RRB-JE 2024

Railway Recruitment Board

Junior Engineer Examination

Mechanical Engineering

Thermodynamics

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY PUBLICATIONS

Thermodynamics

Contents

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CHAPTER 01

Introduction

1.1 Introduction

Thermodynamics is the science of energy transfer and its causes and effects.

- In **microscopic** thermodynamics, the behaviour of the gas is described by summing up the behaviour of each molecule.

  In **macroscopic** thermodynamics, the behaviour of the gas is described by the net effect of action of all the molecules, which can be perceived by human senses.
- A **system** is a matter or region on which analysis is done. System is separated from the surrounding by boundary. Everything external to the system is called ***surroundings***. System & surrounding together is called a *universe*.

Table 1.1:

	Mass Transfer	Energy Transfer	Example
Open	Yes	Yes	Compressor, Turbine etc.
Close	No	Yes	Piston cylinder arrangement, gas in a closed container.
Isolated	No	No	Universe

Control Mass: Analysis of system based on fixed amount of matter.
Control Volume: Volume surrounding an open system on which study is focussed.

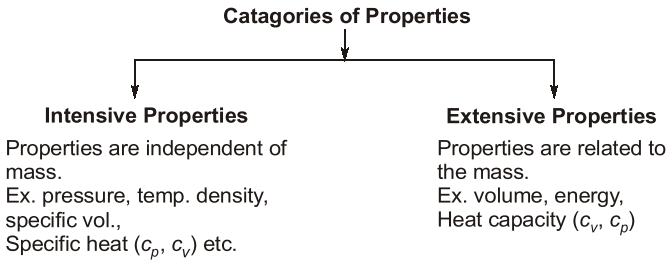
1.1.1 Concept of Continuum

- Continuum hyptohesis suggests that the matter is continuously distributed with no voids being present.
- In case of gases it is valid when mean free path (average distance travelled by a molecule between two successive collision is much smaller than the system dimensions.)
- In case of "Rarefied gases theory" the concept of continuum is not valid.

1.2 Properties

- Every system has certain characteristics by which its physical condition may be described.
  Example:- Volume, temperature, pressure. Such characteristics are called properties of the system.
- These are all macroscopic in nature.
- Properties are point function and are exact or perfect differentials.
  Ex. Internal energy, enthalpy, entropy

1.2.1 Categories of Properties



1.2.2 Specific Extensive Properties

- Extensive properties per unit mass is specific extensive properties.
- It is an intensive property.
  Example:- Specific volume, Specific energy.
- It is independent of mass.

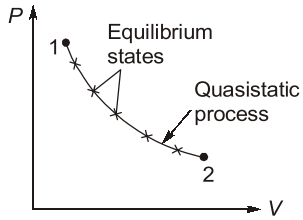


Figure 1.1: A quasi-static process

- **State:** It gives the complete description of the system.
- **Phase:** It is a quantity of mass that is homogeneous throughout in chemical composition and physical structure. Example:- solid, liquid, vapour, gas.
- **Path and Process:** The succession of states passed through during a change of state is called the path of the system. A system is said to go through a process if it goes through a series of changes in state.
- **Quasistatic Process:** Infinite slowness is the characteristic feature of quasistatic process. All states of the system passes through the equilibrium states.

1.3 Reversible Process or Ideal Process

- Which can be reversed without leaving any effect on system and surrounding.
- All reversible processes can be shown on diagrams. Example:- P–V, T–S, P–T diagrams.
- A reversible process is carried out infinitely slowly with an infinitesimal gradient. Hence every state passed through by the system is an equilibrium state. So a reversible process coincides with a quasi-static process.
- A quasi-static process without friction is reversible process.
- All reversible processes are quasi-static process but all quasi-static process are not reversible.
- If the time allowed for a process to occur is infinitely large, even through the gradient is finite, the process becomes reversible.

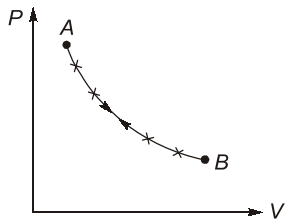


Figure 1.2: A reversible process

Example 1.1 A reversible process

(a) Must pass through a continuous series of equilibrium states.
(b) Leaves no history of the events in surroundings.
(c) Must pass through the same states on the reversed path as on the forward path.
(d) All options are correct

[SSC-JE (Forenoon) : 2017]

Solution: **(d)**

Example 1.2 Which of the following is/are reversible process(es)

1. Isentropic expansion
2. Slow heating of water from a hot source.
3. Constant pressure heating of an ideal gas from a constant temperature source.
4. Evaporation of a liquid at constant temperature.

Select the correct answer using the code given below:

(a) 1 only (b) 1 and 2

(c) 2 and 3 (d) 1 and 4

[IES : 2005]

Solution: **(b)**

1.4 Irreversible Process or Natural Process

- All spontaneous processes are irreversible process.
- Irreversible process cannot be shown on diagrams. They are shown as dotted lines.
  Example:- Heat transfer through finite temperature difference, Free expansion, mixing of fluids, presence of friction.
- A system will be in a state of thermodynamic equilibrium if the conditions for the following three types of equilibrium are satisfied.
  (i) Mechanical equilibrium
  (ii) Chemical equilibrium
  (iii) Thermal equilibrium

1.5 A Pure Substance

- A substance homogeneous in chemical composition and homogeneous in chemical aggregation.

  Examples of Pure Substance: Atmospheric air, steam water mixture and combustion products of a fuel.
- Mixture of air and liquid air is not a pure substance since the relative proportion of oxygen and nitrogen differ in gas and liquid phases in eqn....

Example 1.3 Assertion (A): Water is not a pure substance.

Reason (R) : The term pure substance designates a substance which is homogeneous and has the same chemical composition in all phases.

(a) Both Assertion and Reason are true and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are true but Reason is not a correct explanation of Assertion.

(c) Assertion is true but Reason is false.

(d) Assertion is false but Reason is true.

Solution: **(d)**

Assertion is false, Reason is true. Water for all practical purpose can be considered at pure substance because it is homogeneous and has same chemical composition under all phases.

1.5.1 Gibb's Phase Rule

$P + F = C + 2$

P = Number of phases

F = Degree of freedom

C = Number of component

Example 1.4 Determine the degree of freedom of the following systems and comment on the result:

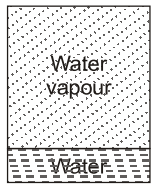
(1) Water and water vapour system

(2) A mixture of oxygen and nitrogen gas as system

(3) Water at its triple point

Solution :

(1)



In the given system,

Number of phases, $P = 2$ (liquid + vapour)

Number of components, $C = 1$ (only water)

$\therefore$ From Gibbs phase rule,

$$P + F = C + 2$$

$$\Rightarrow \quad F = 1 + 2 - 2 = 1$$

Comment : Only one variable is enough to fix the state of the system.

(2) It the given system,

$P = 1$ (only gas)

$C = 2$ $(O_2 + N_2)$

$P + F = C + 2$

$F = 2 + 2 - 1 = 3$

Comment : We will require 3 independent intensive variables to fix the state of the system.

(3)

$P = 3$ (solid, liquid and gas)

$C = 1$ (only water)

$F = C - P + 2$

$F = 1 - 3 + 2 = 0$

Comment : Triple point of water is a fix point at particular pressure and temperature. $P_{TP} = 0.6112$ kPa

$T_{TP} = 0.01°C = 173.16$ k

1.6 Thermodynamic Cycle

- It is a series of processes when initial and final points are same.
- There is no change in property of system.
- Minimum number of processes required for a cycle are 2.

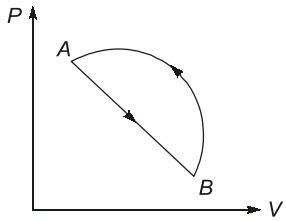


Figure 1.3:

STUDENT'S ASSIGNMENT

Q.1 Mixture of ice and water form a
(a) closed system
(b) open system
(c) isolated system
(d) heterogeneous system
[SSC-JE : 2010]

Q.2 According to kinetic theory of gases, at absolute zero _____
(a) specific heat of molecules reduces to zero.
(b) kinetic energy of molecules reduces to zero.
(c) volume of gas reduces to zero.
(d) pressure of gas reduces to zero.
[SSC-JE : 2017]

Q.3 Three states of matter are distinguished with respect to molecules by the _____
(a) Atoms in molecules
(b) Number
(c) Orientation
(d) Character of motion
[SSC-JE : 2017]

Q.4 Total heat of a substance is also known as
(a) Internal energy (b) Entropy
(c) Thermal capacity (d) Enthalpy
[SSC-JE : 2017]

Q.5 Which of the following is expected to have highest thermal conductivity?
(a) Steam (b) Solid ice
(c) Melting ice (d) Water

Q.6 Gases have
(a) two specific heats
(b) three specific heats
(c) one specific heats
(d) none of these
[SSC-JE : 2018]

Q.7 Which of the following are intensive properties
1. Kinetic energy 2. Specific enthalpy
3. Pressure 4. Entropy
Select the correct answer using the codes given below:
(a) 1 and 3 (b) 2 and 3
(c) 1, 3 and 4 (d) 2 and 4

Q.8 Universal gas constant of a gas is the product of molecular weight of the gas and
(a) gas constant
(b) specific heat at constant pressure
(c) specific heat at constant volume
(d) none of these
[ISRO : 2007]

Q.9 What are the properties of a thermodynamic system, whose value for the entire system is equal to the sum of their values for individual parts of the system?
(a) Thermodynamic properties
(b) Extensive properties
(c) Intensive properties
(d) None of these
[IAS 2006]

Q.10 Which thermometer is independent of the substance or material used in its construction?
(a) Memory thermometer
(b) Alcohol thermometer
(c) Ideal gas thermometer
(d) Resistance thermometer
[IAS 2006]

Q.11 The definition of 1 K as per the internationally accepted temperature scale is
(a) $1/100^{th}$ the difference between normal boiling point and normal freezing point of water
(b) $1/273.15^{th}$ the normal freezing point of water
(c) 100 times the difference between the triple point of water and the normal freezing point of water
(d) $1/273.16^{th}$ of the triple point of water
[GATE 1994]

Q.12 Match item from group I, II, III, IV and V

Group I	Group II	Group III	Group IV	Group V
	When added to the system is	Differential	Function	Phenomenon
E Heat	G Positive	I Exact	K Path	M Transient
F Work	H Negative	J Inexact	L Point	N Bounday

(a) E-G-J-K-M
E-G-I-K-N
(b) E-G-I-K-M
F-H-I-K-N
(c) F-H-J-L-N
E-H-I-L-M
(d) E-G-J-K-N
F-H-J-K-M
[GATE 2006]

ANSWER KEY // STUDENT'S ASSIGNMENT

1. (d)	**2.** (b)	**3.** (d)	**4.** (d)	**5.** (b)
6. (a)	**7.** (b)	**8.** (a)	**9.** (b)	**10.** (c)
11. (d)	**12.** (d)			

HINTS & SOLUTIONS // STUDENT'S ASSIGNMENT

1. (d)

A heterogeneous system is defined as one consisting of two or more homogeneous bodies. Each phase is separated from other phase by interfaces or boundaries.

A homogeneous system is defined as the one whose chemical composition and physical properties are same in all parts of the system, or change continuously from one point to another.

2. (b)

Absolute zero is the point where all the moleculus have no kinetic energy.

3. (d)

By character of motion, a matter is considered as solid, liquid and gas.

4. (d)

Enthalpy involves internal energy as well as flow works as $H = U + pV$.

5. (b)

$K_{solid\ ice} > K_{melting\ ice} > K_{water} > K_{steam}$

6. (a)

Actually gases have infinite specific heats but majorly C_p and C_u are used. Here best option is (a).

as $$C_{poly} = \left(\frac{n-\gamma}{n-1}\right)C_u$$

For different value of n C_{poly} will different.

8. (a)

As $\bar{R} = M \cdot R$

M = Molecular weight of gas

R = Characteristic gas constant

$\bar{R}$ = Universal gas constant

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