CHEMICAL ENGINEERING

Thermodynamics

Comprehensive Theory
with Solved Examples *and* Practice Questions

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Thermodynamics

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CHAPTER

1

1.1 INTRODUCTION

Thermodynamics is the branch of science which deals with the energy and energy interactions. More specifically it deals with energy conversions, energy exchange and the direction of exchange.

1.1.1 Macroscopic and Microscopic Approach

- **Macroscopic Approach:** In this approach individual molecular behaviour of a gas is not taken into consideration and the average behaviour of all the molecules is studied. This approach is applied when the continuum concept is valid.

Do You Know?

- Continuum hypothesis 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 collisions) is much smaller than the system dimensions.

- **Microscopic Approach:** In this the individual molecular behaviour is taken into consideration. For example: It is used in space exploration.

Remember : For our use, in classical thermodynamics, we often use macroscopic approach.

1.2 SYSTEM, SURROUNDINGS AND PROPERTIES

1.2.1 System, Surroundings and Properties

- **System:** A thermodynamics system is defined as the fixed mass or fixed region in space (also called control volume) upon which our study is focused.
- **Surroundings:** Everything external to the system is called surroundings.
- **Boundary:** It is a real or imaginary surface which separates system from the surroundings. A boundary can be fixed or movable. A boundary has zero thickness, no mass and no volume.

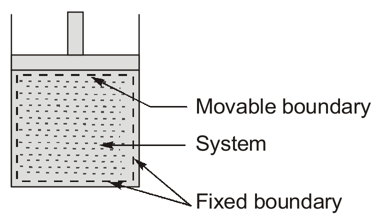


Figure 1.1 Fixed Mass System

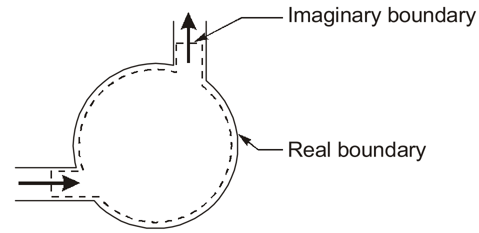


Figure 1.2 Fixed Region in Space (Control Volume)

1.2.2 Types of System

Based on energy-mass interaction with the surroundings the system has been categorized as given below.

Type of system	Energy transfer	Mass transfer	Example
Open	Yes	Yes	Piston cylinder arrangement with valves
Closed	Yes	No	Piston cylinder arrangement without valves
Isolated	No	No	Universe

Remember : Control volume is a volume surrounding an open system on which study is focused. The boundaries of a control volume is called control surface.

1.2.3 Properties of a System

- Properties are macroscopic characteristics of a system such as mass, volume, energy, pressure and temperature to which numerical values can be assigned at a given time without knowledge of the past history of the system. They have been classified as follows:
  1. **Intensive (Intrinsic) Properties:** The properties which are independent of the mass of system under consideration.

     For examples: Pressure, temperature, density, viscosity etc.

Remember

- All specific properties are intensive properties, e.g. specific volume, specific heat, specific internal energy etc.
- Density is an intensive property.

2. **Extensive (Extrinsic) Properties:** The properties which are dependent on the mass of system under consideration.

   For examples: Mass, energy, volume etc.

NOTE : While deciding the type of property we should not change the system under consideration.

- 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 figure 1.3. Each part will have same value of the property in case it is intensive but half the value in case it is extensive.

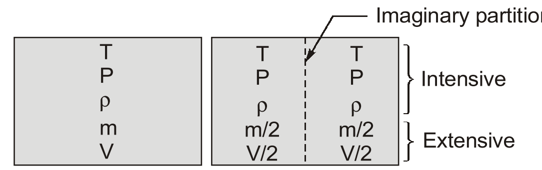


Figure 1.3

- Important points with respect to properties:
  1. They are point or state functions.
  2. They are independent of past history.
  3. They are exact differentials.

1.3 STATE OF THE SYSTEM AND PROCESS

- Any equilibrium condition of the system is called state of the system. At a given state all the properties of a system have fixed values throughout the entire system [may/may not be uniform]
- A change in state is called a process.
- The infinite number of states through which the system passes while going from an initial to a final state is called the path of the process. A process can be classified as:

1. **Quasistatic and Non-Quasistatic Process:** If a process takes place infinitely slowly it is called a quasistatic process, otherwise a non-quasistatic process.
   - A quasistatic process is generally represented by a joined line on property diagrams. Whereas a non-quasistatic process is represented by dotted lines. (Fig. 1.4) [i.e. every point on the path represents an equilibrium state and hence can be represented on the curve.]
2. **Reversible and Irreversible Process:** A process is said to be reversible if it can be reversed in direction following the same path as that of the forward process without leaving any change in the system as well as the surroundings. The process is said to be irreversible otherwise.

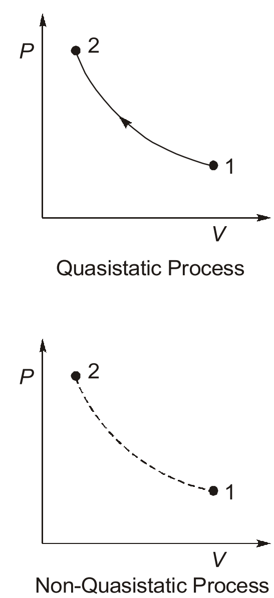


Figure 1.4

NOTE

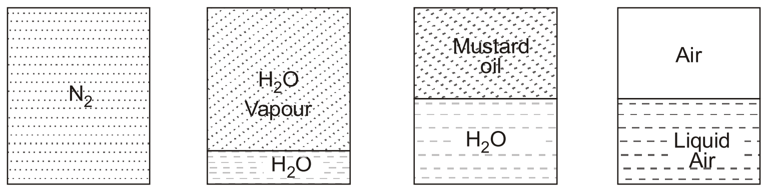
- Quasistatic and reversible processes are not always same but for our study we take them as same.
- All reversible processes are quasistatic but all quasistatic processes might not be reversible.
- Frictionless quasistatic process is reversible.

Remember

- The reversibility of a process in problems can be conveyed in following ways:
  (a) Quasistatic compression/expansion
  (b) Ideal flow (open system)

1.4 PURE SUBSTANCES

- A substance is said to be a pure substance if it is of homogeneous chemical composition throughout.
- It does not have to be a single chemical element or compound. A mixture of various chemical elements or compounds also qualifies as a pure substance as long as mixture is homogeneous. For example: air.
- Some more examples are shown in figure 1.5.



Pure Pure Impure Impure

Figure 1.5

Remember

- The mixture of refrigerants which behaves as a pure substance is called Azeotrope.
- Mixture of ethyl alcohol and water is also a pure substance due to molecular level hydroxyl bond formation.

1.4.1 Gibbs Phase Rule

- Phase is defined as a quantity of mass that is homogeneous throughout in chemical composition and physical structure. Eg. solid, liquid, vapour, gas.
- In general the minimum number of independent intensive variables required to fix the state of the system for multiphase, multi-component system is given by the Gibbs phase rule, expressed as:

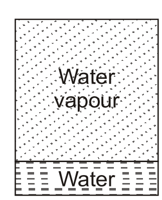
$$F = C - P + 2$$

where, F = Degree of freedom or minimum number of independent intensive variables required
C = Number of chemical components
P = Number of phases present in equilibrium

Example 1.1 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 it can be asserted that:

Number of phases, P = 2 (liquid + vapour)
Number of components, C = 1 (only water)

∴ From Gibbs phase rule, we know

$$F = C - P + 2$$

Substituting the values in above equation

$$F = 1 - 2 + 2 = 1$$

1.5.3 Calibration of Thermometers

- If two different thermometers using alcohol and mercury respectively, are calibrated at ice point and steam point and the distance between ice point and steam point is divided into 100 equal parts then they are not guaranteed to give the same reading anywhere between the calibration points, but they will always give the same readings at the calibration points itself.

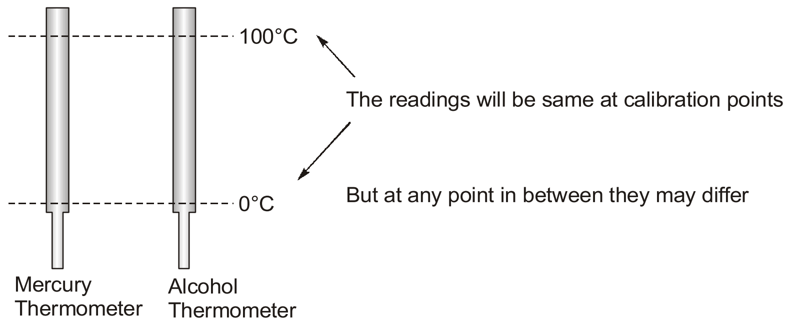


Figure: 1.12

Summary

- Thermodynamics is the science that primarily deals with energy.
- A system with fixed mass is called a closed system and a system that involves mass transfer across it boundary is called an open system.
- Mass dependent properties are called extensive properties and mass independent properties are called intensive properties.
- All temperature measurements are based on Zeroth law.
- Temperature scales are arbitrary/random in nature.

Objective Brain Teasers

Q.1 An open system is one in which
(a) Heat and work cross the boundary, but the mass does not
(b) Mass crosses the boundary, but the heat and work do not
(c) Heat, work and mass cross the boundary
(d) None of heat, work and mass cross the boundary

Q.2 Which of the following is not a point function?
(a) Temperature (b) Pressure
(c) Energy (d) Power

Q.3 Which of the following is an intensive property of a thermodynamics system?
(a) Volume (b) Temperature
(c) Mass (d) Energy

Q.4 Which of the following is the basis of temperature measurement?
(a) Zeroth law of thermodynamics
(b) First law of thermodynamics
(c) Second law of thermodynamics
(d) Third law of thermodynamics

Q.5 The absolute zero pressure will be
(a) When molecular momentum of the system becomes zero
(b) at sea level
(c) at a temperature of –273.15 K
(d) under vacuum conditions

Q.6 The standard fixed point of thermometry is the
(a) ice point
(b) triple point of water

(c) boiling point of water
(d) sulphur point

Q.7 A system comprising of a single phase is called
(a) Closed system
(b) Open system
(c) Heterogeneous system
(d) Homogeneous system

Q.8 A mixture of air and liquid air is
(a) a pure substance
(b) not a pure substance
(c) homogeneous and invariable in chemical composition throughout its mass
(d) one having relative proportions of oxygen and nitrogen constant in gas and liquid phases

Q.9 When mean free path of the molecules of a gas approaches the order of magnitude of the dimensions of the vessel, which concept of the following loses its validity?
(a) Continuum (b) Stability
(c) Equilibrium (d) Entropy

Q.10 Most of the real processes are
(a) quasi-static (b) non-quasi-static
(c) adiabatic (d) isothermal

ANSWERS

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

STUDENT'S ASSIGNMENTS

1. A new temperature scale N is to be defined. The boiling and freezing points of water on this scale are 100°N and 400°N respectively. Then (a) What will be the reading on the new scale corresponding to 60°C? (b) At what temperature both the Celsius and the new temperature scale reading would be same?

[Ans. (a) 220°N, (b) 100°]

2. The reading t_A and t_B for centigrade thermometer A and B graded at ice point 0°C and steam point 100°C are related by the equation $t_A = l + mt_B + nt_B^2$ where l, m, n are constants. When both are immersed in a liquid, A reads 51°C and B reads 50°C. Determine the reading of A when B reads 25°C? Comment on which thermometer is correct.

[Ans. (a) 25.75°C; (b) Not possible to say]

■■■■

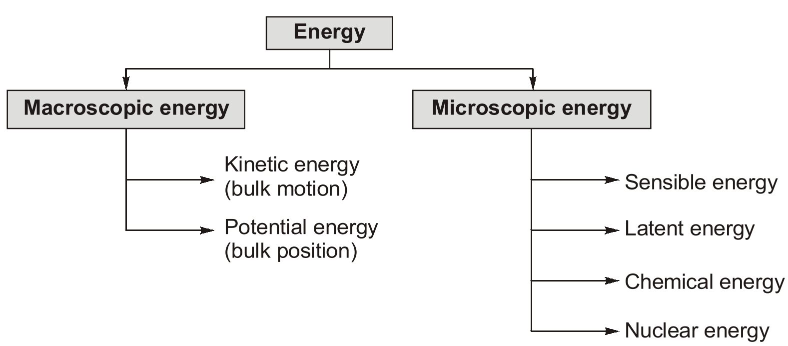
CHAPTER

2

Energy and Energy Interactions

2.1 INTRODUCTION

- Energy can exist in numerous forms such as thermal, mechanical, kinetic, potential, electrical, magnetic, chemical and nuclear, and their sum constitutes total energy *E* of the system. Thermodynamics provides no information about the absolute value of the total energy. It deals only with the change of the total energy.
- In thermodynamics, the various forms of energy are considered in two groups, macroscopic and microscopic forms of energy.
- The energy possessed by the system as a whole with respect to an external reference frame constitute macroscopic forms of energy, such as kinetic and potential energies.
- The energy possessed by the system with respect to then molecular structure and molecular level interactions constitute microscopic forms of energy. The sum of all microscopic forms of energy of a system is called its internal energy and is denoted by *U*.



NOTE

Sensible energy → due to molecular kinetic energy and is temperature dependent.
Latent energy → associated with phase of the system and comes into picture during phase change.
Chemical energy → associated with atomic bonds in a molecule.
Nuclear energy → associated with strong bonds within the nucleus.

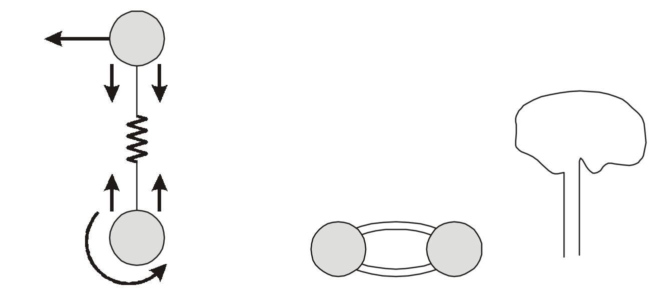


Figure 2.1 Internal energy of a system is sum of all microscopic energies

- Energy interaction for a closed system with its surroundings can take place in two ways:
  (a) by work transfer
  (b) by heat transfer
- Work and heat are modes of energy transfer. The discussion related to their quality will be done later in the second law of thermodynamics.

2.2 WORK

- The work is said to be done by a force when it acts on a body moving in the direction of force. This definition of work is more suitable from mechanics point of view.
- In thermodynamics, work transfer is considered occurring between the system and the surroundings. Work is said to be done by the system if the sole effect on the things external to the system can be converted into raising of weights, though the weight may not be actually raised.
- In Fig. 2.2 (a), a battery is connected to a motor which is in turn driving a fan. The system is doing work on the surroundings. When the fan is replaced by a pulley and a weight as shown in Fig. 2.2 (b), the sole effect on things external to the system is then the raising of a weight.

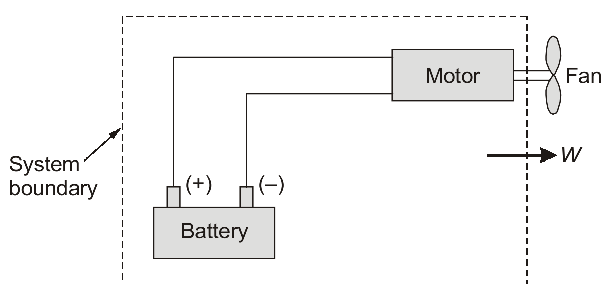


Figure 2.2 (a)

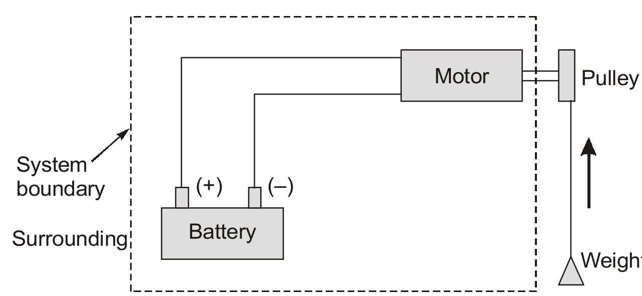


Figure 2.2 (b)

Remember : Force should act on the system boundary and it should cause some displacement in the surroundings. Hence this is also called boundary work.

Types of Work Interaction

(i) Expansion and compression work (Displacement work) – this has been dealt with in detail later.

(ii) Stretching of wire: If a wire is stretched by length dL due to force F, then work done on the system.

$$\delta W = F dl$$

(iii) Electrical work: Electricity flowing in or out is always deemed to be work.

$$\delta W = VI\,dt$$

(iv) Work done in stretching of liquid film: If the soap film is stretched through an area dA.

Then, $$\delta W = \sigma dA$$

where σ is the surface tension. Other examples include work of a reversible chemical cell; work of polarization and magnetization etc.

2.3 CLOSED SYSTEM ANALYSIS

2.3.1 *PdV* or Displacement Work

- Let us consider the raising of the mass m from an initial elevation h_1 to a final elevation h_2 against gravitational force. To raise this mass, the force acting on the mass is given by $F = mg$.

  Thus the work done on the body is

  $W = mg\,(h_2 - h_1)$.

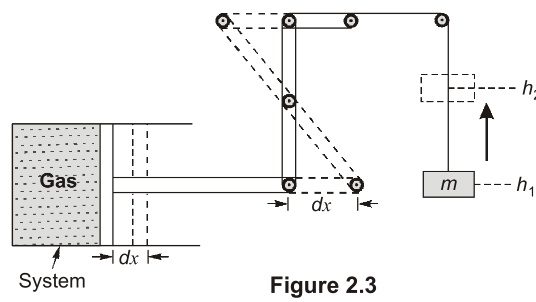


Figure 2.3

- From fig 2.3, it can be seen that expansion of the gas gets reduced to raising of a mass against gravitational force.

$$\delta W = F\,dx$$
$$= PA\,dx$$

Now, $dV = A\,dx$ {small change in volume}

$\therefore$ $\delta W = PdV$

Hence total work: $W = \int \delta W = \int_1^2 PdV$ ...(i)

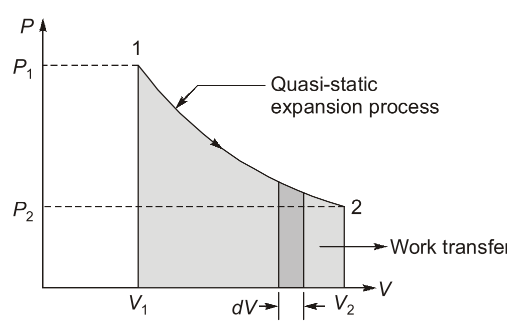


Figure 2.4

- Plotting the above process on a P-V diagram, assuming the process to be quasi-static Fig. 2.4.
- When the piston moves infinitely slowly, the process is reversible and we get a solid line on the P-V diagram. The integration $\int PdV$ gives the work which is actually the area enclosed under the curve on P-V diagram.

Remember : The equation (i), $W = \int PdV$ is applicable for **(a)** Closed system, **(b)** Quasi-static (reversible) process.

- **Sign convention:** The signs of work and heat transfer are arbitrarily chosen. The most followed sign convention for work transfer is:

  Work done by the system is +ve

  Work done on the system is –ve

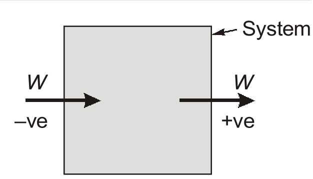


Figure 2.5

Remember : Work is done by a system to overcome some resistance, since vacuum does not offer any resistance there is no work transfer involves in free expansion.

2.3.2 Path Function and Point Function

- With reference to Fig. 2.6 below, it is possible to take a system from state 1 to state 2 along paths labelled *A*, *B* or *C*. As the area enclosed under the curve along each path is different therefore work done along each path is different. Hence work is dependent on the path followed and not just the initial and final states. This makes work a path function and an inexact differential i.e. $W = \int_1^2 \delta W \neq W_2 - W_1$ rather $W = \int_1^2 \delta W = W_{1-2}$ or ${}_1W_2$.

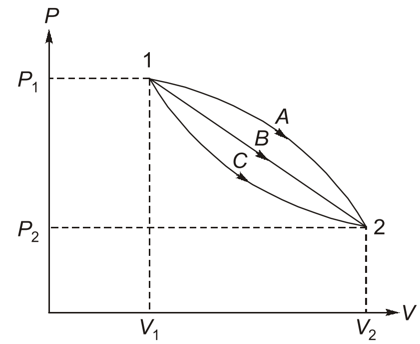


Figure 2.6 Work a Path Function

- The thermodynamic properties (recall chapter 1) like pressure, volume, temperature etc are point functions, since for a given state, there is a definite value for each property. The properties are independent of the path followed and just depend on the state of the system. This also makes them exact differentials i.e. for e.g. $\int_1^2 dV = V_2 - V_1$.

NOTE

For a cyclic process, the initial and final states of the system are the same and hence, the change in any property is zero, i.e. $\oint dV = 0, \oint dP = 0, \oint dT = 0,$ where the symbol $\oint$ denotes the cyclic integral for the closed path.

Remember

Important points with respect to work.

- Work done by the system is taken as positive and work done on the system as negative.
- Work interaction is a path function.
- Work depends on past history.
- It is a boundary phenomenon.
- It is a transient phenomenon and not a property.
- It is an inexact differential.

2.3.3 Non-Flow Work in Various Quasi-Static Processes

1. **Constant Volume Process (isochoric or isometric process)** (Fig. 2.7)

$$W_{1\text{-}2} = \int_1^2 PdV$$

as $dV = 0$ for isochoric process

∴ $W_{1\text{-}2} = 0$

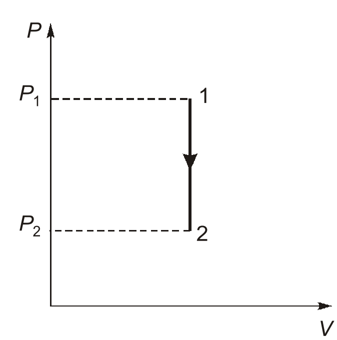


Figure 2.7 Constant Volume Process

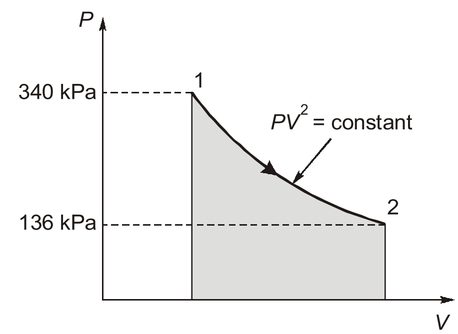
NOTE

- All left to right processes on the *P-V* diagram represent work done by the gas or the system hence are taken positive in nature and vice versa.
- Area enclosed by a cycle on *P-V* diagram represents net work interaction during the cycle.
- All clockwise cycles on *P-V* diagram are power producing cycles and vice-versa.

Example 2.1 A gas expands from an initial state with P_1 = 340 kPa and V_1 = 0.0425 m^3 to a final state where P_2 = 136 kPa. If the pressure volume relationship during the process is PV^2 = constant, determine the work in kJ.

Solution:

Refer to figure



Given: $P_1 = 340$ kPa, $P_2 = 136$ kPa, $V_1 = 0.0425$ m^3

As $PV^2 = C$ {Polytropic process with $n = 2$}

$\therefore$ $P_1V_1^2 = P_2V_2^2$ {Applying between (1) and (2)}

Assumption: (i) Gas is ideal gas (ii) Process is quasi-static

Putting values $340 \times 0.0425^2 = 136 \times V_2^2$

$\Rightarrow$ $V_2 = 0.0672$ m^3

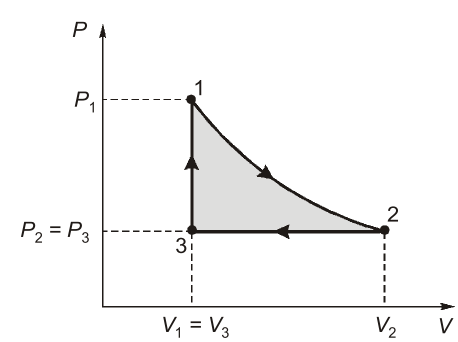
We know for a polytropic process, $W = \dfrac{P_1V_1 - P_2V_2}{n-1}$

$$= \frac{340 \times 0.0425 - 136 \times 0.0672}{2-1} = 5.311 \text{ kJ}$$

Example 2.2 Unit mass of a fluid is contained in a cylinder at an initial pressure of 20 bar. The fluid is allowed to expand reversibly behind a piston according to law PV^2 = constant until the volume is doubled. The fluid is then cooled reversibly at constant pressure until the piston regains its original position; heat is then supplied reversibly with the piston firmly locked in position until the pressure rises to original value of 20 bar. Calculate the net work done by the fluid, for an initial volume of 0.05 m^3.

Solution:

The following *P-V* diagram is plotted with the help of processes given in the problem.



Process 1-2 $\rightarrow$ Polytropic

Process 2-3 $\rightarrow$ Isobaric

Process 3-1 $\rightarrow$ Isochoric

Assumption:

1. Fluid is ideal gas
2. Processes are quasi-static

Given: $P_1 = 20$ bar, $V_1 = 0.05$ m^3

and $PV^2 = C$ for process 1-2,

$V_2 = 2V_1 = 0.1$ m^3

$\therefore$ For process 1-2, $P_1V_1^2 = P_2V_2^2$

$$20 \times 0.05^2 = P_2 \times 0.1^2$$

$$P_2 = 5 \text{ bar}$$

$\therefore$ $$W_{1\text{-}2} = \frac{P_1V_1 - P_2V_2}{n-1} \quad \{\text{Polytropic process work}\}$$

$\Rightarrow$ $$W_{1\text{-}2} = \frac{20 \times 0.05 - 5 \times 0.1}{2-1} \times 10^5 \text{ J} = 50 \text{ kJ}$$

For process 2-3, $V_3 = V_1 \quad P_2 = P_3$

$\therefore$ $$W_{2\text{-}3} = P_2(V_3 - V_2) = 5\,(0.05 - 0.1) \times 100 \text{ kJ}$$

$$W_{2\text{-}3} = -25 \text{ kJ} \quad \{\text{–ve sign implies work done on the fluid}\}$$

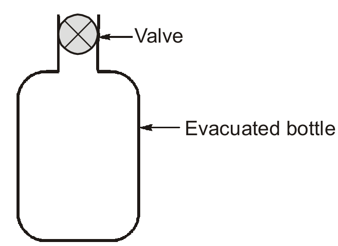
For process 3-1, $W_{3\text{-}1} = 0$ {Isochoric process}

$\therefore$ $$W_{net} = W_{1\text{-}2} + W_{2\text{-}3} + W_{3\text{-}1}$$

$$= 50 - 25 \text{ kJ} = \mathbf{25 \text{ kJ}}$$

NOTE : As W_{net} comes out to be positive, this implies that it is a work producing cycle.

Example 2.3 When the valve of the evacuated bottle as shown in figure is opened atmospheric air rushes into it. If the atmospheric pressure is 101.325 kPa and 0.6 m^3 of air (measured at atmospheric condition) enters into the bottle, calculate the work done by air.



Solution:

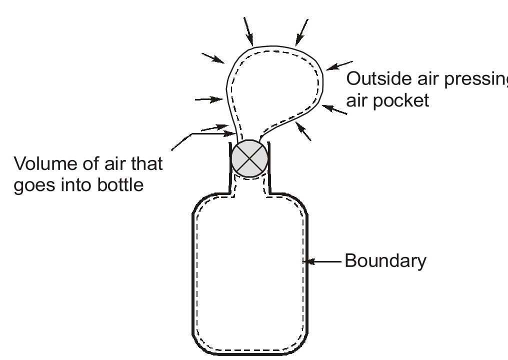
If we take outside air as our system, then the displacement work done by the air

$$W = P_0 \Delta V$$

where P_0 = Atmosphere pressure

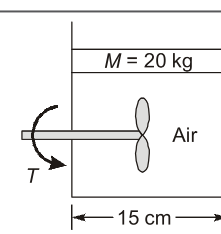
ΔV = Change in volume

$\therefore$ $W = 101.325 \times 0.6 = \mathbf{60.8 \text{ kJ}}$



- This work done is positive if we consider our system as surrounding air (as it pushes air into the bottle).
- If we consider air entering the bottle as our system it will be negative as that amount of work is done on the air entering to make it enter the bottle.

Example 2.4 A paddle wheel as shown in figure requires a torque of 25 Nm to rotate at 100 rpm. If it rotates for 20 seconds, calculate the net work done by the air if the frictionless piston rises by 1 m during this time [Assume P_{atm} = 101.325 kPa]



Objective Brain Teasers

Q.1 A 2 kW electric resistance heater in a room is turned on and kept on for 30 min. The amount of energy transferred to the room is
(a) 1800 kJ (b) 3600 kJ
(c) 7200 kJ (d) 900 kJ

Q.2 In a hot summer day, the air in a well sealed room is circulated by a 0.60 hp fan driven by a 70% efficient motor. The rate of energy supply from the fan motor assembly to the room is
(a) 0.981 kJ/s (b) 0.754 kJ/s
(c) 0.639 kJ/s (d) 0.4721 kJ/s

Q.3 Thermodynamic work is the product of
(a) two intensive properties
(b) two extensive properties
(c) an intensive property and change in an extensive property
(d) an extensive property and change in an intensive property

4. Match **List-I (Parameter)** with **List-II (Property)** and select the correct answer using the codes given below the lists:

List-I	List-II
A. Volume	1. Path function
B. Density	2. Intensive property
C. Pressure	3. Extensive property
D. Work	4. Point function

Codes:

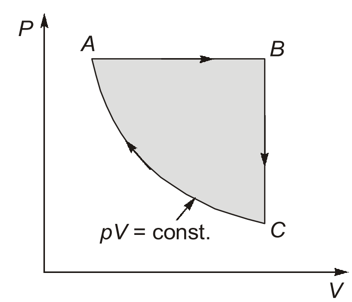
	A	B	C	D
(a)	3	2	4	1
(b)	3	2	1	4
(c)	2	3	4	1
(d)	2	3	1	4

Q.5 A man is pulling a bucket of water up to the roof of a building of 6 m height. The total weight of the rope is 20 N and the weight of the bucket with water is 100 N. The work done by the man is
(a) 720 Nm (b) 660 Nm
(c) 420 Nm (d) 600 Nm

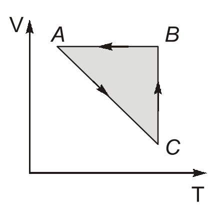
Q.6 One kg of a perfect gas is compressed from pressure P_1 to pressure P_2 by
1. Isothermal process
2. Adiabatic process
3. The law $PV^{1.1}$ = constant

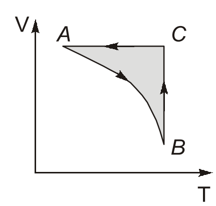
The correct sequence of there processes in increasing order of their slope on P-V diagram is:
(a) 1, 2, 3 (b) 1, 3, 2
(c) 2, 3, 1 (d) 3, 1, 2

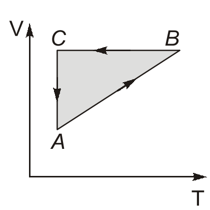
Q.7 A cyclic process ABC is shown on a P-V diagram

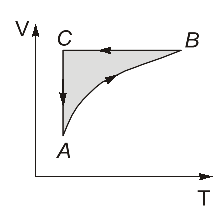


The same process on V-T diagram will be represented by

(a)


(b)


(c)


(d)


Q.8 Polytropic index n is given by
(a) $\dfrac{\ln(P_2/P_1)}{\ln(V_1/V_2)}$ (b) $\dfrac{\ln(P_1/P_2)}{\ln(V_1/V_2)}$
(c) $\dfrac{\ln(V_1/V_2)}{\ln(P_2/P_1)}$ (d) $\dfrac{\ln(V_2/V_1)}{\ln(P_2/P_1)}$

Q.9 Reversible adiabatic process may be expressed as $\frac{T_1}{T_2}$ equal to

(a) $\left(\frac{V_2}{V_1}\right)^{\gamma+1}$ (b) $\left(\frac{V_2}{V_1}\right)^{\frac{(\gamma+1)}{\gamma}}$

(c) $\left(\frac{P_1}{P_2}\right)^{\frac{(\gamma-1)}{\gamma}}$ (d) $\left(\frac{P_1}{P_2}\right)^{\gamma-1}$

Q.10 A gas is so expanded in a cylinder that its temperature remains constant. The resulting variation of pressure vs volume is

(a) A parabola (b) A hyperbola
(c) A straight line (d) None of these

Q.11 When air expands from initial pressure, P_1 and volume V_1 to final volume $5V_1$ following the law $pV^n = C$

(a) greater the value of n, greater the work obtained
(b) smaller the value of n, smaller the work obtained
(c) for $n = 0$, the work obtained is greatest
(d) for $n = 1.4$, the work obtained is greatest

Q.12 When the gas expands under adiabatic conditions, its temperature

(a) increase (b) decreases
(c) does not change (d) None of these

Q.13 What mass of steam at 100°C must be mixed with 150 g of ice at 0°C, in a thermally insulated container to produce liquid water at 50°C? Take L_f of ice = 333 kJ/kg, L_V of water = 2256 kJ/kg and c of water = 4.19 kJ/kg K.

(a) 0.022 kg (b) 0.033 kg
(c) 0.044 kg (d) 0.055 kg

Linked Date Question Q.14 to Q.15

An aluminium electric kettle of mass 0.560 kg contours a 2.4 kW heating element. It is filled with 0.640 L of water at 12°C.
Given c_{Al} = 0.9 kJ/kgK, c_{water} = 4.19 kJ/kgK, L_V for water = 2256 kJ/kgK, ρ_{water} = 998 kg/m^3

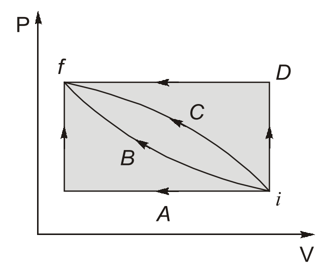
Q.14 How long will it take for the boiling to begin?

(a) 105 s (b) 110 s
(c) 117 s (d) 134 s

Q.15 Total time taken for the kettle to boil dry (Assume that the temperature of the kettle does not exceed 100°C at any time)

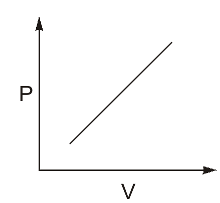
(a) 117 s (b) 600 s
(c) 483 s (d) 717 s

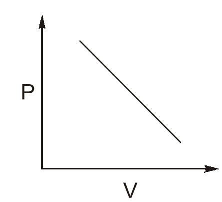
Q.16 In which of the paths between initial state i and final state f in the below figure is the work done on the gas, the greatest?

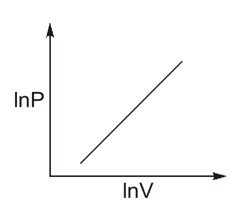


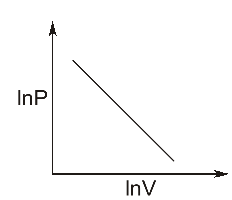
(a) A (b) B
(c) C (d) D

Q.17 In a closed system, the adiabatic reversible expansion of an ideal gas with constant specific heats is represented by

(a) 

(b) 

(c) 

(d) 

■ ANSWERS

1.	(b)	**2.**	(c)	**3.**	(c)	**4.**	(a)	**5.**	(b)
6.	(b)	**7.**	(c)	**8.**	(a)	**9.**	(c)	**10.**	(b)
11.	(c)	**12.**	(b)	**13.**	(b)	**14.**	(c)	**15.**	(d)
16.	(d)	**17.**	(d)						

Hints & Explanation

1. (b)

Given, $P = 2$ kW; $t = 30$ min

$\therefore$ Energy supplied to room

= Energy used by heater

$= P \times t = 2 \times 30 \times 60$

= 3600 kJ

2. (c)

$$P_{fan} = 0.6 \text{ hp}; \quad \eta_{motor} = 0.7$$

$$1 \text{ hp} = 746 \text{ W} = 0.746 \text{ kW}$$

$$\therefore \quad P_{fan} = 0.6 \times 0.746 \text{ kW}$$

$$P_{supplied} = \frac{P_{fan}}{\eta_{motor}} = \frac{0.6 \times 0.746}{0.7}$$

$$= 0.639 \text{ kJ/s}$$

3. (c)

We know by definition thermodynamic work

W = Displacement work

$$= \int pdv$$

here, p = Intensive property

and V = Extensive property

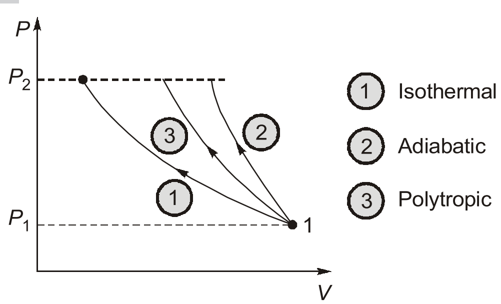
Hence option (c) is correct

5. (b)

$$\text{Work done} = 100 \times 6 + 20 \times \frac{6}{2}$$

$$= 660 \text{ N}$$

6. (b)



$\therefore$ The correct sequence of slope in increasing order is 1, 3, 2

7. (c)

Process $AB \rightarrow$ Constant pressure

Process $BC \rightarrow$ Constant volume

Process $CA \rightarrow$ isothermal ($pV = C$)

for A-B $\quad pV = mRT$

$\therefore \quad V \propto T \Rightarrow V = kT$

Straight line through origin.

8. (a)

For a polytropic process $pV^n = C$

Taking $\log_e$ on both sides, we get

$$\ln P + n \ln V = C'$$

Now applying it in between (1) and (2)

$$\ln P_1 + n \ln V_1 = \ln P_2 + n \ln V_2$$

$$n(\ln V_1 - \ln V_2) = \ln P_2 - \ln P_1$$

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

9. (c)

For reversible adiabatic assuming ideal gas

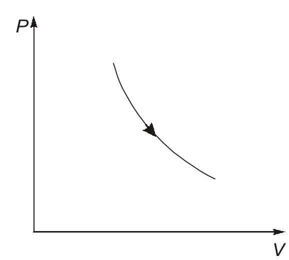
We know $\quad \dfrac{T_1}{T_2} = \left(\dfrac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}} = \left(\dfrac{V_2}{V_1}\right)^{\gamma-1}$

10. (b)

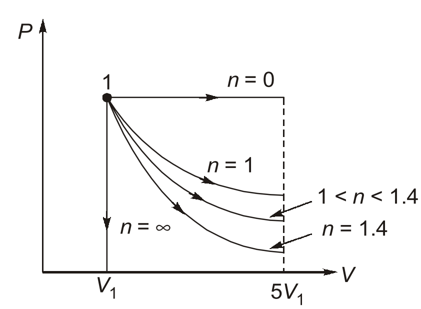
The process is isothermal i.e.

pV = Constant

Thus the nature of the curve is a hyperbola



11. (c)



As can be seen, area enclosed under the curve is maximum in case of

$$n = 0$$

$\therefore \quad W_{max}$ for $n = 0$