

UNIT 1 BASIC CONCEPTS OF THERMODYNAMICS

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1.1 INTRODUCTION

In your daily life you might have observed that when you use a bicycle pump to inflate the tyre, the pump gets hot. Similarly when you rub your hands together you get the feeling of warmth. In these examples, the heating is not caused in the conventional way by putting a flame or something hot underneath the pump or the hand. But it arises as a result of the mechanical work done in compressing the gas in the pump or forcing the hand to move against friction. These examples show that there is a relation between mechanical and thermal effects. The study of the relationships between mechanical and thermal energy is known as thermodynamics.

The study of thermodynamics is based on Four empirical laws, that is, thermodynamics is a phenomenological science. This means that the laws are derived from experience and they need no proof. These laws find application in design of internal combustion engines, refrigeration and air conditioning systems, power stations etc. With the help of these laws one can determine the efficiency of all types of mechanical devices such as steam engines, electric power plants and automobiles. These laws are also used to analyse energy transformations in bio-chemical and geological systems,

In this unit we will discuss the basic concepts which will be used in the study of thermodynamics. We will also introduce the concept of temperature through the zeroth law of thermodynamics. Finally, you will learn to use the equation of state for deriving mathematical relations between quantities such as coefficient of volume expansion, compressibilities, elasticity, etc.

In the next unit you will read about the principles of measurement of temperature.

Objectives

After studying this unit, you should be able to

- identify several thermodynamic systems with its surroundings and boundaries
- explain what are thermodynamic variables and identify these variables for several systems
- explain thermal, mechanical and chemical equilibria
- distinguish between a reversible and an irreversible process
- understand the importance of a quasistatic process

- identify and represent different kinds of thermodynamic processes
- explain the concept of temperature using the zeroth law of thermodynamics
- apply the equation of state of a system to solve problems in thermodynamics.

1.2 THERMODYNAMIC SYSTEMS

Whenever we read a biography our attention gets drawn towards an individual. We get to know about his achievements, how he has interacted with other individuals and many such other things. To the reader's mind this individual assumes the role of someone who is distinct from others and around whom the biography develops almost like a story. Likewise, for any kind of study in thermodynamics we need to set aside a certain quantity of matter or a region of space which is considered distinct and separated from everything else, which can influence it. We refer to this as thermodynamic system or simply a system. Every such system is enclosed by an arbitrary surface which is called its boundary. The boundary may be real or imaginary, either in rest or in motion and may change its size or shape. The region of space that lies outside the boundary of a system is called its surroundings. Strictly speaking everything other than the system is its surroundings. But in thermodynamics we consider that portion as the effective surroundings of a system which can influence it. In Unit 3, you will read about the different manners in which the surroundings can influence a system. Any study in thermodynamics begins with the identification of the system, its boundary and its surroundings. These are schematically illustrated in Fig. 1.1. Let us now take up some specific examples of systems with different kinds of boundaries.

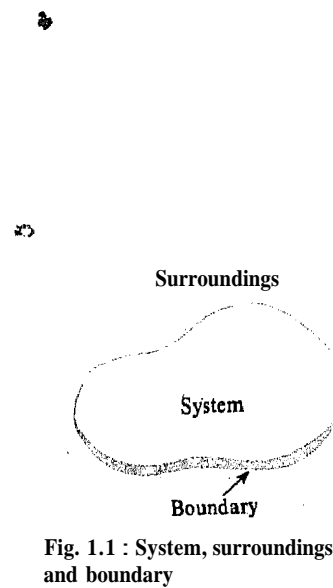


Fig. 1.1 : System, surroundings and boundary

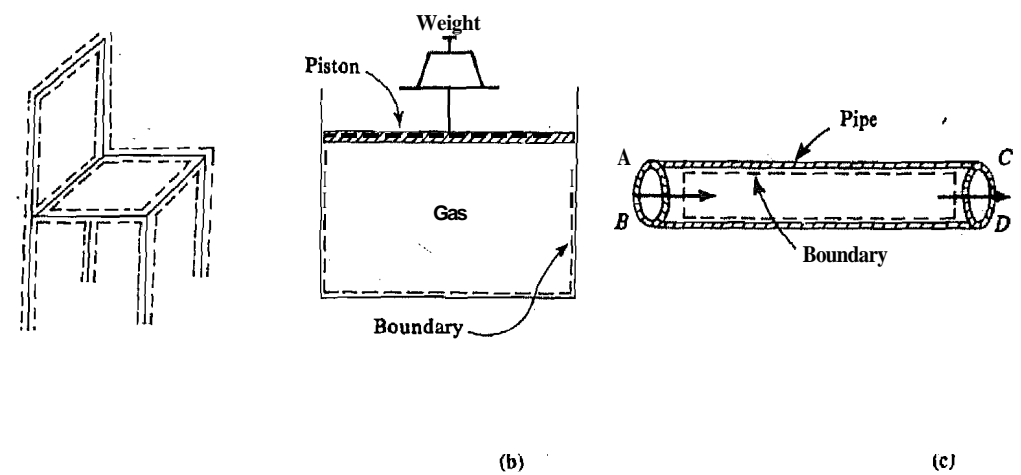


Fig. 1.2: Several thermodynamic systems and their boundaries. In each case the boundary is shown by means of a dotted line. (a) The chair system, (b) Compressed gas in a cylinder, (c) Flow of liquid through a pipe.

For the chair system (Fig. 1.2a) the boundary is real and fixed. Everything other than the chair constitutes the surroundings. For the system of a compressed gas in a cylinder (Fig. 1.2b) the boundary is real. It is movable as the inner surface of the piston, which is a part of the boundary, can be moved. Everything outside the gas, including the piston and the cylinder, is the surroundings. For the system of a certain mass of liquid flowing along a pipe as shown in Fig. 1.2c the boundary is imaginary. The inside surface of the pipe may form a part of the boundary as it presents an obstruction to the flow of liquid. But there is no real obstruction at the two ends AB and CD. So a real boundary does not exist. However, the dotted line is one possible choice of a boundary, fixed in space. Such type of boundary is imaginary. Everything lying outside this imaginary boundary is the surroundings.

A system may be simple, such as water in a vessel; or complex like a Daniel cell, which has Zn and Cu electrodes, dilute H_2SO_4 electrolyte and CuSO_4 depolariser. A system may be completely uniform with respect to its chemical composition and physical conditions (homogeneous) or otherwise (heterogeneous). For instance, air in a cylinder, air being a mixture of gases (N_2 , O_2 , CO_2 , etc.) is a homogeneous system. This is because the constituent gases have the same composition throughout. Whereas ice and water in a beaker form a heterogeneous system of a solid and a liquid.

The classification of systems from the point of view of its interaction with its surroundings is of more importance in thermodynamics. We shall do that now.

1.2.1 Classification of Systems

Closed System : A closed system consists of a fixed amount of mass. It is also known as control mass. No mass can cross its boundary. But energy can cross the boundary and the volume of such a system need not be fixed (Fig. 1.3).

For example, let us again consider the case of the enclosed gas in a cylinder fitted with a piston (Fig. 1.2b). In this case the gas is a system. The inner surfaces of the piston and the surface of the cylinder form the boundary. As no mass can cross this boundary it is a closed system. You must note that energy may cross the boundary.

Open System: An open system is a properly selected region in space which has a fixed volume. It is also known as control volume. Both mass and energy can cross its boundary (Fig. 1.4).

As an example of such a system let us consider the water heater shown in Fig. 1.5. Suppose the water in the tank is heated in order to get a steady supply of stream of hot water. Since hot water will leave the tank and will get replaced by cold water, it is not convenient to choose a fixed mass of water as our system. Instead we can direct our attention on the volume formed by the inner surfaces of the tank. Then we can consider the hot and cold water streams as mass leaving and entering the control volume or the open system.

Isolated system : An isolated system is that for which there can be no interchange of energy with the surroundings. The contents of an ideally sealed thermos flask is an example of such a system.

While reading about the classification of systems did you realise that the characteristics of the boundary plays an important role in determining the nature of the system. So let us now study about the different kinds of boundary.

1.2.2 Classification of Boundaries

- Diathermal Boundary:** If the boundary is such that heat can flow between the system and its surroundings, then we say that it is diathermal or thermally conducting and the system is in thermal contact with the surroundings. A metallic tea pot provides a diathermal boundary to its contents.
- Adiabatic Boundary :** If the boundary is such that it does not allow any heat flow across it, then we refer to it as an adiabatic boundary and the system is said to be thermally isolated. The walls of an ideal thermos flask are adiabatic and a filled thermos is an example of a thermally isolated system.
- Rigid Boundary :** If the boundary is such that it cannot be moved, however great an external force acting on it might be, we call it rigid. A system having such a boundary can neither be compressed nor expanded. Strictly speaking, an ideal rigid boundary does not exist. The surface of a heavy spherical ball (used for "shot put") is a close approximation to a rigid boundary.
- Permeable Boundary :** If the boundary allows exchange of matter, we refer to it as permeable.
- Semi-permeable Boundary :** The boundary which permits some components to pass through and stops others is known as semi-permeable. For example, hot quartz allows helium to pass but stops other gases.

Now you may like to work out an SAQ based on what you have learnt so far.

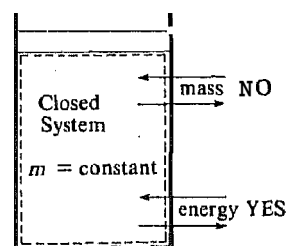


Fig. 1.3 : Characteristics of a closed system

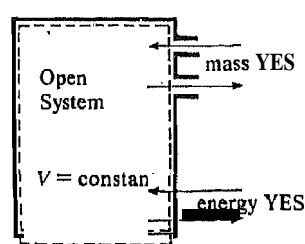


Fig. 1.4 : Characteristics of an open system

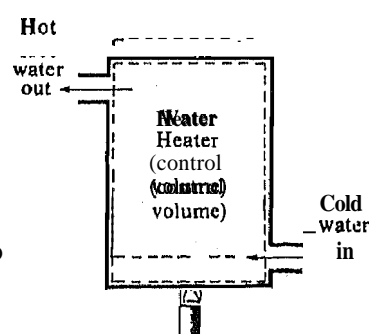


Fig. 1.5 : An open system with one inlet and one exit

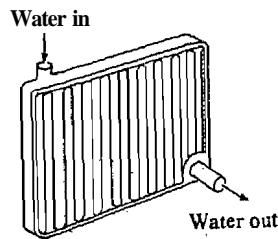


Fig. 1.6 : Car Engine Radiator

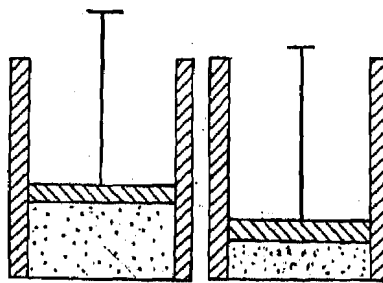


Fig. 1.7 : Different set of values of pressure and volume in (a) and (b) shows two different states of the same system

You know that the pressure of a gas can be related to the average rate of change of momentum due to the collision of the molecules made on a unit area of the wall of the container in which it is kept. Higher the rate of change of momentum, higher the pressure. Similarly, the temperature of a gas can be related to the average kinetic energy of translation of its molecules. This means that the system can also be described in terms of the properties of the

atoms and molecules that constitute the system. These properties are not directly perceptible and are referred to as microscopic properties. You will be required to describe a system in the above manner while studying its thermodynamic behaviour using statistical methods. You will do that in Block 4 of this course.

SAQ 1

- Cite an example (different from what you have read just now) each for a system with (i) a real fixed boundary, (ii) a real movable boundary, and (iii) an imaginary boundary.
- The schematic diagram of a car engine radiator is shown in Fig. 1.6. Should it be modelled as a closed or an open system?
- A bottle of soft drink at room temperature is put into the refrigerator so that it can cool. Would you model the bottle of soft drink as a closed or an open system?
- A rose plant in a garden is an example of an open system. Comment.
- Mention the nature of the system (i.e. open, closed or isolated) that is enclosed by a (i) diathermal boundary, (ii) permeable boundary.

Now, you learnt what is meant by a system and its surroundings. For a particular problem these must be properly defined as per its requirement and the boundary must fulfil the conditions imposed by it.

As an illustration of the statement made above, suppose you want to assess the performance of a refrigerator kept in your dining room. Here the refrigerator along with its contents forms a system, its walls the boundary and the room in which it is placed constitutes its surroundings. However, if we consider the problem of air conditioning of the same dining room, then the room itself becomes the system while its walls, roof, doors, windows etc. constitute the boundary and its neighbouring rooms, verandah, etc. are its surroundings.

Thus you have learnt to identify a thermodynamic system, its surroundings and its boundary. Once we have selected a system for study, we must be able to describe it in terms of precise numerical quantities. For example in mechanics we need to define primarily the position and velocity of a particle in order to describe its motion. We say that the variables viz. position and velocity specify the mechanical state of the particle. Likewise we define the thermodynamic state of a system about which you will study now.

1.3 THERMODYNAMIC STATE OF A SYSTEM AND THERMODYNAMIC VARIABLES

In thermodynamics a system is described by specifying its physical properties such as pressure, volume, temperature, mass, density etc. For example, the state of a gas is characterised by the value of its temperature, pressure and volume. The state of a stretched wire is specified by its length and tension in it. These physical properties or parameters are called thermodynamic variables. The value of a property, which uniquely defines the state of a system, is always fixed. This value depends on the condition of the system at that particular instant at which the property is being measured. For example, the pressure and volume of a system of a gas kept in cylinder have fixed but different values in the two conditions shown in Fig. 1.7a and 1.7b. Therefore, the state of a system means specifying those properties of the system which ensure that it is uniquely defined.

You must note that the properties mentioned above can be measured directly using calibrated devices. In other words they can be perceived by our senses. These properties which represent the gross characteristics of the system are called macroscopic properties.

There are two classes of thermodynamic variables – intensive and extensive. Let us study the difference between them.

1.3.1 Intensive and Extensive Variables

Let us consider a system A as shown in Fig. 1.8. Suppose it is divided into two parts A_1 and A_2 having equal masses. Now if you measure the temperature of system A and then of the systems A_1 and A_2 you will find that its value is the same. But the volume of the systems A_1 and A_2 is different from that of system A . Those variables which have the same values when the system is sub-divided or multiplied in size are called intensive and those variables for which values are altered are called extensive. Here, pressure and temperature are intensive whereas mass and volume are

extensive. The intensive variables are independent of mass whereas the extensive variables are dependent on mass. We have given below a list of systems along with intensive and extensive variables describing them. Some places are kept vacant for you to fill up.

Table 1.1: Thermodynamic Variables

System	Intensive variable(s)	Extensive variable(s)
Gas in a cylinder	pressure (p) temperature (T) density (ρ)	mass (m) volume (V)
Paramagnetic solid	flux density (B)	intensity of magnetisation (M)
Stretched wire	tension (F)	— —
Surface film	— —	area (A)
Electric cell	— —	— —

SAQ 2

- Fill in the gaps in Table 1.1.
- "If f and g are two extensive variables, f/g is intensive." Justify this statement with the help of an example.
- What are the thermodynamic variables required for specifying the following systems :
 - Air inside a bicycle pump
 - A dielectric substance placed in an electric field.

At times the state of a system may be completely identified even from a knowledge of some of its properties. This is because the values of all remaining properties can be obtained using the known properties. For example, say, we know the values of pressure (p), volume (V) and the number of molecules (n) of an ideal gas. Then we can obtain its temperature (T) by using the ideal gas equation

$$pV = nRT \quad (1.1)$$

An equation of the type (1.1) is called an equation of state. It is a relation between the values of the variables p , V , n and T , when the system has attained equilibrium. In fact the properties of a system are truly defined only when it is in equilibrium. We refer to this as thermodynamic equilibrium. Let us learn about this in some detail

1.3.2 Thermodynamic Equilibrium

Suppose you have some water at 60°C in a container. If the container filled with water is left to itself it would finally attain the room temperature. This means that the water in the container interacts with the surroundings, and its temperature decreases with time. When it attains the room temperature, i.e. a temperature equal to that of the surroundings there occurs no further change in its temperature. We say that the water in the container has attained thermal equilibrium with the surroundings.

If within the system, there are variations in pressure or elastic stress then parts of the system may move or expand or contract. Eventually when these expansions or contractions will cease, i.e. when there will be no unbalanced forces or torques acting on the system, it will be in mechanical equilibrium. For example, during the formation of the earth it was in a molten state. So the centrifugal force due to the axial rotation of the earth was greater than the cohesive force. Since the centrifugal force is maximum at the equator and decreases with latitude becoming minimum at the poles, the earth bulged out at the equator in the process of attaining mechanical equilibrium.

Finally, suppose that a system contains substances that can react chemically. After a sufficient time when all possible chemical reactions will have taken place, the system is then said to be in chemical equilibrium. In other words, a mixture of substances is in chemical equilibrium if there is no tendency for a chemical reaction to occur.

A system which is in thermal, mechanical and chemical equilibrium is said to be in thermodynamic equilibrium. Under this condition the macroscopic properties of a

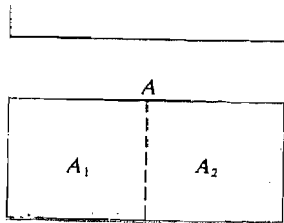


Fig. 1.8 : Illustrating the difference between intensive and extensive variables.

Strictly speaking, in addition to thermal, mechanical and chemical equilibria, one must include the aspect of phase equilibrium. However we shall not consider this now. You will get to know about this in Unit 9, Block 2.

system do not change with time. Thus, from now onward, by the phrase 'state of a system' we will mean an equilibrium state.

Now that you have learnt about an equilibrium state, we shall now discuss how a system goes from one equilibrium state to another.

1.4 THERMODYNAMIC PROCESS

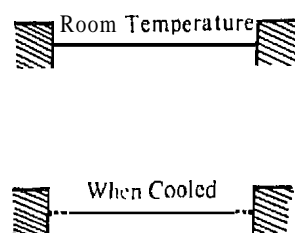


Fig. 1.9 : Tension is developed in the wire when it is allowed to cool. The wire is said to have executed a thermodynamic process.

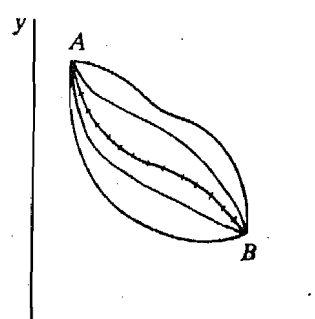


Fig. 1.10 : Graphical representation of several processes occurring between A and B

When any of the thermodynamic variables associated with a system undergoes change in its value while going from one equilibrium state to another the system is said to execute a thermodynamic process. Thus, a process signifies change of a system from one equilibrium state, called the initial state, to another equilibrium state, called the final state. For example, the expansion of a gas in a cylinder at constant pressure due to heating is a thermodynamic process. Again suppose a wire is stretched taut between two rigid supports (Fig. 1.9a). It has a certain tension and length. Now, if this wire is allowed to cool it would shrink. Since the wire is not permitted to shrink, a tension is developed in the wire to stretch it (Fig. 1.9b). So it will have a different tension and length, and will be said to have executed a thermodynamic process.

In the subsequent units, as you will see, our aim will be to analyse thermodynamic processes. In order to do that, first we would like to represent a thermodynamic process graphically. Suppose two variables x and y specify a system. Refer to Fig. 1.10. Here A is the initial equilibrium state represented by the coordinates (x_A, y_A) and B is the final equilibrium state represented by the coordinates (x_B, y_B) . The points A and B are joined. Such a graphical representation of the thermodynamic process is called a **path**. Notice that you can join the points in several ways as shown in Fig. 1.10. But in whichever way you draw a path, you would like that the intermediate points must also be defined by specific coordinates. What does this imply? It implies that all the intermediate stages between A and B must be equilibrium states. But is it possible in practice? To answer this question we shall first define two kinds of thermodynamic processes.

1.4.1 Reversible and Irreversible Processes

If a process is executed in a very slow and controlled manner so that all the intermediate states between the initial and final one are in equilibrium and if necessary the process may be executed back along the same equilibrium states from the final to the initial state then it is called reversible. If the above conditions are not satisfied then it is called irreversible.

Now let us take an example to see whether a reversible process can be executed in practice or not.

Suppose a cylinder containing gas is fitted with a piston (Fig. 1.11a). The volume occupied by the gas is V . The weight W placed on the piston is such that on its removal the piston takes up the position $A'B'$ and the volume of the gas becomes $2V$. Now suppose we want to increase the volume of the gas to $2V$. If we do it just by removing W , the process would be irreversible as it occurs quickly. (The volume of gas will become $2V$ immediately on removing W .)

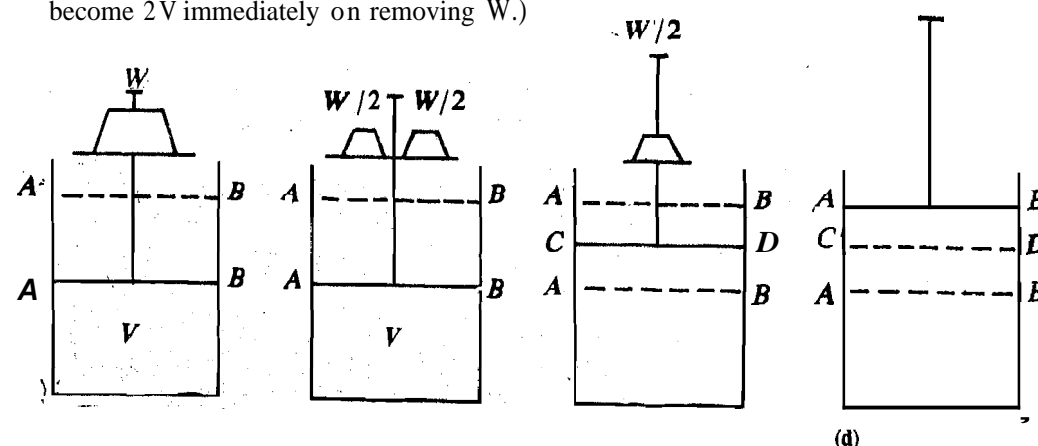


Fig. 1.11: Demonstration showing that a reversible process cannot be achieved in practice; it can only be idealised

Now instead of having a single weight W , if we take two weights, each equal to $W/2$ (Fig. 1.11b), the situation is similar to that of Fig. 1.11a. Now, on removing one such weight the piston will take up a position CD midway between AB and $A'B'$ (Fig. 1.11c). Then on removing the next weight it goes to $A'B'$ (Fig. 1.11d). Thus we get one intermediate equilibrium state (denoted by CD) between the initial and final states.

Likewise by using three weights, each equal to $W/3$, we can generate two intermediate equilibrium states. By using n equal weights, each equal to W/n , we can generate $(n-1)$ intermediate equilibrium states. But for this expansion process to be reversible all the intermediate states must be in equilibrium. For this n has to be infinity, which is impossible. This indicates that a reversible process can only be idealised and cannot be achieved in practice.

You must note that a system can be restored to its initial state either by a reversible or an irreversible process. But, for a reversible process, this restoration is made without leaving any net change in the surroundings, whereas for an irreversible process, there occurs some change in the surroundings. For example suppose a pendulum bob (Fig. 1.12) is released from the position A . It goes up to B and then again comes to A , i.e. the initial state. In doing so the pendulum bob is restored to its original state but there occurs a slight change in the temperature of the surroundings because the bob has to overcome air resistance in course of its motion. So the process is irreversible. Had the pendulum been set up in perfect vacuum, air resistance would have been totally absent and hence there would have been no change in the temperature of the surroundings. Thus the process would have been reversible. But as you know perfect vacuum can never be created. This again shows that a reversible process can only be idealised and never be achieved in practice.

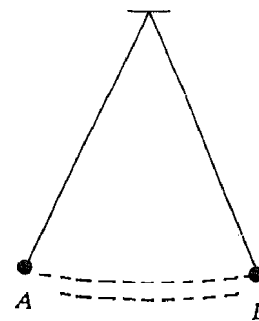


Fig. 1.12 : When the pendulum bob swings from the position A to B and then back to A , there is a slight change in the temperature of the surroundings due to air resistance showing that the process is irreversible.

Thus we understand that all natural processes are irreversible.

This means that for such processes, the intermediate stages are not in equilibrium and hence such processes cannot be represented by a path. If it cannot be represented by a path then its analysis from thermodynamic point of view is not possible. This raises a very vital question. Can we not at all analyse natural processes thermodynamically? The answer lies in the description of a quasistatic process which we shall study now.

1.4.2 Quasistatic Process

If a process is so executed that it passes through states which are not equilibrium states but deviates only infinitesimally from equilibrium, then it is called **quasistatic**. Thus a quasistatic (i.e., almost static) process closely approximates a succession of equilibrium states. If there are finite departures from equilibrium, the process is **non-quasistatic**.

Suppose we wish to increase the temperature of a system from an initial value T_1 to a final value T_2 . The temperature could be increased by enclosing the system in a diathermal boundary and maintaining the surroundings of the system at the temperature T_2 . But this process would not be quasistatic because the temperature of the system near its boundary would increase more rapidly than at the internal points. To increase the temperature quasistatically, the temperature of the surroundings be kept at the initial temperature T_1 and then this temperature should be increased sufficiently slowly so that at all times it is only infinitesimally greater than that of the system.

Now, all actual processes are non-quasistatic because during the process, there always exists a finite difference of pressure, temperature, etc. between several parts of a system. So for dealing with such a process we shall visualise it as being executed quasistatically. This will enable us to analyse the process. You will be able to appreciate the above statement when you solve actual problems.

You may now like to work out an SAQ on the concepts of reversible and irreversible processes.

SAQ 3

- a) Classify the following processes as reversible or irreversible.
- A gas enclosed in a cylinder provided with a frictionless piston is quickly compressed
 - Mixing of sugar in milk
 - Oscillations of an ideal simple pendulum with a frictionless support.

b) Energy is dissipated during an irreversible process — illustrate this statement with the help of an example.

Before moving on to next sub-section try to do an activity which will enable you to understand quasistatic process more clearly.

Activity

Take any clock which has all the three hands. Observe the movement of the second-hand. Compare its movement with the movement of minute and hour-hand. Comment.

Now that you have learnt about a quasistatic process, we can discuss about *the* representation of an actual process.

1.4.3 Representation of a Process on an Indicator Diagram

You must have realised that the stages of a quasistatic process are a series of approximately equilibrium states. As you have seen in Fig. 1.10, equilibrium states can be indicated by a series of points in the xy -plane where x and y are two thermodynamic variables. As you know, a curve through these points represents the path of the process. Such a representation is known as an indicator diagram. Let us now learn to represent an actual process on an indicator diagram.

Consider a gas contained in a cylinder C fitted with a frictionless piston P having diathermal walls and immersed in a constant temperature water bath as shown in Fig. 1.13a.

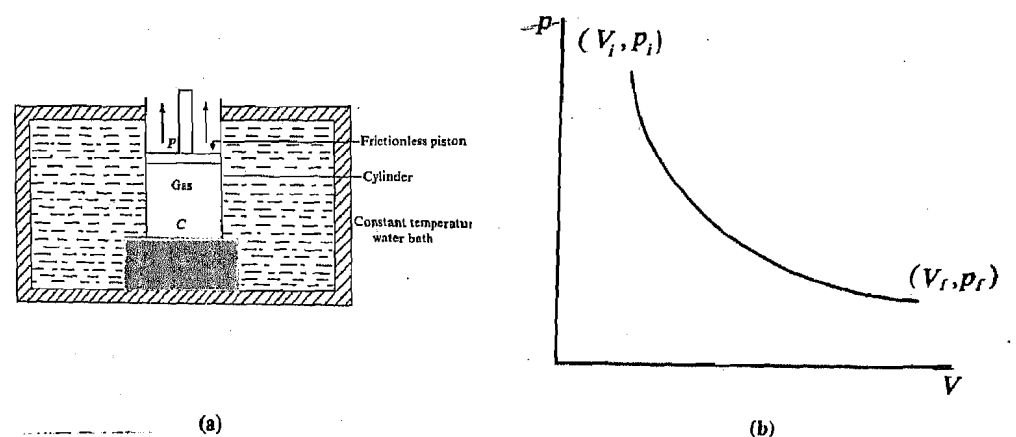


Fig. 1.13(a) : Arrangement for expansion of a gas at constant temperature. (b) p vs. V diagram for a quasistatic isothermal expansion of a gas. It is also referred to as an indicator diagram.

Suppose that the initial state of the gas is defined by (p_i, V_i, T_i) . Now, we pull out the piston very slowly so that the gas expands at constant temperature in such a way that at any instant the external pressure on the piston differs from the gas pressure by an infinitesimal amount dp . Let the final state of the gas be (p_f, V_f, T_i) . While undergoing change from the initial state to the final state, the system is characterised by a series of values of p and V differing only infinitesimally from each other. The plot of these successive values with V along the abscissa and p along the ordinate gives us the required representation (Fig. 1.13b).

So far we have classified processes on the basis of the pace of their execution. We can also classify processes, on the basis of the fact that some property of the system remains constant during the process. That is, one of the variables of the system remains constant. We specify these processes by using the prefix 'iso' before that property. For example, in the abovesaid process, the gas has been expanded at constant temperature. Thus, the above process is isothermal. If a process takes place at constant pressure, we label it as isobaric. A process taking place at constant volume is called isochoric or isovolumic or isovolumetric. A change of state (i.e. water to steam or water to ice) takes place at constant temperature and pressure. This is an example of isothermal-isobaric process.

Furthermore, if the system has adiabatic boundaries and the process takes place without any exchange of heat between the system and the surroundings, we refer to

it as an adiabatic process. For example, a single stroke of the piston or an internal combustion engine is very nearly adiabatic. The reason is that the duration of the process is extremely small and no heat can flow in or out of the system during this time.

If the transformation of the system is such that it returns to its original state covering any path, then we say that it has undergone a cyclic process. The working substances of all heat engines and refrigerators go through several cycles of operation.

We have represented some of the above-mentioned processes on the p-V diagrams (Fig. 1.14) below:

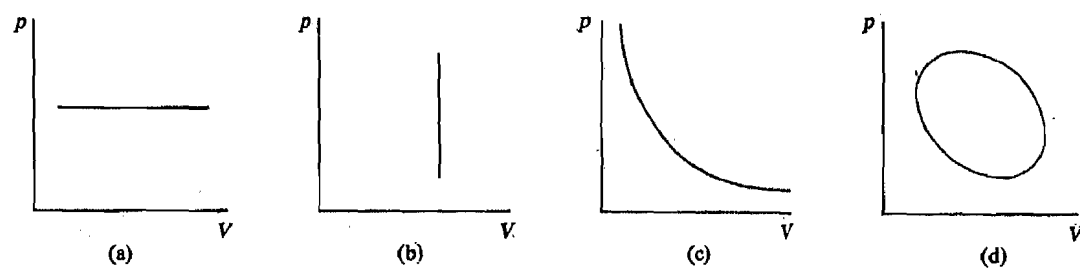


Fig. 1.14: (a) isobaric (b) isochoric (c) isothermal (d) cyclic

You may now like to work out an SAQ on the representation of processes.

SAQ 4

Draw V-T and p-T diagrams for a perfect gas undergoing following processes.

(i) Isobaric expansion (ii) Isochoric compression (iii) Isothermal compression.

Before proceeding further it would be worthwhile to know how the concept of temperature got introduced. Actually, we have been using the term temperature quite freely (since it is very familiar to you) but its basis lies in a law of thermodynamics. Let us study this law which is known as the zeroth law.

1.5 THE ZEROTH LAW OF THERMODYNAMICS

The zeroth law of thermodynamics states :

"If two systems A_1 and A_2 are in thermal equilibrium independently with a third system A_3 , then A_1 and A_2 are also in thermal equilibrium with each other."

Let us discuss the meaning of this law. Refer to Fig. 1.15a.

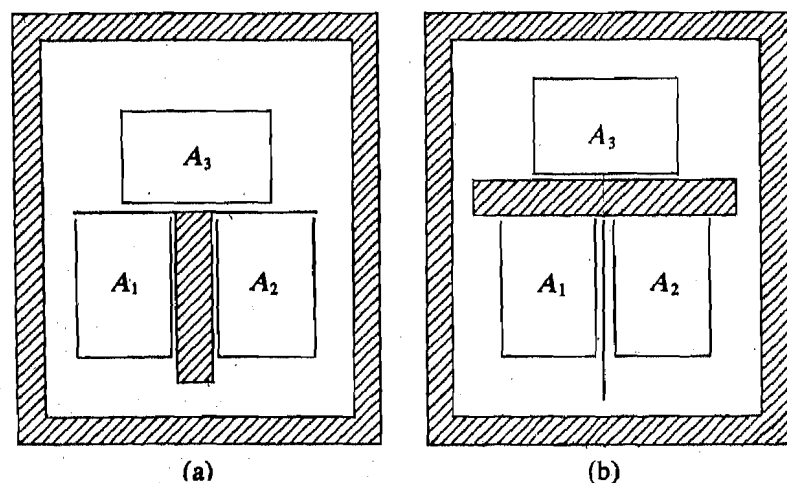


Fig. 1.15 : The Zeroth law of thermodynamics (adiabatic walls are denoted by shading and diathermic walls by solid lines) : (a) A_1 and A_2 are in thermal contact with A_3 . (b) A_1 and A_2 are in thermal contact with one another.

Here A_1 and A_2 are two systems separated by adiabatic walls. They are in thermal contact with another system A_3 . Both A_1 and A_2 individually will come in thermal equilibrium with A_3 . If now A_1 and A_2 are put in thermal contact with each other (Fig. 1.15b) then according to the zeroth law both A_1 and A_2 will be in thermal equilibrium.

All bodies in thermal equilibrium must have a common property which has the same value for all of them. This property is called the temperature. Thus the temperature of a body is the property which determines whether or not the body is in thermal equilibrium with other bodies. The phenomenon that two things in contact tend towards a common temperature is so common that its importance has been overlooked. When physicists finally did appreciate its significance and fundamental nature, it was decided to have it elevated to the status of a "Law of thermodynamics". By that time the first and second laws were already enunciated. So in order to place it ahead of these laws it is named as the zeroth law.

Now we would like you to look at Eq. (1.1) and read once again the paragraph following it. Eq. (1.1) is quite well known to you. Can such relations, exist for other thermodynamic systems? In fact from the zeroth law it can be established mathematically that a relation does exist between temperature and other thermodynamic variables associated with a system. Such a relation, as you know, is called an equation of state. Let us study about it in some detail before rounding off this unit.

1.6 THE EQUATION OF STATE

You know that the temperature of a system can be expressed as a function of any other two thermodynamic parameters. If the two parameters are x and y then mathematically it can be expressed as

$$T = f_1(x, y) \tag{1.2a}$$

Eq. (1.2a) can be solved for x in terms of T and y and can even be solved for y in terms of T and x so that we have the relations

$$x = f_2(T, y) \tag{1.2b}$$

$$y = f_3(T, x) \tag{1.2c}$$

In other words Eqs. (1.2a, b and c) can be expressed as

$$f(x, y, T) = 0 \tag{1.3}$$

Eq. (1.3) is parametric as the form of f is not given. But the equation of state of an ideal gas (Eq. 1.1) is exact. Likewise we may have equations of state for a real gas or for several other systems. We will not aim to derive any such equation here. We will only provide a few examples in Table 1.2,

Table 1.2

System (variables)	Equation of State	
	Parametric	Exact
Ideal gas (p, V, T)	$f(p, V, T) = 0$	$pV = RT$, where R is the universal gas constant
Real gas (p, V, T)	$f(p, V, T) = 0$	$(p + \frac{a}{V^2})(V - b) = RT$, where a and b are constants
Paramagnetic solid (M, B, T)	$f(M, B, T) = 0$	$M = C \frac{B}{T}$, where M is the intensity of magnetisation and B is the flux density of the magnetic field in which the solid is placed. C is a constant
Stretched wire (L, F, T)	$f(L, F, T) = 0$	$L = L_0 [1 + pF + q(T - T_0)]$ where L and L_0 are the lengths of the wire at temperatures T and T_0 respectively. F is the tension in the wire, p and q are constants.

The parametric form of the equation of state **may** be used to study some typical characteristics like **coefficient of thermal expansion**, elasticity, compressibility and so on of any substance. We shall do that now. This exercise will make you competent to handle thermodynamic relations involving partial derivatives. You will encounter several such relations, particularly in Block 2 of this course.

1.6.1. Deductions from Equation of State

Before you proceed to study the several characteristics using the **equation** of state you will be **taught** to **learn** a little about partial differentiation. You will find that it is an **extension** of the idea of ordinary differentiation. We come across such differentiation when a quantity is a function of more than one variable and it is required to find the change in the quantity when any one of the variables changes by a small amount. For example the temperature of a gaseous system is a **function** of pressure and volume. Now, we may like to obtain the rate of variation of temperature with respect to an isochoric (volume = constant) variation of pressure. Likewise we may wish to obtain the rate of variation of temperature with respect to an isobaric (pressure = constant) variation of volume. In the former case we are seeking the partial derivative of

T with respect to p at constant V , denoted by $\left(\frac{\partial T}{\partial p}\right)_V$, whereas in the latter case

the partial derivative of T with respect to V , denoted by $\left(\frac{\partial T}{\partial V}\right)_p$. Notice that instead

of using the symbol ' d ' as in the case of ordinary differentiation here we are using the symbol ' ∂ ' (pronounced 'del'). We shall now work out mathematical relationship between the partial derivatives involving any three variables. These will be very useful in doing the relevant deductions from equation of state:

Let z be a function of x and y :

$$z = z(x, y) \quad (1.4)$$

Then total differential dz is given by the following relation :

$$dz = \left(\frac{\partial z}{\partial x}\right)_y dx + \left(\frac{\partial z}{\partial y}\right)_x dy \quad (1.5)$$

Eq. (1.5) expresses the change in z which results from changes in x and y on which z depends.

Now if we take three variables as p , V and T of a gaseous system then we may say that

$$V = V(p, T)$$

Thus using Eq. (1.5) the volume difference dV between two neighbouring equilibrium states may be expressed as

$$dV = \left(\frac{\partial V}{\partial p}\right)_T dp + \left(\frac{\partial V}{\partial T}\right)_p dT \quad (1.6a)$$

and similarly for the pressure difference dp as

$$dp = \left(\frac{\partial p}{\partial V}\right)_T dV + \left(\frac{\partial p}{\partial T}\right)_V dT \quad (1.6b)$$

Now, substituting Eq. (1.6b) in Eq. (1.6a), we get

$$dV = \left(\frac{\partial V}{\partial p}\right)_T \left[\left(\frac{\partial p}{\partial V}\right)_T dV + \left(\frac{\partial p}{\partial T}\right)_V dT \right] + \left(\frac{\partial V}{\partial T}\right)_p dT$$

$$\text{or } 0 = \left[1 - \left(\frac{\partial V}{\partial p}\right)_T \left(\frac{\partial p}{\partial V}\right)_T \right] dV - \left[\left(\frac{\partial V}{\partial p}\right)_T \left(\frac{\partial p}{\partial T}\right)_V + \left(\frac{\partial V}{\partial T}\right)_p \right] dT \quad (1.7)$$

Now, of the three variables p , V , and T only two are independent. Choosing V and T as the independent variables, Eq. (1.7) must be true for all sets of values of dV and dT . Thus for two states which are at the same temperature ($dT = 0$) but having different volumes ($dV \neq 0$) we get from Eq. (1.7)

$$1 - \left(\frac{\partial V}{\partial p}\right)_T \left(\frac{\partial p}{\partial V}\right)_T = 0$$

or

$$\left(\frac{\partial V}{\partial p}\right)_T = \frac{1}{\left(\frac{\partial p}{\partial V}\right)_T} \quad (1.8)$$

This is the mathematical relation which allows us to replace any partial derivative by the reciprocal of the inverted derivative *with the same variable(s) held constant*. This is another important relation which you will derive in the following SAQ.

SAQ 5

- a) Imposing the condition $dV = 0$, $dT \neq 0$ in Eq. (1.7) prove that

$$\left(\frac{\partial V}{\partial p}\right)_T \left(\frac{\partial p}{\partial T}\right)_V \left(\frac{\partial T}{\partial V}\right)_p = -1 \quad (1.9)$$

- b) Write down the equation corresponding to Eq. (1.9) for
(i) a paramagnetic solid
(ii) a stretched wire.

We shall now learn to use Eqs. (1.8) and (1.9). For that we shall first define expansivity, β (or the isobaric coefficient of volume expansion) and the bulk modulus, E_T (or the isothermal elasticity) in the language of partial derivatives.

$$\beta = \frac{1}{V} \left(\frac{\partial V}{\partial T}\right)_p \quad (1.10)$$

and $E_T = -V \left(\frac{\partial p}{\partial V}\right)_T \quad (1.11)$

You must note that for all known systems pressure decreases with volume. So $\left(\frac{\partial p}{\partial V}\right)_T$ is negative. Hence, we have the minus sign in Eq. (1.11) to give E_T a positive value. Combining Eqs. (1.10) and (1.11) we get

$$\beta E_T = - \left(\frac{\partial V}{\partial T}\right)_p \left(\frac{\partial p}{\partial V}\right)_T$$

or $\frac{1}{\left(\frac{\partial V}{\partial T}\right)_p \left(\frac{\partial p}{\partial V}\right)_T} = -\frac{1}{\beta E_T}$

or $\left(\frac{\partial T}{\partial V}\right)_p \left(\frac{\partial V}{\partial p}\right)_T = -\frac{1}{\beta E_T}$

On using Eq. (1.9), we get

$$\left(\frac{\partial p}{\partial T}\right)_V = \beta E_T$$

An infinitesimal change in pressure may now be expressed in terms of these physical quantities. Thus

$$dp = \left(\frac{\partial p}{\partial T}\right)_V dT + \left(\frac{\partial p}{\partial V}\right)_T dV$$

or $dp = \beta E_T dT + \left(\frac{\partial p}{\partial V}\right)_T dV$

At constant volume,

$$dp = \beta E_T dT$$

At constant volume, when the change in temperature is finite and small, the quantities β and E_T are assumed as constant. Hence, the finite change in pressure, Δp , corresponding to a finite change in temperature, ΔT , at a constant volume is given by

$$\Delta p = \beta E_T \Delta T \quad (1.12)$$

Now, let us take up a numerical example to illustrate Eq. (1.12).

Example 1

The temperature of a block of copper is increased from 400K to 410K. What change in pressure is necessary to keep the volume constant? It is given that for copper, $\beta = 5 \times 10^{-5} \text{ K}^{-1}$ and $E_T = 1.3 \times 10^{11} \text{ Nm}^{-2}$.

Solution

In Eq. (1.12), we have $\Delta T = 10 \text{ K}$,

So $\Delta p = (5 \times 10^{-5} \text{ K}^{-1}) (1.3 \times 10^{11} \text{ Nm}^{-2}) (10 \text{ K})$

$$\Delta p = 6.5 \times 10^7 \text{ Nm}^{-2}$$

Before rounding off this unit you may like to work out an SAQ on the use of partial derivatives.

SAQ 6

a) Isothermal compressibility, κ , is the reciprocal of isothermal elasticity. Now if ρ be the density of a substance, show that

$$(i) \kappa = \frac{1}{\rho} \left(-\frac{\partial \rho}{\partial p} \right)_T \quad (ii) \beta = \frac{1}{\rho} \left(\frac{\partial \rho}{\partial T} \right)_p$$

b) Show that for an ideal gas, $\kappa = \frac{1}{p}$, $\beta = \frac{1}{T}$

c) Prove that for a pVT -system

$$\frac{dV}{V} = \beta dT - \kappa dp$$

Let us now sum up what we have learnt in this unit.

1.7 SUMMARY

- A region of space under study is called the system and everything else around it is the surroundings. An arbitrary surface enclosing the system is known as the boundary.
- Thermodynamic state of a system is specified by the properties of the system, which uniquely defines it.
- The macroscopic quantities that determine the above properties of the system are called thermodynamic variables.
- Thermodynamic variables are classified as extensive or intensive depending on whether these are dependent on the mass of the system or not.
- The variables of a system in thermodynamic equilibrium can be expressed in the form of a mathematical relationship called the equation of state of the system.
- A system is said to be in thermodynamic equilibrium if its state does not change in any way (thermal, mechanical and chemical) with time.
- When any of the properties of a system changes, the state of the system changes and it is said to undergo a process.
- A reversible process is one that is performed in such a way that, at the conclusion of the process, both the system and the local surroundings may be restored to their initial states, without producing any change in the rest of the universe. If the above conditions are not satisfied then it is called irreversible process.
- If the process is carried out in such a way that at every instant the system departs only infinitesimally from an equilibrium state; the process is called quasistatic.
- The zeroth law of thermodynamics states that if systems A_1 and A_2 are separately in thermal equilibrium with system A_3 then A_1 and A_2 are also in thermal equilibrium with each other.
- All systems in thermal equilibrium with each other have same temperature.
- The general equation of state for any gaseous system is represented by

$$f(p, V, T) = 0$$

where f is a single-valued function of pressure p , volume V and the absolute temperature T .

- If $z = z(x, y)$ then total differential dz is expressed as

$$dz = \left(\frac{\partial z}{\partial x}\right)_y dx + \left(\frac{\partial z}{\partial y}\right)_x dy$$

This leads to two important mathematical relations:

$$(i) \quad \left(\frac{\partial z}{\partial x}\right)_y = \frac{1}{(\partial x/\partial z)_y} \quad (ii) \quad \left(\frac{\partial z}{\partial x}\right)_y \left(\frac{\partial x}{\partial y}\right)_z \left(\frac{\partial y}{\partial z}\right)_x = -1$$

- In the language of partial derivatives the coefficient of isobaric coefficient of volume expansion (β), isothermal elasticity (E_T) and isothermal compressibility (κ) are defined as follows

$$\beta = \frac{1}{V} \left(\frac{\partial V}{\partial T}\right)_p$$

$$E_T = -V \left(\frac{\partial p}{\partial V}\right)_T$$

$$\kappa = -\frac{1}{V} \left(\frac{\partial V}{\partial p}\right)_T$$

1.8 TERMINAL QUESTIONS

- 1) a) Can a system composed of 200 molecules be called a thermodynamic system? Justify your answer.
b) **Prove** that the specific value corresponding to an extensive variable is an intensive property. (Hint : Specific value of any variable is its value per unit mass.)
c) The **weight** of 2 m³ of Hg at 0°C and 1 bar pressure at a place where $g = 9.80\text{ms}^{-2}$ is $2.67 \times 10^5 \text{ N}$. Give two extensive and five intensive variables of this system.
2. Consider the following statements :
 - i) **Specific gravity** of a substance is an intensive property **but** density is an extensive property.
 - ii) Reversible processes are only an idealisation and all the natural processes are irreversible.
 - iii) An isolated system is necessarily **adiabatic**. **Choose** your answer.
 - (a) if only (i) and (ii) are correct.
 - (b) if only (ii) and (iii) are correct.
 - (c) if only (i) and (iii) are correct.
 - (d) if all the statements are correct.
- 3) A certain stretch of railway track is laid without expansion joints in Thar desert where day and night temperatures differ by 25 K. The cross-sectional area of rail is $3.6 \times 10^{-3} \text{ m}^2$. The Young's modulus, Y , of its material is $2 \times 10^{11} \text{ N m}^{-2}$ and its co-efficient of linear expansion, α , is $8 \times 10^{-6} \text{ K}^{-1}$. (a) If the length of the track is kept constant, what is the **difference** in the tension in the rails between day and night? (b) If the track is 15 km long, and is free to expand, what is the change in its length between day and night?

(Hint: Use $f(L, F, T) = 0$ along with $Y = \frac{L}{A} \left(\frac{\partial F}{\partial L}\right)_T$ and $\alpha = \frac{1}{L} \left(\frac{\partial L}{\partial T}\right)_F$

where L , F and T denote length, tension and temperature respectively.)

1.9 SOLUTIONS AND ANSWERS

SAQs

- 1) (a) (i) A dice (Fig. 1.16a) (ii) A car (Fig. 1.16b) as its doors, bonnet and dickey can be opened (iii) Smoke coming out of a chimney (Fig. 1.16c).

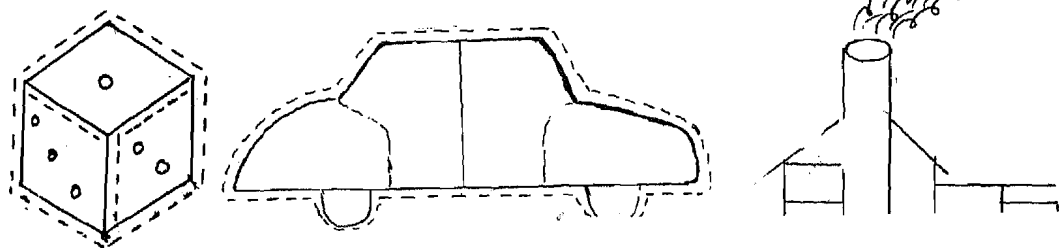


Fig. 1.16 : Diagrams for answer to SAQ 1 (a). In each case the dotted line represents the boundary.

- (b) The volume of the system is constant. Hence, it is an open system.
- (c) This system has a constant mass so it is a closed system.
- (d) When we consider a rose plant in a garden it is a system with other plants, soil and atmosphere as surroundings. In day time it takes up sunlight (energy) and CO_2 (matter) from the atmosphere and gives out O_2 . It also takes nutrients (matter) from the soil and increases its own matter content. Thus, exchange of energy and matter both takes place, which makes the rose plant in a garden an open system.
- (e) (i) Closed (ii) Open
- 2) a) Intensive : surface tension (s), e.m.f. (E)
Extensive: length (L), charge (q)
- b) Let f be mass and g be volume of a substance then f/g is its density.
- c) (i) Pressure, volume, temperature, mass and density.
(ii) Intensity of polarisation, temperature, electric field intensity.
- 3) a) (i) and (ii) irreversible (iii) reversible.
- b) Let us consider the case of expansion of a gas contained in a cylinder. Suppose this is done by pulling the piston outward. If there is a friction between piston and the inner wall of the cylinder the process is definitely irreversible. In this case a portion of mechanical energy provided by the pull goes in heating of the piston and the wall of the cylinder. This illustrates that energy is dissipated during an irreversible process.

Activity

$$\begin{aligned}\text{Angular speed of second-hand} &= \frac{2\pi}{60} \text{ rad s}^{-1} = \frac{\pi}{30} \text{ rad s}^{-1} \\ &= 3.3\pi \times 10^{-2} \text{ rad s}^{-1}\end{aligned}$$

$$\begin{aligned}\text{Angular speed of minute-hand} &= \frac{2\pi}{60 \times 60} \text{ rad s}^{-1} = \frac{\pi}{1800} \text{ rad s}^{-1} \\ &= 5.5\pi \times 10^{-4} \text{ rad s}^{-1}\end{aligned}$$

$$\begin{aligned}\text{Angular speed of hour-hand} &= \frac{2\pi}{12 \times 60 \times 60} \text{ rad s}^{-1} = \frac{\pi}{21600} \text{ rad s}^{-1} \\ &= 4.6\pi \times 10^{-5} \text{ rad s}^{-1}\end{aligned}$$

The movement of second-hand can be perceived. Angular speeds of minute and hour-hand being small their movements cannot be perceived. Hence their movement is quasistatic in nature.

- 4) Refer to Fig. 1.17. Here i and f represents initial and final state respectively. Note that in V - T diagram for (i) the extrapolated portion of the straight line must pass through the origin as $\frac{V}{T} = \text{constant}$. The case of p - T diagram for (ii) will be similar.

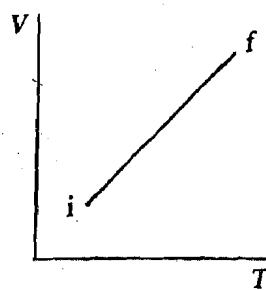
- 5) a) Putting $dV = 0$ and $dT \neq 0$ in Eq. (1.7) we get

$$\left(\frac{\partial V}{\partial p}\right)_T \left(\frac{\partial p}{\partial T}\right)_V + \left(\frac{\partial V}{\partial T}\right)_p = 0$$

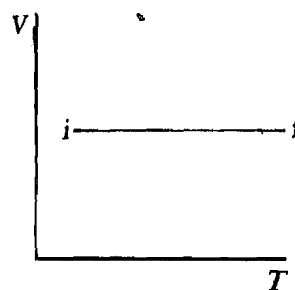
or

$$\left(\frac{\partial V}{\partial p}\right)_T \left(\frac{\partial p}{\partial T}\right)_V = -\left(\frac{\partial V}{\partial T}\right)_p$$

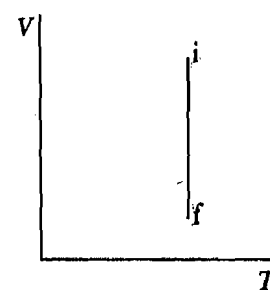
V - T Diagrams



(i)

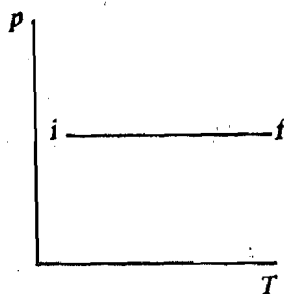


(ii)

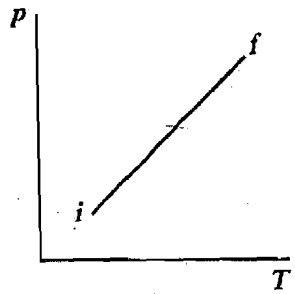


(iii)

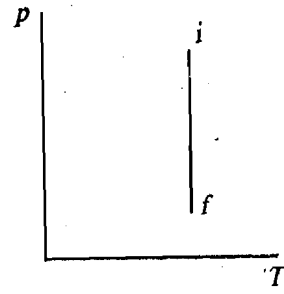
p - T Diagrams



(i)



(ii)



(iii)

Now, since $\frac{1}{\left(\frac{\partial V}{\partial T}\right)_p} = \left(\frac{\partial T}{\partial V}\right)_p$, we get

$$\left(\frac{\partial V}{\partial p}\right)_T \left(\frac{\partial p}{\partial T}\right)_V \left(\frac{\partial T}{\partial V}\right)_p = -1$$

This relation is used to split up a derivative into a product of more convenient derivatives. It may be written with any derivative then following through the other variables in cyclic order.

$$\text{b) (i) } \left(\frac{\partial M}{\partial B}\right)_T \left(\frac{\partial B}{\partial T}\right)_M \left(\frac{\partial T}{\partial M}\right)_B = -1$$

$$\text{(ii) } \left(\frac{\partial L}{\partial F}\right)_T \left(\frac{\partial F}{\partial T}\right)_L \left(\frac{\partial T}{\partial L}\right)_F = -1$$

$$\text{6) a) (i) } \text{We know that density} = \frac{\text{mass}}{\text{volume}}; \text{ i.e. } \rho = \frac{m}{V}$$

$$\therefore \rho V = m$$

Differentiating, $d(\rho V) = 0$ (because $m = \text{a constant}$)

$$\therefore \rho dV + V d\rho = 0$$

$$\text{or } -\frac{dV}{V} = \frac{d\rho}{\rho} \text{ or } -\frac{1}{V} \left(\frac{\partial V}{\partial p}\right)_T = \frac{1}{\rho} \left(\frac{\partial \rho}{\partial p}\right)_T$$

$$\text{Since } E_T = -V \left(\frac{\partial p}{\partial V}\right)_T$$

$$\frac{1}{E_T} = \frac{1}{p} \left(\frac{\partial p}{\partial p} \right)_T$$

$$\therefore \kappa = \frac{1}{p} \left(\frac{\partial p}{\partial p} \right)_T$$

(ii) We have

$$-\frac{dV}{V} = \frac{dp}{p} \text{ or } \frac{1}{V} \left(\frac{\partial V}{\partial T} \right)_p = -\frac{1}{p} \left(\frac{\partial p}{\partial T} \right)_p$$

$$\text{or} \quad \beta = -\frac{1}{p} \left(\frac{\partial p}{\partial T} \right)_p$$

b) For an ideal gas,

$$pV = nRT \text{ or } V = \frac{nRT}{p}$$

$$\therefore \left(\frac{\partial V}{\partial p} \right)_T = -\frac{nRT}{p^2}$$

$$\text{Now } \kappa = -\frac{1}{V} \left(\frac{\partial V}{\partial p} \right)_T = \frac{nRT}{Vp^2} = \frac{pV}{Vp^2} = \frac{1}{p}$$

Again,

$$\left(\frac{\partial V}{\partial T} \right)_p = \frac{nR}{p}$$

$$\therefore \beta = \frac{1}{V} \left(\frac{\partial V}{\partial T} \right)_p = \frac{nR}{pV} = \frac{nR}{nRT} = \frac{1}{T}$$

c) We know from Eq. (1.6a) that

$$dV = \left(\frac{\partial V}{\partial p} \right)_T dp + \left(\frac{\partial V}{\partial T} \right)_p dT$$

$$\text{But } \kappa = -\frac{1}{V} \left(\frac{\partial V}{\partial p} \right)_T \text{ and } \beta = \frac{1}{V} \left(\frac{\partial V}{\partial T} \right)_p$$

$$\therefore \left(\frac{\partial V}{\partial p} \right)_T = -\kappa V \text{ and } \left(\frac{\partial V}{\partial T} \right)_p = \beta V$$

So, we get

$$dV = -\kappa V dp + \beta V dT$$

or

$$\frac{dV}{V} = \beta dT - \kappa dp$$

Terminal Questions

1) a) No, because a thermodynamic system should be so large that it can be treated as a continuous collection and a system of 200 molecules does not fulfil this condition.

b) By definition, an extensive variable, say, energy E depends on the mass so that it can be written as $E \propto m$ or $E = km$

where k is constant of proportionality. The corresponding specific value of this variable is E/m which is equal to k . It is independent of mass. Hence, specific value of an extensive variable is an intensive property.

c) Extensive variables: Volume = 2 m^3 , mass = $\frac{2.67 \times 10^5}{9.80} = 2.72 \times 10^4 \text{ kg}$.

Intensive variables: Temperature = 0°C , pressure = 1 bar, acceleration due

to gravity = 9.80 m s^{-2} , density = $\frac{2.72 \times 10^4}{2} = 1.36 \times 10^4 \text{ kg m}^{-3}$,

$$\text{specific Volume} = \frac{2}{2.72 \times 10^4} = 7.35 \times 10^{-5} \text{ m}^3 \text{ kg}^{-1}$$

(specific volume is defined as volume per unit mass)

2) (b)

3) a) Since, $f(L, F, T) = 0$, from Eq. (1.9) we get,

$$\left(\frac{\partial L}{\partial F}\right)_T \left(\frac{\partial F}{\partial T}\right)_L \left(\frac{\partial T}{\partial L}\right)_F = -1$$

Thus

$$\frac{L}{YA} \left(\frac{\partial F}{\partial T}\right)_L \frac{1}{\alpha L} = -1$$

or

$$\left(\frac{\partial F}{\partial T}\right)_L = -YA\alpha$$

So, if the length of the track is kept constant, the difference in tension corresponding to a difference in temperature ΔT is given by

$$\Delta F = -YA\alpha \Delta T$$

Here ΔT is negative when we consider the change from day to night.

Hence, $\Delta F = (2 \times 10^{11} \text{ N m}^{-2}) (3.6 \times 10^{-3} \text{ m}^2) (9 \times 10^{-6} \text{ K}^{-1}) (25 \text{ K})$

$$\Delta F = 1.44 \times 10^5 \text{ N}$$

As the temperature changes from day to night, the track contracts. However, the track is not permitted to contract because its length is being kept constant. Therefore, a force would be required to expand the track and restore it to its original length and hence ΔF is positive,

b) $f(L, F, T) = 0$

or $L = L(F, T)$

$$\therefore dL = \left(\frac{\partial L}{\partial F}\right)_T dF + \left(\frac{\partial L}{\partial T}\right)_F dT$$

Putting $dF = 0$ (since the track is free to expand) and

$\alpha = \frac{1}{L} \left(\frac{\partial L}{\partial T}\right)_F$, the difference in length L corresponding to a difference in

temperature ΔT is given by

$$\Delta L = \alpha L \Delta T$$

If we consider the change from day to night, $\Delta T = -25 \text{ K}$

$\therefore \Delta L = (8 \times 10^{-6} \text{ K}) (15 \times 10^3 \text{ m}) (-25 \text{ K}) = -3 \text{ m}$

i.e. there is a decrease in the length of the track by 3 m.

$$L = L(F, T) = 0$$

UNIT 2 MEASUREMENT OF TEMPERATURE

Structure

- 2.1 Introduction
 - Objectives
- 2.2 Principle of Measurement of Temperature
 - Physical Properties Considered for Measurement of Temperature
 - Scale of Temperature
- 2.3 Gas Thermometer
 - Constant Volume Gas Thermometer
 - Perfect Gas Temperature Scale
- 2.4 Resistance Thermometers
 - Platinum Resistance Thermometer
 - Thermistors
- 2.5 Thermocouples
 - Thermocouples and Thermoelectric Circuits
 - Practical Thermocouples
- 2.6 Radiation Pyrometers
- 2.7 The International Practical Temperature Scale
- 2.8 Summary
- 2.9 Terminal Questions
- 2.10 Solutions and Answers

2.1 INTRODUCTION

Would you like to remain outdoor on a hot summer afternoon? Preferably not. Likewise you will not like to take bath in ordinary tap water during winter. As you can realise that the above examples are related with the most important thermodynamic variable temperature. You have learnt about the concept of temperature in the previous unit. We can have a feeling of this thermodynamic variable by way of our senses. But it has an element of difference from the senses of smell and taste. We do not go for quantifying these senses. In other words we would never go to measure how much higher is the smell of a rose than that of a sunflower. Nor we question how much is a curry tastier than a salad, whereas for temperature we need to quantify. Everyday you get to know about the temperature of the important cities from the newspaper. If someone has a prolonged fever a temperature chart of his/her body is maintained.

The device used for measurement of temperature, as you know, is called thermometer. For the above measurements we normally use a liquid-in-glass thermometer with which you are familiar. It utilises the property of variation of the volume of a liquid with temperature. However, the temperatures of our interest are not only restricted to that of a place or a man's body. It ranges from as low as 0.01 K, where helium solidifies, to 6000 K, the temperature of sun's surface. How do we measure these temperatures? Certainly not by liquid-in-glass thermometers. In fact there are many other kind of thermometers about which you will read in this unit.

The action of every kind of thermometer is based on the temperature-variation of some physical property. In this unit you will read how gas thermometers, resistance thermometers, thermocouples and radiation pyrometers are used for the measurement of temperature.

You will also learn how a scale is developed for the measurement of temperature. We shall chiefly deal with the perfect gas scale. Finally we shall discuss briefly the International Practical Scale of Temperature.

As you know the change in temperature of a body is brought about by heat. But what is the nature of heat? The answer to this question will lead us to the first law of thermodynamics. In the next unit you will read about that.