BASIC
THERMODYNAMICS

(Theory + Objective + Conventional)

[For GATE, UPSC-ESE, State Public Service Commission,
Recruitment tests by Public Sector Undertakings]

By

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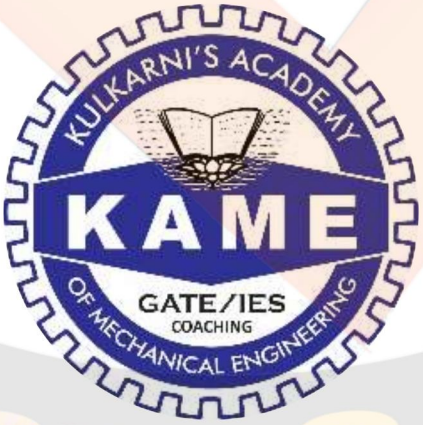

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1 BASIC CONCEPTS

1.1 Thermodynamics

It is the science of energy transfer and its effects on properties of system.

Energy transfer may be heat or work or both heat and work.

The main aim of thermodynamics study is to convert disorganized form of energy (heat) into organized form of energy (work) in an efficient manner.

- **Applications of Thermodynamics:**

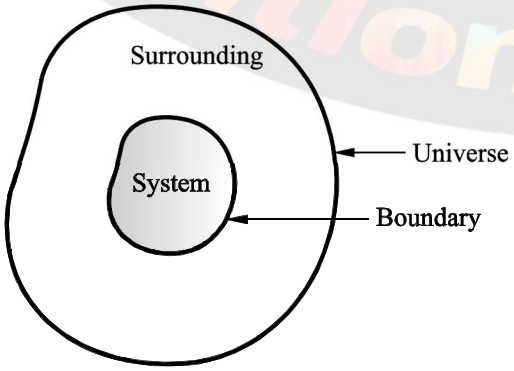
Refrigeration, air-conditioning, steam power plant, I.C. engines etc.

1.2 Basic concepts

System: It is a region in space upon which the study is focused or concentrated,

Surroundings: Anything external to the system, where the effect of system is felt, is known as surrounding.

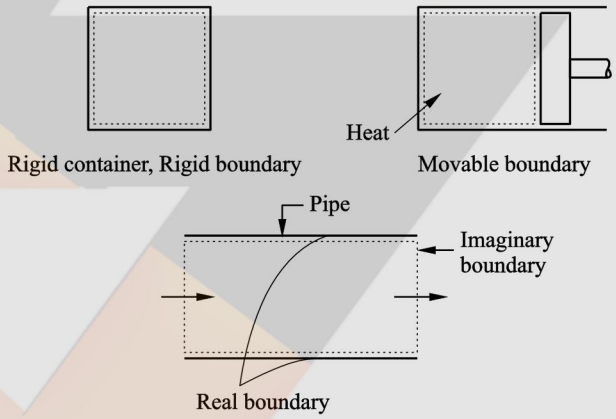
Universe = System + Surrounding



Boundary: The separation between system and surroundings is known as boundary.

Note :

Boundary can be rigid (fixed), it can be flexible (movable), it can be real or imaginary.



1.3 Types of system

Type of System	Mass Transfer	Energy Transfer	Example
Closed	×	✓	Water in sealed container, piston cylinder without valve
Open	✓	✓	Turbine, compressor, pump, boiler
Isolated	×	×	Universe, hot tea in well insulated flask

Note:

- **Control mass system:** In a closed system, as there is no mass transfer- the system mass remains constant and hence it is also known as control mass system.
- **Control Volume system:** It is the volume enclosing or surrounding the device which we wish to analyze, across the control volume both mass transfer and energy transfer can take place.

1.4 Microscopic and macroscopic approach of Thermodynamics

In microscopic approach- the behavior of individual molecules is taken into consideration, this approach is also statistical thermodynamics. This approach is useful at low densities (at higher altitudes).

In macroscopic approach individual molecular behavior is not taken into consideration, that is average behavior of molecules is taken into consideration. This approach is also known as classical thermodynamics.

Note: In our course we follow classical thermodynamics.

- **Thermodynamic Equilibrium:** A system is said to be in thermodynamic equilibrium if it is in-

(1) Thermal equilibrium (Equality of temperature).

(2) Mechanical equilibrium (Equality of pressure/forces).

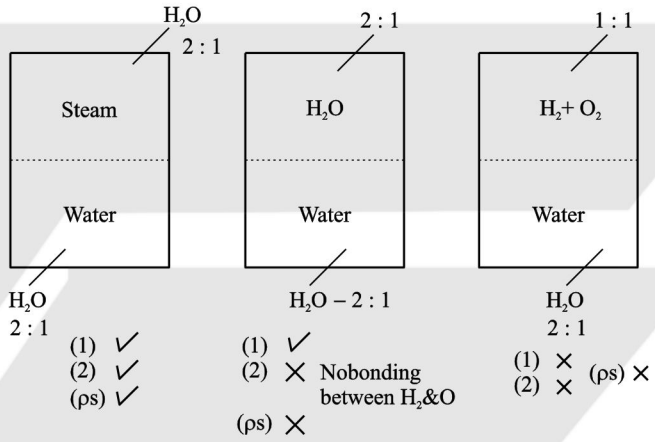
(3) Chemical equilibrium (Equality of chemical potential).

1.5 Pure substances

A substance is said to be pure substance, if it is

(1) Homogeneous in chemical composition.

(2) Homogeneous in chemical aggregation (bonding).



- A pure substance can exist in a single phase or more than one phase.
- Dry air is a pure substance but moist air (liquid air) is not a pure substance that is, in moist air water vapour can be condensed and separated.
- A pure substance can be mixture of gases also.

Ex. Gaseous air, which is a mixture of oxygen, nitrogen and other inert gases.

1.6 Property of a system

Any Measurable characteristic is a property.

Ex. Pressure, temperature, volume, density etc.

- Properties are of two types-

(1) Intensive

(2) Extensive

- Intensive properties are independent of size or mass of the system.

Ex. Pressure, temperature, density, viscosity, thermal conductivity, velocity.

- Extensive properties are dependent on size or mass of the system.

Ex. Volume, Mass, All forms of energy (K.E, P.E, Internal Energy), momentum.

M	$\frac{M}{2}$	$\frac{M}{2}$	Extensive
V	$\frac{V}{2}$	$\frac{V}{2}$	Extensive
P	P	P	Intensive
T	T	T	Intensive

- **Note:**

  (1) Ratio of two extensive properties is an intensive property.

  (2) All specific properties (Extensive properties divided by mass) are intensive properties.

  Ex. specific volume, specific enthalpy, specific internal energy, specific entropy.

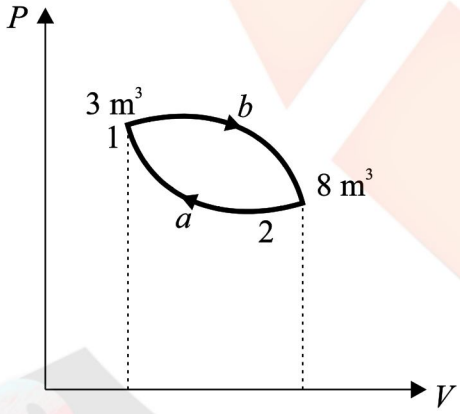
- **Important Points with respect to properties:**

  (1) Properties are point functions or state functions.

  (2) Properties are independent of past history i.e. they are independent of path.

  (3) Properties are exact differentials.

$$dV_a = dV_b = 5\ m^3$$



  (4) Properties are macroscopic characteristic of a system.

- **State of a system:** The condition of a system is known as state of a system.

1.7 Process

Any change of state is a process.

- **Reversible and Irreversible process:** A process is said to be a reversible process if when reversed, follows the same path without leaving any effect on system and surrounding.

  A process which is not a reversible process is an irreversible process. Friction is one of the reasons which makes the process irreversible.

- Most of the practical processes are irreversible processes. Reversible process are discussed-

  (i) To simplify the analysis.

  (ii) They are efficient process.

- **Quasi-static process**: A process which is carried out very slowly with a small difference in properties is known as a Quasi-static process.

- **Note:** Though all reversible processes are quasi-static process, but the converse is not true i.e., all quasi-static processes need not to be reversible.

- Friction Less Quasi-Static Process is a Reversible Process.

1.8 Gibbs phase rule

According to Gibbs Phase Rule

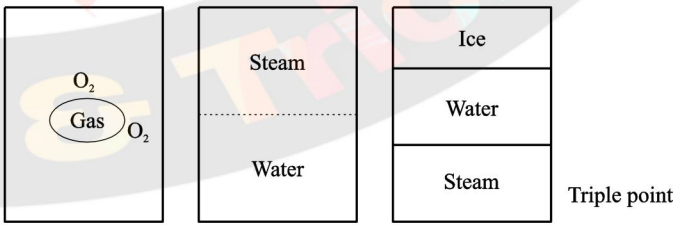
$$P + F = C + 2$$

Where,

P = No. of phases

F = Minimum number of independent intensive variable required to fix the state or degree of freedom

C = No. of component



$P = 1$
$C = 1$
$P + F = C + 2$
$1 + F = 1 + 2$
$\boxed{F = 2}$

$P = 2$
$C = 1$
$\boxed{F = 1}$

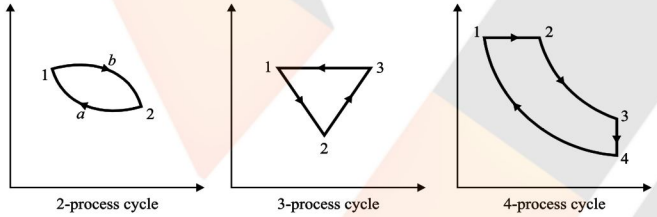
$P = 3$
$C = 1$
$3 + F = 1 + 2$
$\boxed{F = 0}$

- At triple point the degree of freedom is zero.

1.9 Thermodynamic Cycle

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

- Minimum number of processes required for a cycle are Two.
- The cyclic integral of any property is zero i.e. the change in property for a cycle is zero.



2-process cycle

$\Delta P_a = P_2 - P_1$

$\Delta P_b = P_1 - P_2$

$\oint dP = \Delta P_a + \Delta P_b = 0$

$\Delta P_b = P_1 - P_2$

3-process cycle

Same

$\oint dV = 0$

$\oint dT = 0$

4-process cycle

$\oint dS = 0$

$\oint dP = 0$

1.10 Concept of continuum

Continuum means continuous, in continuum concept is assumed to be distributed uniformly and continuously. For applying the concept of continuum-

(1) There should be large no. of molecules.

(2) Mean free path must be small i.e. mean free path (distance between molecules) must be less than system dimension.

(3) Continuum concept is a macroscopic approach.

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P Practice Questions

1.1 A Control volume is

(A) An isolated system

(B) A closed system but heat and work can cross the boundary

(C) A specific amount of mass in space

(D) A fixed region in space where mass, heat and work can cross the boundary of that region

1.2 For a pure substance at its triple point, the number of degree of freedom is

(A) 0 (B) 1

(C) 2 (D) 3

1.3 In which system, boundaries allow only energy transfer

(A) Isolated system (B) Closed system

(C) Open system (D) None

1.4 Which property remains unchanged when the system is partitioned into number of parts

(A) Intensive

(B) Extensive

(C) Both intensive and extensive

(D) Neither intensive nor extensive

1.5 What are the properties of thermodynamic system, whose value for the entire system is equal to the sum of their value for individual parts of the system?

(A) Thermodynamic properties

(B) Extensive properties

(C) Intensive properties

(D) None of the above

1.6 Which of the following statements regarding thermodynamic properties are correct?

P. They are exact differentials

Q. They are point functions

R. Does not depend on past history of the system

S. Depends on past history of the system

(A) Q and S (B) Q only

(C) P, Q and R (D) P and S

1.7 Which of the following statements regarding the concept of continuum are correct?

P. Large number of molecules enable meaningful statistical averaging and assignment of property values

Q. Mean free path of the molecules is order of magnitude higher than system dimensions

R. Behavior of individual molecules is disregarded

S. Mean free path of the molecules approaches the order of magnitude of the system dimensions

(A) P and R (B) Q and R

(C) R and S (D) P and S

1.8 Which of the properties listed below are intensive properties?

P. Weight Q. Temperature

R. Volume S. Density

(A) Q and S (B) P and R

(C) P and Q (D) R and S

1.9 A system is said to be consisting of a pure substance when

(A) It is homogeneous is composition

(B) It is homogeneous and invariable in chemical composition and aggregation

(C) It has only one phase

(D) It has more than one phase

1.10 Which of the following are pure substances?

P. Gaseous air

Q. A mixture of gaseous air and liquid water

R. A mixture of liquid water and water vapour

S. A mixture of gaseous air and oil]

1.11 **Assertion (A) :** Air is a pure substance but a mixture of air and liquid air in a cylinder is not a pure susbstance.

Reason (R) : Air is homogeneous in composition but a mixture of air and liquid air is heterogeneous.

(A) Both A and R are individually true and R is the correct explanation of A

(B) Both A and R are individually true but R is not the correct explanation of A

(C) A is true but R is false

(D) A is false but R is true

1.12 Given P = Pressure, T = Temperature; V = Specific volume. Which one of following can be considered as a property of system?

(A) $\int pdv$

(B) $\int vdp$

(C) $\int\left(\frac{dT}{T}+\frac{pdv}{V}\right)$

(D) $\int\left(\frac{dT}{T}+\frac{vdp}{T}\right)$

1.13 Identify the group containing the appropriate match of items in List I and List II

List-I

P. A jet engine in flight

Q. Water being heated in a sealed container

R. Internal energy

S. Specific entropy

List-II

1. Closed system
2. Control system
3. Intensive Property
4. Extensive Property

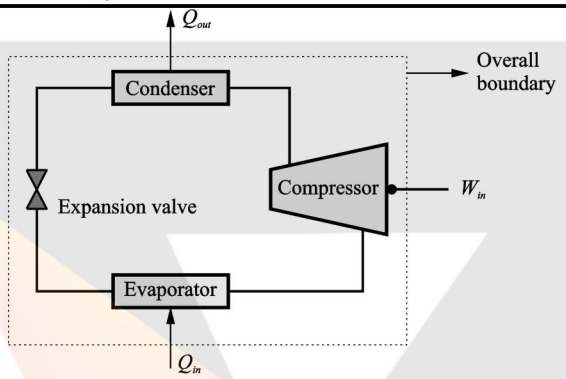
(A) P-1, Q-2, R-3, S-4

(B) P-2, Q-1, R-3, S-4

(C) P-2, Q-1, R-4, S-3

(D) P-1, Q-2, R-4, S-3

1.14 In the fig. showing a schematic of a vapour compression refrigeration system, the system (s) and control volume (s) are as



(A) Compressor and condenser are control volumes; and expansion valve and evaporator are systems

(B) Expansion valve and evaporator are control volumes; and compressor and condensor are systems

(C) Compressor, condenser, expansion valve and evaporator are control volumes; and overall boundary is a system

(D) Overall boundary is a control volume; and compressor, condenser, expansion valve and evaporator are systems

A Answer Key

1.1	D	1.2	A	1.3	B
1.4	A	1.5	B	1.6	C
1.7	A	1.8	A	1.9	B
1.10	P&R	1.11	A	1.12	D
1.13	C	1.14	C		

E Explanation

1.1 (D)

1.2 (A)

By using Gibb's phase rule

$$P+F=C+2$$

At triple point $P=3$

$$C=1$$

$$3+F=1+2$$

$$F=0$$

Hence, the correct option is (A).

1.3 (B)

1.4 (A)

1.5 (B)

1.6 (C)

1.7 (A)

1.8 (A)

1.9 (B)

1.10 (P&R)

1.11 (A)

1.12 (D)

$$PV=RT$$

$$\frac{V}{T}=\frac{R}{P}$$

$$z=\int\left(\frac{dT}{T}-\frac{VdP}{T}\right) \quad \begin{cases} dz=Mdx+Ndy \\ =\left(\frac{\partial M}{\partial Y}\right)_X=\left(\frac{\partial N}{\partial X}\right)_Y \end{cases}$$

$$dz=\frac{dT}{T}-\frac{VdP}{T}$$

$$dz=\frac{1}{T}(dT)-\frac{V}{T}(dP)$$

$$M=\frac{1}{T} \qquad x=T$$

$$N=\frac{-V}{T} \qquad y=P$$

$$\left(\frac{\partial M}{\partial Y}\right)_X=\left[\frac{\partial}{\partial P}\left[\frac{1}{T}\right]\right]_T=0 \quad \begin{cases} PV=mRT \\ \frac{V}{T}=\frac{mR}{P} \end{cases}$$

$$\left(\frac{\partial N}{\partial X}\right)_Y=\left[\frac{\partial}{\partial T}\left(\frac{-V}{T}\right)\right]_P$$

$$\Rightarrow \left[\frac{\partial}{\partial T}\left(\frac{-mR}{P}\right)\right]_P=0$$

So it is a property

Hence, the correct option is (D).

1.13 (C)

1.14 (C)