# Basic and Applied Thermodynamics

**For**

## Mechanical Engineering

**By**

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# Syllabus for Basic and Applied Thermodynamics

Zeroth, First and Second Laws of Thermodynamics, Thermodynamic System and Processes, Carnot Cycle. Irreversibility and Availability, Behaviour of Ideal and Real Gases, Properties of Pure Substances, Calculation of Work and Heat In Ideal Processes, Analysis of Thermodynamic Cycles Related to Energy Conversion.

Power Engineering: Steam Tables, Rankine, Brayton Cycles with Regeneration and Reheat.

I.C. Engines: Air-Standard Otto, Diesel Cycles. Refrigeration and Air-Conditioning: Vapour Refrigeration Cycle, Heat Pumps, Gas Refrigeration, Reverse Brayton Cycle; Moist Air: Psychrometric Chart, Basic Psychrometric Processes.

## Previous Year GATE Papers and Analysis

### GATE Papers with answer key

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### Subject wise Weightage Analysis

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# Contents

“To succeed in life, you need two
things ignorance and confidence”
.... **Mark Twain**

# CHAPTER 1

# Basics of Thermodynamics

## Learning Objectives

After reading this chapter, you will know:

1. Microscopic and Macroscopic View Point
2. Thermodynamic Systems, Thermodynamic Properties, Thermodynamic Processes, Quasi- Static Process
3. Various Thermodynamic Processes, Thermodynamic Cycle, Thermodynamic Equilibrium, GIB'S Phase Rule
4. Zeroth Law of Thermodynamics , Temperature Measurements, Work Transfer, Heat Transfer
5. First Law of Thermodynamics for Close Systems, First Law of Thermodynamics for Open Systems
6. Second Law of Thermodynamics, Kalvin Planck and Clausius Statements, Clausius Inequality

## Introduction

Thermodynamics is the branch of science deals with the heat and work transfer (energy transfer) and its effect on the properties of the system. The main aim of thermodynamics is to convert the non-organized form of energy (heat) into organized form of energy (work). The subject thermodynamics is based on certain basic law’s like law of conservation of energy.

## Microscopic View Point and Macroscopic View Point

Matter is composed of myriads of molecules. In microscopic view point the behavior of individual molecule is taken in consideration. The overall behavior is described by summing up the behavior of each molecule by some statically means, Microscopic view point is also known as statical thermodynamics.

In macroscopic view point, we fix our attention to certain quantity of matter without going the event occurring at molecular level. Macroscopic view point is also known as classical thermodynamics.

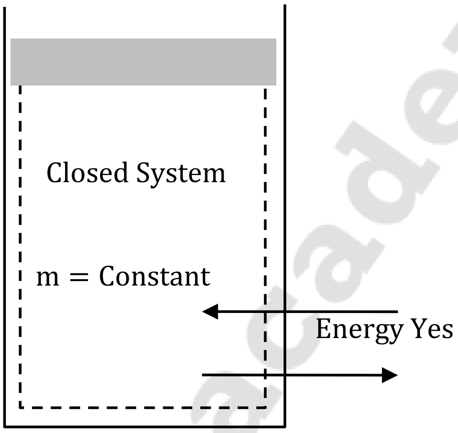
**Note:**

1. Macroscopic view point deals with the average behavior of molecule. Whereas microscopic view point deals with the behavior of individual molecule.
2. Microscopic view point is only use for low densities (low pressure gas).
3. In our course we follow only classical thermodynamics.

## Thermodynamic Systems

A system is defined as a quantity of matter or a region in "control space". The mass or region outside the system is called the surroundings. The real or imaginary surface that separates the system from its surroundings is called the boundary. The boundary of a system can be fixed or movable.

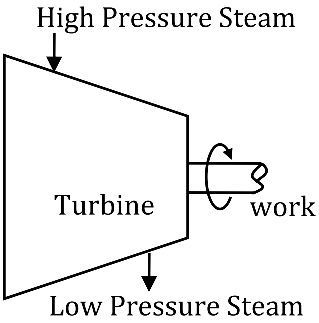
Systems may be considered to be closed or open, depending on whether a fixed mass or a fixed volume in space is chosen for study. A closed system (also known as a control mass or just system when the context makes it clear) consists of a fixed amount of mass and no mass can cross its boundary. That is, no mass can enter or leave a closed system, as shown below in figure. But energy, in the form of heat or work, can cross the boundary and the volume of a closed system is necessarily not fixed bounded. If, as a special case, even energy is not allowed to cross the boundary, that system is called an isolated system.



**Mass Cannot Cross the Boundaries of Closed System, but Energy Can Cross the Boundaries**

An open system or a control volume as it is often called is a properly selected region in space. It usually encloses a device that involves mass flow such as a compressor, turbine or nozzle. Flow through these devices is best studied by selecting the region within the device as the control volume as shown in below figure. Both mass and energy can cross the boundary of a control volume.

A large number of engineering problems involve mass flow in and out of a system and therefore, are modelled as control volumes. In general, any arbitrary region in space can be selected as a control volume. The boundaries of a control volume are called a control surface and they can be real or imaginary.

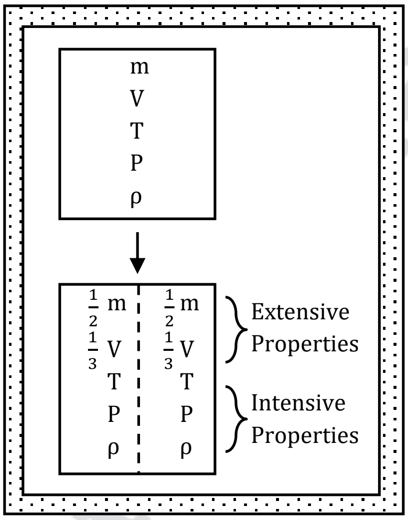


**An Open System (A Control Volume) with One Inlet and One Exit**

## Thermodynamic Properties

Properties are the characteristics of the system by which the system can be identified. Some familiar properties are Pressure P, Temperature T, Volume V and Mass m. The list can be extended to include less familiar ones such as viscosity, thermal conductivity, modulus of elasticity, thermal expansion coefficient, electric resistivity and even velocity and elevation.

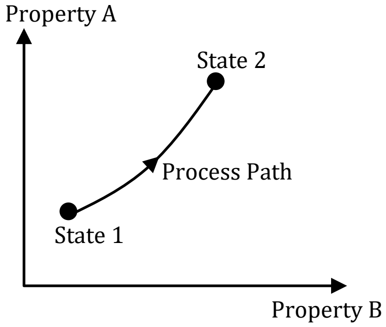
Properties are considered to be either intensive or extensive. Intensive properties are those that are independent of the mass of a system, such as temperature, pressure and density. Extensive properties are those whose values depend on the size or extent of the system. Total mass, total volume and total momentum are some examples of extensive properties. An easy way to determine whether a property is intensive or extensive is to divide the system into two equal parts with an imaginary partition, as shown in below figure. Each part will have the same value of intensive properties as the original system, but half the value of the extensive properties.



**Criterion to Differentiate between Intensive and Extensive Properties**

## Thermodynamic Processes

Any changes that a system undergoes from one equilibrium state to another is called a process and the series of states through which a system passes during a process is called the path of the process. To describe a process completely one should specify the initial and final states of the process, as well as the path it follows and the interactions with the surroundings.



**A Process between States 1 and 2 and the Process Path**

Some of the general thermodynamic processes are explained as under with the help of process diagrams.

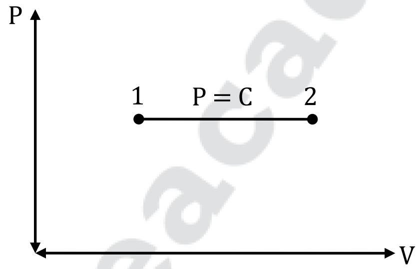
## Quasi – Static Process

When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times, it is called a quasi-static or quasi-equilibrium process. A quasi-equilibrium process can be viewed as a sufficiently slow process that allows the system to adjust itself internally so that properties in one part of the system do not change any faster than those at other parts. It should be pointed out that a quasi-equilibrium process is an idealized process and is not a true representation of an actual process. These processes are analyzed using process diagrams. Process diagrams plotted by employing thermodynamic properties as coordinates are very useful in visualizing the processes. Some common properties that are used as coordinates are Temperature T, Pressure P and Volume V (or specific volume V).

The departure of the state of the system from the thermodynamic equilibrium is infinitely small. Quasi-means "near" or "almost". Hence there may be changes or movement occurring in the change or movement is not important for dynamics of the system. The quasi – static process is an 'infinite slow' process.

## Various Thermodynamic Processes (Non-Flow Processes)

a) **Constant Pressure or Isobaric Process**



For ideal gas

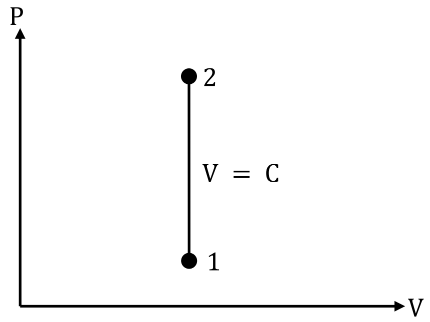
$PV = mRT$

$P = \text{Constant}(C)$

$V \propto T$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

b) **Constant Volume Process or Isochoric Process**



For ideal gas

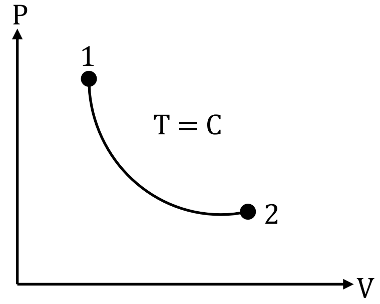
$PV = mRT$

$V = \text{Constant}(C)$

$P \propto T$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

c) **Isothermal (Constant Temperature) Process**



For ideal gas

$PV = mRT$

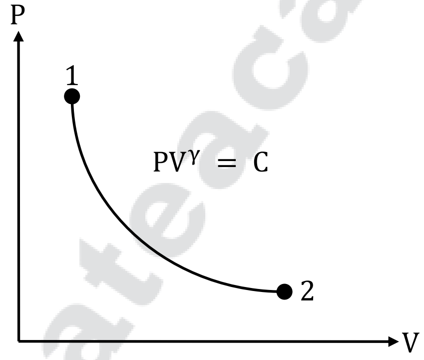
$T = C$

$PV = C$

$P_1V_1 = P_2V_2$

d) **Reversible Adiabatic or Isentropic Process**

$PV^\gamma$ = Constant



For adiabatic process

$P\,V^\gamma = C \ldots.$ ①

$P_1V_1^\gamma = P_2V_2^\gamma$

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^\gamma$$

For ideal gas

$PV = mRT$

$P = \dfrac{mRT}{V} \ldots\ldots.$ ②

Put value of equation ② in equation ①

$$\frac{mRT}{V}V^\gamma = C$$

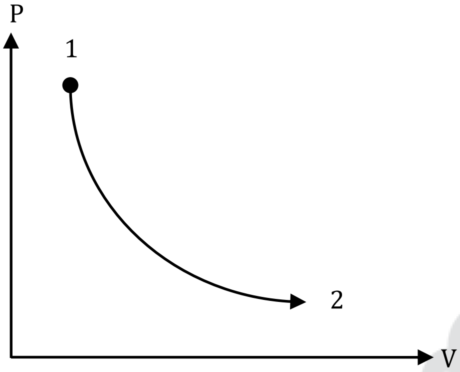
$T\,V^{(\gamma-1)} = C$

$T_1V_1^{(\gamma-1)} = T_2V_2^{(\gamma-1)}$

e) **Polytropic Process (Generalized Process)**

$PV^n = \text{Constant}$

n = Index of expansion



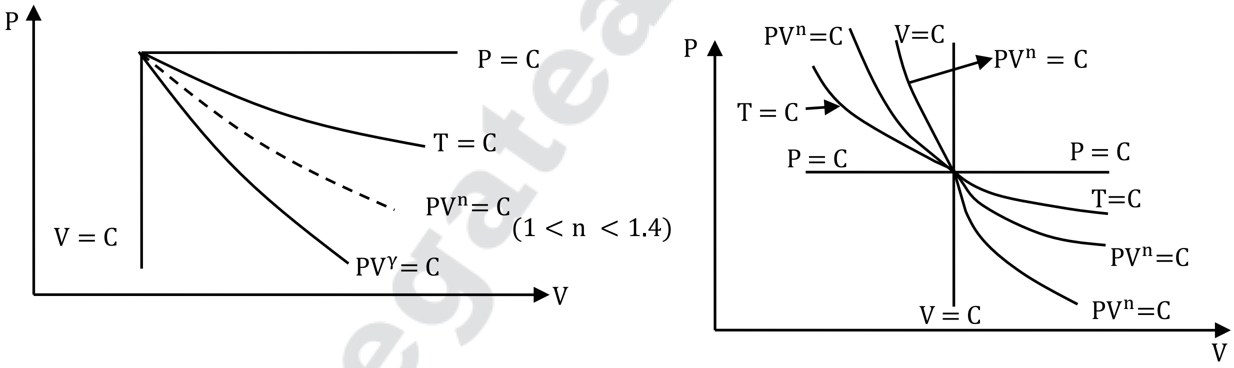
$$n = \frac{\ln\left(P_1/P_2\right)}{\ln\left(V_2/V_1\right)}$$

1) $PV^n = \text{Constant}$

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^n$$

2) $T_1V_1^{(n-1)} = T_2\,V_2^{(n-1)}$

## Representation of Thermodynamic Processes on P-V Diagram



| Thermodynamic Process | Index of Expansion (n) |
|---|---|
| Constant volume (V = C) | ∞ |
| Constant pressure (P = C ) | 0 |
| Isothermal (T = C) | 1 |
| Polytrophic ($PV^n = C$ ) | $1 < n < 1.25$ |
| Reversible adiabatic ($PV^\gamma = C$) | ($\gamma = 1.4$ ) |

## Thermodynamic Cycle

A system is said to have undergone a cycle if initial and final state are same.

**Note:**

1. For a cycle change in properties are zero.
2. Minimum number of process required for a cycle is two.