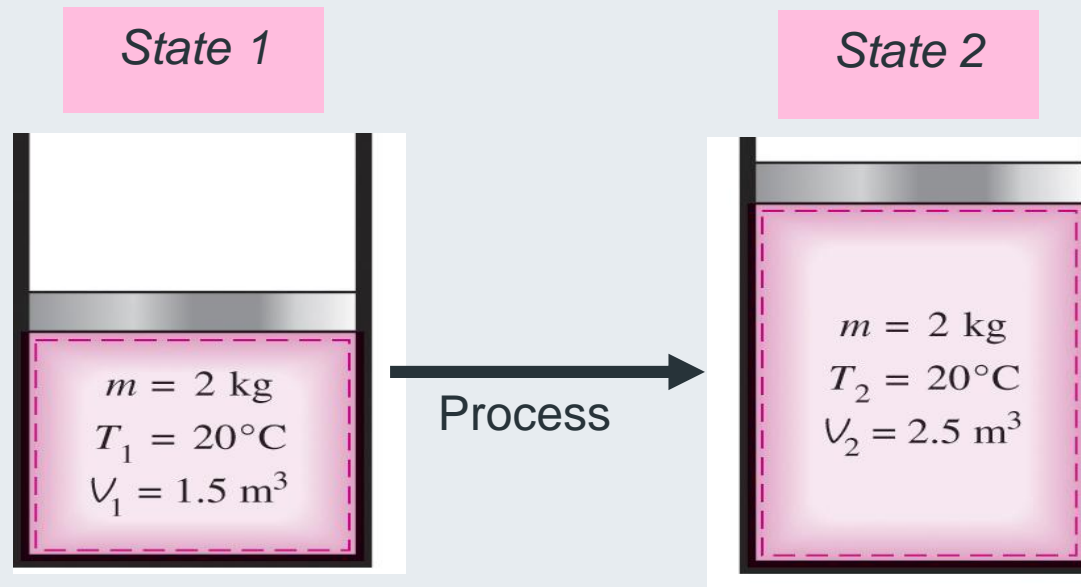
## Thermodynamic Process

- It is the **transformation** of a system from one state to another state through a succession of states.
- A **thermodynamic process** refers to the sequence of changes that a system undergoes in its thermodynamic properties, such as **temperature, pressure, volume, and internal energy**.
- These changes result from interactions between the system and its surroundings, typically involving the transfer of energy as **heat** or **work**.

# 2. Thermodynamics Path and Processes

Cont...

## Thermodynamic Process



**Figure 4:** A system at two different states

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# 2. Thermodynamics Path and Processes

Cont...

## Types of Thermodynamic Processes:

The common types of thermodynamic processes include:

### 1. Isothermal Process:

- The temperature remains constant throughout the path.
- Heat is exchanged with the surroundings to maintain the temperature.

**Example:** Expansion or compression of a gas in contact with a heat reservoir.

### 2. Adiabatic Process:

- No heat is transferred to or from the system during the path.
- Changes in the system occur due to work done on or by the system.

**Example:** Rapid compression or expansion of gas.

## 2. Thermodynamics Path and Processes

Cont...

### 3. Isochoric Process:

- The volume remains constant (no change in volume).
- Heat transfer leads to changes in pressure and temperature.

**Example:** Heating a gas inside a rigid container.

### 4. Isobaric Process:

- The pressure remains constant throughout the process.
- Heat transfer causes changes in the system's volume and temperature.

**Example:** Heating water in an open container.

**There are also specific types of thermodynamic processes:**

### 5. Isentropic Process:

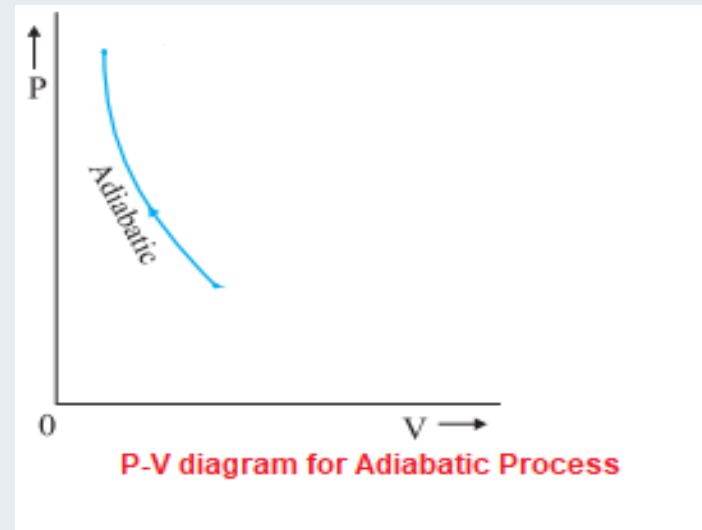
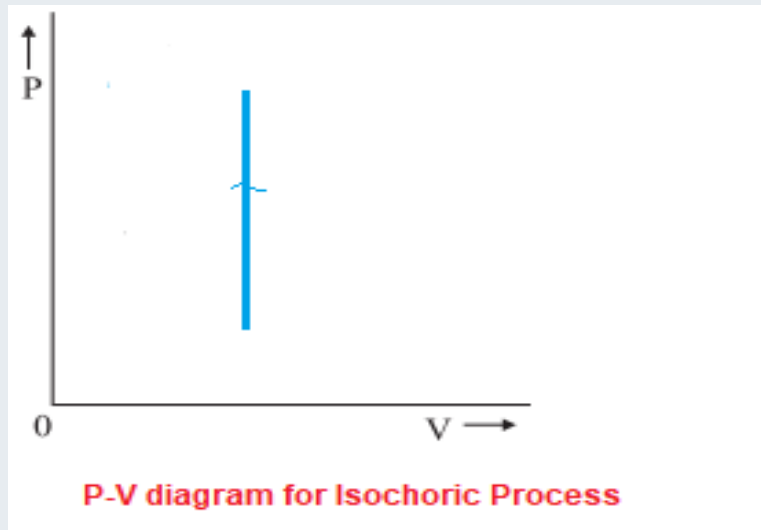
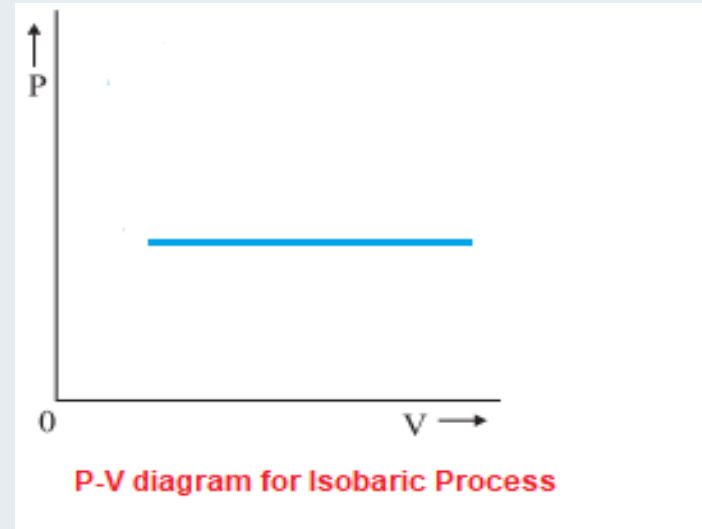
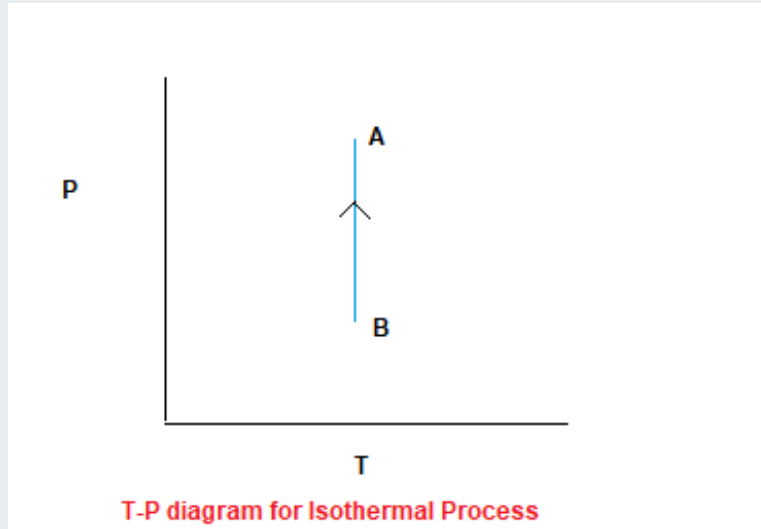
- Entropy remains constant (no entropy change).
- It is a special type of adiabatic process where there is no heat transfer and no entropy generation.
- Often idealized for efficiency analysis in systems like turbines and compressors.

### 6. Isenthalpic Process:

- Enthalpy remains constant.
- Commonly associated with processes like throttling, where fluid expands through a valve or a porous plug without heat transfer or work.

# 2. Thermodynamics Path and Processes

Cont...



**Figure 5:** Common types of thermodynamic processes

[url: https://physicscatalyst.com/heat/thermodynamic-processes.php](https://physicscatalyst.com/heat/thermodynamic-processes.php)

# 3. Quasi-Static and Non-Quasi-Static Processes

## Quasi-Static Processes

- A quasi-static process is a theoretical thermodynamic process that occurs **infinitely slowly**, allowing the system to remain in equilibrium at every step.
- Each state during the process is well-defined and can be described using thermodynamic variables like pressure, temperature, and volume.

### Some of the key characteristics are:

1. **Infinitely Slow:** The process occurs so slowly that the system has enough time to adjust and maintain equilibrium.
2. **Reversible:** Because the system is always in equilibrium, the process is reversible, meaning it can return to its original state without energy losses.
3. **Idealized:** Quasi-static processes are not practically achievable but serve as a useful approximation in theoretical thermodynamics.

## Quasi-Static Processes

### Examples:

- Compression or expansion of gas in a piston, done extremely slowly.
- Idealized heat transfer where the temperature gradient between system and surroundings is negligible.

## Non-Quasi-Static Processes

- A non-quasi-static process occurs at a finite rate, meaning the system does not have enough time to maintain equilibrium during the transitions.
- As a result, thermodynamic variables like pressure and temperature may not be uniform throughout the system.

### Some of the Key Characteristics are:

1. **Finite Rate:** The process happens **quickly**, leading to deviations from equilibrium.
2. **Irreversible:** Since equilibrium is not maintained, the process is irreversible, involving energy losses due to factors like friction or turbulence.
3. **Realistic:** Non-quasi-static processes are common in real-world applications.

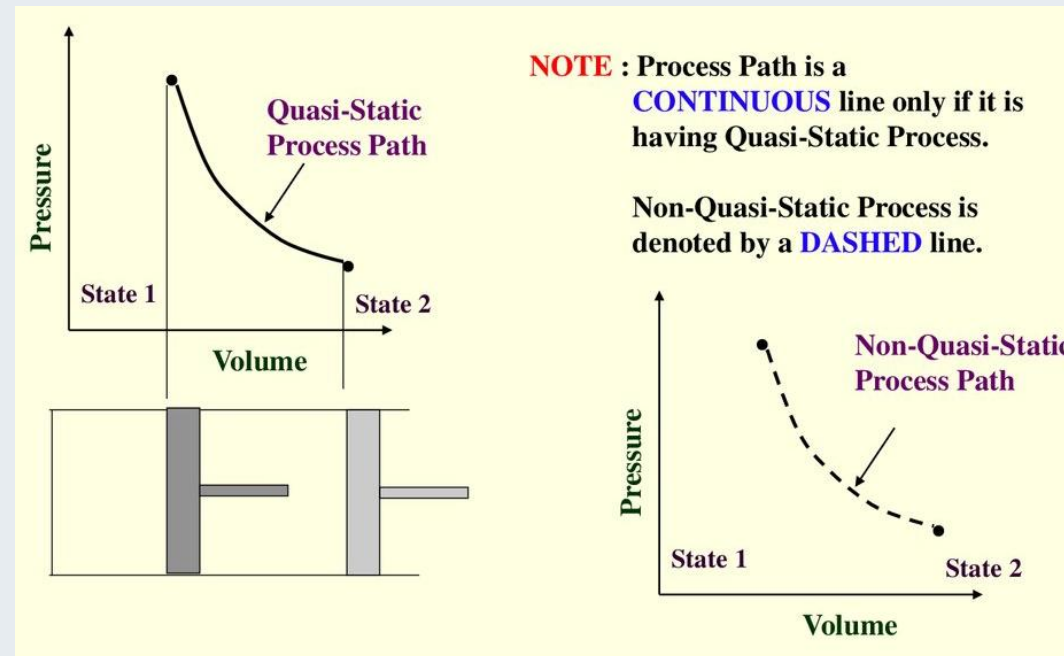
# 3. Quasi-Static and Non-Quasi-Static Processes

Cont...

## Non-Quasi-Static Processes

### Examples:

- Rapid compression or expansion of gas (like in engines).
- Sudden heat transfer where the temperature difference is significant.



**Figure 6:** Quasi-static and Non-quasi-static processes  
url: <https://cf.ppt-online.org/files/slide/q/QKfceBZqTp7ojsXwG1W5O2lvNLSYnk68D0tdPM/slide-12.jpg>

# 3. Quasi-Static and Non-Quasi-Static Processes

Cont...

## Comparison of Quasi-Static and Non-Quasi-Static Processes

Aspect	Quasi-Static	Non-Quasi-Static
Rate of Change	Infinitely slow	Finite/fast
Equilibrium Maintenance	Always in equilibrium	Deviates from equilibrium
Practicality	Theoretical (idealized)	Realistic

- Quasi-static processes are essential for understanding theoretical concepts like **maximum efficiency** in heat engines, while non-quasi-static processes help in modeling **real-life** scenarios.

# 4. Reversible and Irreversible Processes

- In thermodynamics, **reversible** and **irreversible** processes represent two different ways a system can change its state while interacting with its surroundings.

## Reversible Processes

- A reversible process is an **idealized process** that occurs infinitely slowly and is perfectly efficient, allowing the system to return to its initial state without any net loss of energy.
- That is, both the system and the surroundings are returned to their initial states at the end of the reverse process.

## Reversible Processes

- Reversible processes actually do not occur in nature. They are merely idealizations of actual processes [4].
- Reversible processes can be approximated by actual devices, but they can never be achieved.
- That is, all the processes occurring in nature are irreversible.
- Why we are bothering with such fictitious processes. There are **two** reasons.
  - they are easy to analyze.
  - they serve as idealized models to which actual processes can be compared and can be viewed as theoretical limits for the corresponding irreversible ones.

## Reversible Processes

A thermodynamic process is said to be a reversible process if:

- The system remains in **equilibrium** at all times during the process.
- There is **no entropy generation** or entropy stays constant, as there are no inefficiencies or losses.
- The process happens **extremely slowly** to avoid deviations from equilibrium.
- The process is **perfectly efficient** and has no friction, turbulence, or other factors causing energy loss.

## Reversible Processes

### Example:

- Slow compression or expansion of a gas in a frictionless piston-cylinder setup.
- Idealized heat exchange where the temperature difference between the system and surroundings is negligible.



**Figure 7:** Reversible process

url: <https://i.ytimg.com/vi/v97DLR1PIb0/maxresdefault.jpg>

## Irreversible Processes

- An irreversible process is a **real-world process** that occurs at a finite rate and involves inefficiencies, leading to a net loss of energy that cannot be recovered [4].
- A thermodynamic process is said to be an irreversible process if:
  - The system is **not in equilibrium** during the process.
  - **Entropy increases** (entropy generation) due to inefficiencies like friction, heat loss, and turbulence.
  - The process **happens quickly**, making it impossible to return to the original state without external intervention.
  - The processes are **realistic** or they are common in everyday applications.

## Irreversible Processes

- The factors that cause a process to be irreversible are called **irreversibilities**.
- They include friction, unrestrained expansion, mixing of two fluids, heat transfer across a finite temperature difference, electric resistance, inelastic deformation of solids, and chemical reactions.

### Examples:

- Rapid expansion or compression of gas in engines.
- Heat transfer with a significant temperature difference.
- Mixing of fluids or chemical reactions.

## Internally and Externally Reversible Processes

- A process is called **internally reversible** if no irreversibilities occur within the boundaries of the system during the process.
- A process is called **externally reversible** if no irreversibilities occur outside the system boundaries during the process.
- A process is called **totally reversible**, or simply **reversible**, if it involves no irreversibilities within the system or its surroundings.

# 5. Common Thermodynamic Properties

## 1. Pressure

- **Pressure** is the force exerted per unit area on a surface by an object, substance, or fluid (such as a gas or liquid).
- It's a measure of how concentrated a force is over a specific area, and it plays a crucial role in physics, engineering, and everyday life [5].

*Units*

$$P = \frac{\text{Normal Force}}{\text{Area}}$$

$$1 \text{ Pascal (Pa)} = 1 \text{ N/m}^2$$

$$1 \text{ bar} = 10^5 \text{ Pa} = 0.1 \text{ MPa}$$

$$1 \text{ atm} = 101325 \text{ Pa} = 101.325 \text{ kPa}$$

# 5. Common Thermodynamic Properties

Cont...

## Types of Pressure

### 1. Absolute Pressure ( $P_{\text{absolute}}$ or, $P$ )

- Measured relative to a perfect vacuum (absolute zero)
- Includes atmospheric pressure as a reference.

**Example:** Pressure inside a sealed gas cylinder.

### 2. Gauge Pressure ( $P_{\text{gauge}}$ or, $P_g$ )

- Measured relative to the atmospheric pressure.
- Positive for pressures above atmospheric pressure and negative for below.

**Example:** Tire pressure measurements.

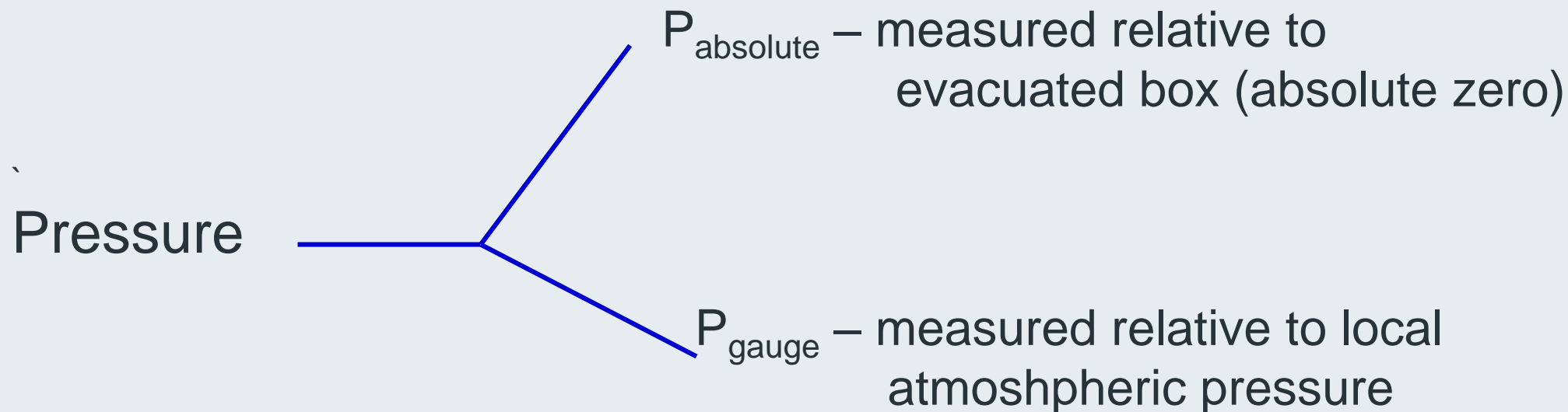
# 5. Common Thermodynamic Properties

Cont...

## Types of Pressure

### 3. Atmospheric Pressure ( $P_{atm}$ or, $P_o$ )

- Pressure exerted by the Earth's atmosphere.
- Decreases with altitude because of lower air density.



$$P = P_{atm} + P_g \quad P_{atm} = P_o = 101.325 \text{ kPa at sea level}$$

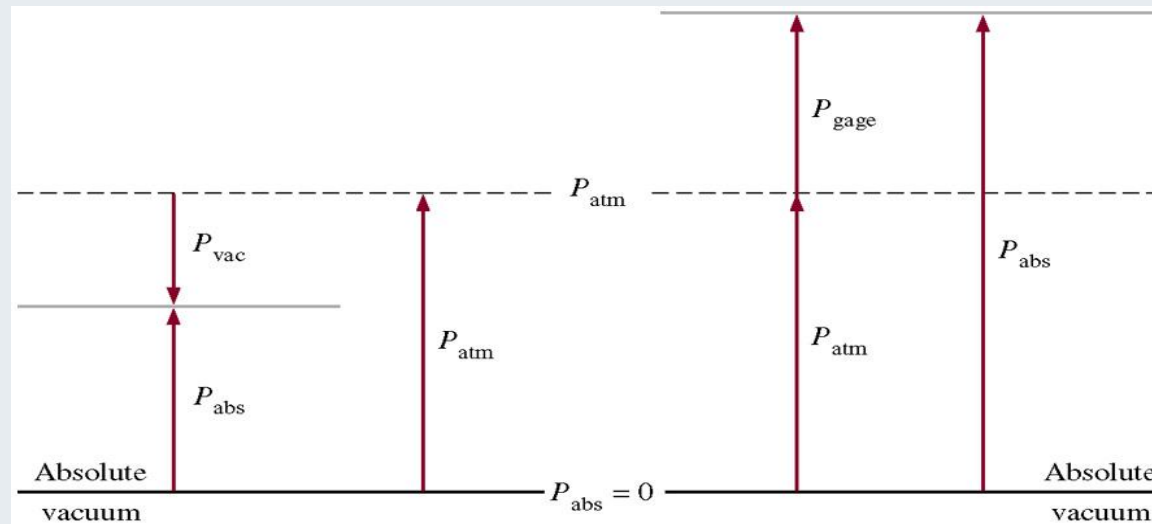
# 5. Common Thermodynamic Properties

Cont...

## Types of Pressure

- Pressures below atmospheric pressure are called **vacuum pressures** and are measured by vacuum gages that indicate the difference between the atmospheric pressure and the absolute pressure.

$$P_{vac} = P_{atm} - P_{abs}$$



**Figure 8:** Absolute, gauge and atmospheric pressures

[url: https://image.slideserve.com/1356564/absolute-gage-and-vacuum-pressures-l.jpg](https://image.slideserve.com/1356564/absolute-gage-and-vacuum-pressures-l.jpg)

# 5. Common Thermodynamic Properties

Cont...

## Methods of Measuring Pressure

**Manometer:** used to measure gauge pressure

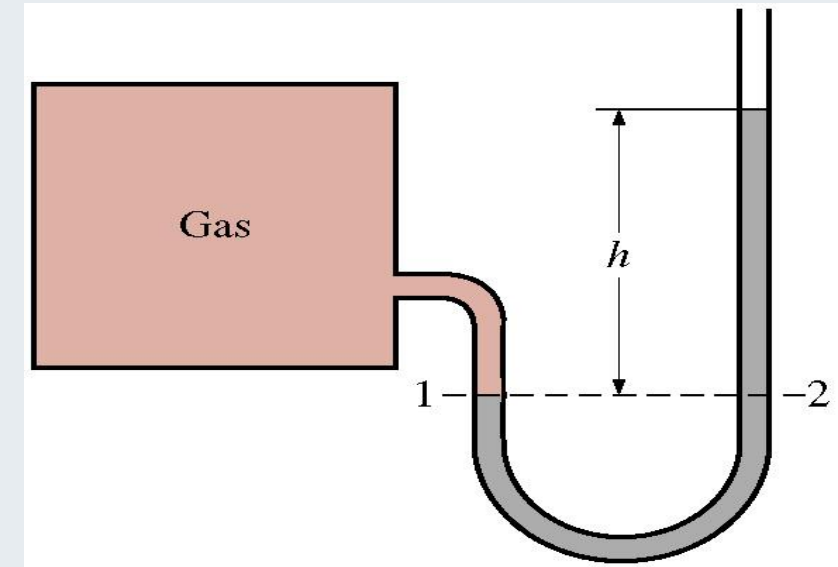
Points 1 and 2 at the same height and connected by the same liquid have the same pressure. i.e.

$$P_1 = P_2 \quad \text{or} \quad \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$P = P_1 = P_2 = P_{atm} + \frac{\text{Weight of liquid above point 2}}{\text{Cross sectional area}}$$

$$P = P_{atm} + \frac{\rho * \text{area} * h * g}{\text{area}} \quad \rho = \text{density of measuring liquid}$$

$$P = P_{atm} + \rho hg \quad g = 9.81 \text{ m/s}^2$$



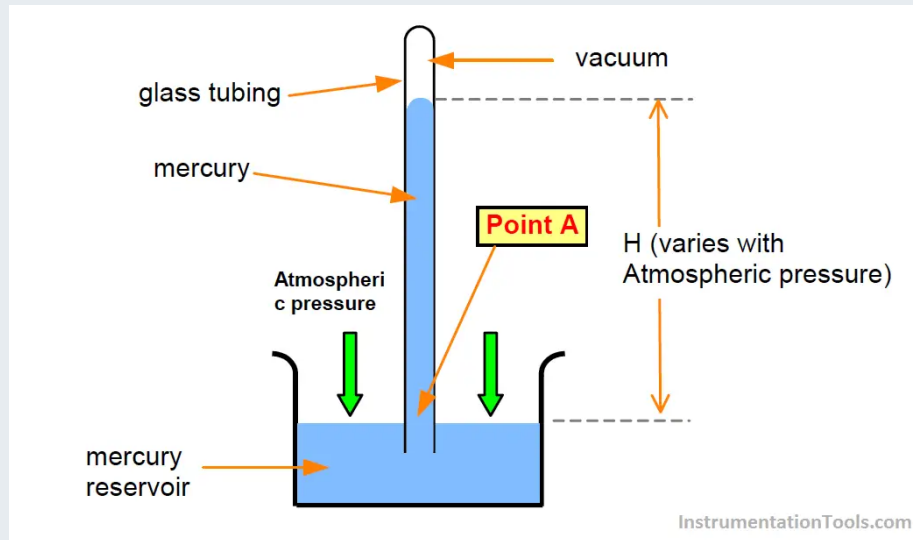
**Figure 9:** The basic manometer

<https://images.theengineeringprojects.com/image/webp/2022/10/pressure-and-fluid-statics-4.jpg.webp?ssl=1>

# 5. Common Thermodynamic Properties

## Methods of Measuring Pressure

**Barometer:** used to measure atmospheric pressure



$$P = P_{atm} + \rho hg$$

$$\text{but, } P_{atm} = 0$$

$$P = \rho hg$$

**Figure 10:** The basic manometer

[url: https://instrumentationtools.com/wp-content/uploads/2017/09/instrumentationtools.com\\_barometer-principle.png](https://instrumentationtools.com/wp-content/uploads/2017/09/instrumentationtools.com_barometer-principle.png)

# 5. Common Thermodynamic Properties

## 2. Temperature

- **Temperature** is a measure of the average kinetic energy of the particles in a substance.
- Degree of hotness or coldness
- Temperature is measured using thermometers

### Scales of Temperature:

- Degree Celsius ( $^{\circ}\text{C}$ )
- Degree Fahrenheit ( $^{\circ}\text{F}$ )
- Kelvin (K)

	$^{\circ}\text{C}$	$^{\circ}\text{F}$	K	R
Upper Limit	BP of $\text{H}_2\text{O}$ =100	BP of $\text{H}_2\text{O}$ =212	TP of $\text{H}_2\text{O}$ =273.15	TP of $\text{H}_2\text{O}$ = 459.69
Lower Limit	FP of $\text{H}_2\text{O}$ =0	FP of $\text{H}_2\text{O}$ =32	T=0 (absolute zero)	T=0 (absolute zero)
Relation	Linear	Linear	Linear	Linear

# 6. Zeroth Law of Thermodynamics

- The **Zeroth Law of Thermodynamics** is a fundamental principle that establishes the concept of **thermal equilibrium** and provides the basis for temperature measurement.

It states that:

- "If two systems are each in thermal equilibrium with a third system, then they are in thermal equilibrium with each other." [5]

$$\text{If } T_A = T_C \text{ and } T_B = T_C \text{ then } T_A = T_B$$

- The Zeroth Law is deceptively simple but foundational to the study of thermodynamics.

# Summary

A concise summary of the lecture are:

- **Thermodynamic state:** The condition of a system described by its properties, such as temperature, pressure, volume, and internal energy.
- **Thermodynamic path and processes:** The sequence of states a system goes through during a process, which can be isothermal, adiabatic, isobaric, or isochoric.
- **Quasi-static and non-quasi-static processes:** Quasi-static processes occur slowly, maintaining equilibrium, while non-quasi-static processes happen rapidly, disrupting equilibrium.

# Summary

Cont...

A concise summary of the lecture are:

- **Reversible and irreversible processes:** Reversible processes occur infinitely slowly and can be undone without affecting the surroundings, while irreversible processes cause permanent changes.
- **Common thermodynamic properties:** Includes temperature, pressure, which define the state and behavior of a thermodynamic system.
- **Zeroth law of thermodynamics:** If two systems are in thermal equilibrium with a third system, they are also in thermal equilibrium with each other, forming the basis for temperature measurement.

# References

- [1]. Fundamentals of Engineering Thermodynamics”, Moran, Michael J.5th ed.2017.
- [2]. Thermodynamics – An Engineering Approach, Cengel Y A.,Bole M A., McGraw-Hill Education, 8th edition 2015.
- [3]. Wonders of Thermodynamics: Energy, Heat, Physics Formula and Entropy, [Gaurav Mehra](https://vocal.media/education,2023,https://issuu.com/gauravm1612/docs/wonders_of_thermodynamics_energy_heat_physics_f/1),  
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- [4]. Fundamentals of Engineering Thermodynamics, Michael J. Moran, Howard N. Shapiro, Daisie D. Boettner, Margaret B. Bailey - (2010, Wiley) - libgen.lc
- [5]. A New Approach to Engineering Thermodynamics, Renaud Gicquel - Energy Systems\_ (2021, CRC Press) - libgen.li

Thank you !