



**Discipline Course-I
Semester-II
Paper No: Thermal Physics : Physics-IIA
Lesson: Zerith Law of Thermodynamics
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Zeroth law of thermodynamics

Objectives

By reading this lesson, you will be able to understand;

- ✓ What is a thermodynamic system;
- ✓ What are the thermodynamic variables;
- ✓ What is thermodynamic equilibrium;
- ✓ The concept of temperature;
- ✓ The Zeroth law of thermodynamics.

1.1 Introduction

We know thermodynamics as a branch of science that basically deals with the relations between heat and mechanical energy (or work), and the conversion of one into the other. Heat is a form of energy that may be utilized to perform some mechanical work. The heat energy supplied to some matter may be identified in the form of modified atomic/molecular motions of the constituents of the matter. The effect of this heat energy can be visualized by observing some macroscopic properties of the matter such as change in volume, pressure etc. However, to study these effects quantitatively, we have to define/limit the required region of space which contains the matter. Also, the effect of heat on macroscopic variables may be different for different phases of matter and hence it is essential, too, to consider the phase of matter and the condition how is it contained. Secondly, it may not always be possible to observe the transfer of heat energy from one to another region containing matter and, if it is possible then, how long the heat transfer will continue? These are some basic facts to be understood to learn the thermodynamics further, so let me start with the discussion about these facts;

1.2 Thermodynamic system

A thermodynamic system in terms of thermodynamic coordinates may be defined as a precisely specified macroscopic region of the universe separated by walls of particular natures. Gases, vapors, mixtures *etc* are some important thermodynamic systems. In addition, the systems such as stretched wires, capacitors, thin surface films, and thermocouples *etc* are other thermodynamic systems. Everything outside the system that can impart its influence to the behavior of the system's constituents is termed as **surroundings** and the envelope enclosing the system and separating it from its surroundings is termed as the **boundary** of the system.

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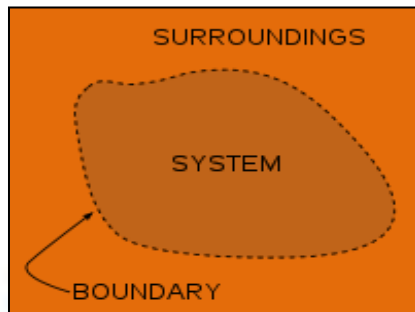


Figure 1.1: Cartoon showing a system, its boundary and surroundings.

The boundary of any system may be real or imaginary depending on the system characteristics. The boundary works as a mediator between the system and its surroundings, so it plays very important role. It may or may not permit the interaction between the system and its surroundings. A boundary which allows the exchange of energy and matter between the system and its surroundings is obviously an open boundary and the systems having such kind of boundaries are termed as **open systems**. On the other hand, in **isolated systems**, the exchange of energy and matter between system and its surroundings is prevented by the boundary. In some of the cases, the boundary allows the exchange of heat but not the matter and the systems having such kind of boundaries are termed as **closed systems**. Below is shown a cartoon depicting isolated, closed and open systems [Figure 1.2].

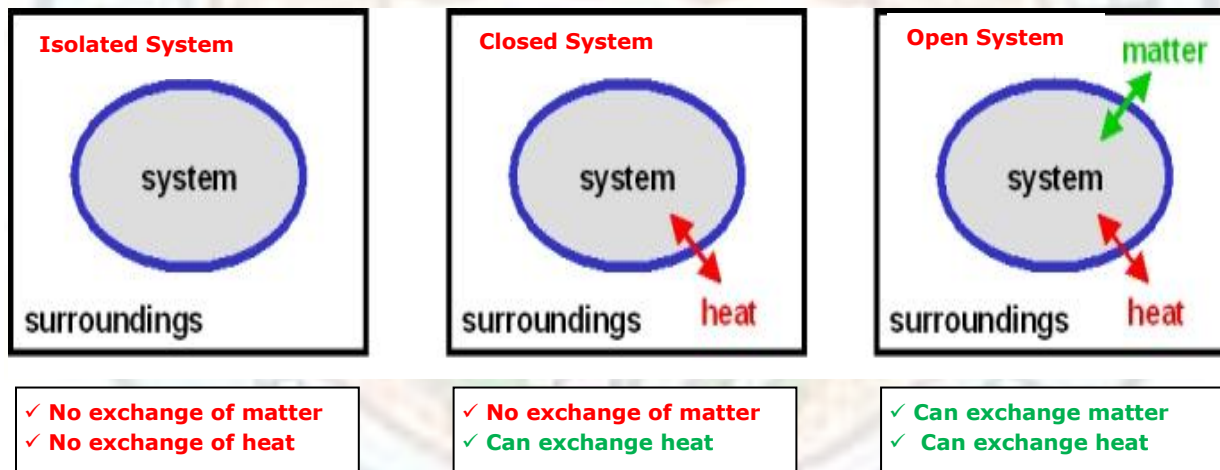


Figure 1.2: Cartoons illustrating the characteristics of isolated, closed, and open systems.

A thermodynamic system may be very simple having only a single component or a complex one composed of more than one component. In case of a system consisting of multiple components, it may happen that each component exists in a different **phase** and this make the behavior of the system more complex. Depending up on the exiting phases of the constituent components, the systems may further be categorized into the following two kinds.

1.2.1 Homogeneous and heterogeneous systems

The systems having single component or multiple components but in same phase are homogeneous systems. In other words, a homogeneous thermodynamic system may be

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defined as the one whose chemical composition and physical properties are the same in all parts of the system, or change continuously from one point to another. A gas in a cylinder fitted with leak proof piston is an example of homogeneous system. On the other hand, if the each component of the system can exists in a different phase, the system is said to be heterogeneous e.g. a mixture of water and phenol. Each phase is separated from other phases by interfaces (or boundaries) and in passing over such a boundary the chemical composition of the substance or its physical properties abruptly change. This phase boundary must not be regarded as a mathematical surface but as a thin layer separating the phases, a layer where the properties of one phase pass, or turn, rapidly into the properties of the other phase. Another example of a heterogeneous system is water with ice floating in it. This system has two homogeneous bodies, water and ice. The chemical composition of the two phases is the same, but their physical properties differ drastically.

1.3 Thermodynamic variables

The behavior of a thermodynamic system is basically expressed in terms of its macroscopic measurable quantities. The condition of the system at any instant of time is specified by such experimental quantities and we define it as the **state** of the system. The set of measurable macroscopic quantities which specify the condition/state of the system at any given instant of time are known as thermodynamic variables. Pressure, volume, temperature etc are examples of such variables. The thermodynamic variables defining the state of a system may be dependent or independent of the mass (or the number of particles). Depending up on their dependence/independence on the mass, the thermodynamic variables are divided into two categories which have been discussed below:

1.3.1 Intensive and extensive variables

If the variables of a thermodynamic system in a given state are independent of the mass or the number of particles of the system, then such variables will be called as **intensive variables**. The variables such as pressure for a hydrostatic system, *surface tension* for a surface film come under the category of intensive variables. On the other hand, the variables that are dependent on the system's mass or the number of its constituents particles are termed as **extensive variables**. Volume in a hydrostatic system, electric dipole moment in a system of dielectric solid etc. are examples of extensive variables. The extensive variables are often expressed in terms of their specific values (*i.e.* the value per unit mass of the system) such as specific volume and the variables obtained so are known as specific variables.

Did you know??

- **The product of intensive and extensive variables has the dimension of energy e.g. the dimensions of the product of: i) pressure (p) and volume (V), and ii) Electric field (E) and electric dipole moment (p_e) are that of energy.**
- **In general, the extensive variables are designated by capital letters and their specific values by corresponding small letters.**

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In most of the cases, the mathematical combinations of two intensive variables preserve their nature to be intensive. Suppose x and y are two arbitrary intensive variables then, the combinations xy , x/y , $x+y$, and $\frac{\partial x}{\partial y}$ will be of intensive kind. However, if X and Y were the arbitrary extensive variables then, the combination $X+Y$ will only be extensive and the rest will work as intensive one. Below is given a table showing the intensive and extensive variables of some of the thermodynamic systems:

Table 1.1: The intensive and extensive variables of some thermodynamic systems

S. No.	Thermodynamic system	Intensive variables	Extensive variables
1.	Hydrostatic system	Pressure	Volume
2.	Electric cell	Potential difference	Charge
3.	Dielectric solid	Electric field	Electric dipole moment
4.	Surface film	Surface tension	Area
5.	Paramagnetic substance	Magnetic induction	Magnetic moment
6.	Stretched wire	Tension	Length

1.4 Thermodynamic equilibrium

The interaction between the system and its surroundings such as performing some mechanical work or transfer of heat energy can change the state of the system that can be monitored by observing the changes in the macroscopic variables of the system. The change in the state of the system may continue over time and then a state may be reached where the changes in the variables of the system cease as long as external conditions remain unaltered. This state is known as **equilibrium** state and the system is said to be in thermodynamic equilibrium. A system that is in thermodynamic equilibrium experiences no changes when it is isolated from its surroundings. The system may be of hydrostatic, mechanical or chemical kind and hence the **thermodynamic equilibrium may be defined as a state of the system which exhibits mechanical, thermal and chemical equilibrium with its surroundings**. Let us discuss one by one about the three equilibriums:

Mechanical equilibrium: It may be defined as a state of the system in which no pressure or elastic stresses are experienced by the system and there are no unbalanced forces between the system and its surroundings. For example, a gas in a cylinder fitted with leak-proof piston is said to be in mechanical equilibrium if there is no unbalanced force on the system.

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Chemical equilibrium: Chemical equilibrium is related with the reaction rates of the reactants and products involved in the reaction. It may be defined as the state in which both reactants and products are present in concentrations which have no further tendency to change with time. The chemical equilibrium represents the state when the forward reaction proceeds at the same rate as the reverse reaction. There are no net changes in the concentrations of the reactant(s) and product(s) at equilibrium state.

Thermal equilibrium: The discussion of the thermal equilibrium is related with the main theme of this lesson *i.e.* Zeroth law of thermodynamics or concept of temperature and hence it has been discussed later on.

1.5 Thermodynamic processes

As we know there are a number of thermodynamic variables such as pressure, volume etc. associated with a system, the values of which changes whenever the system undergoes a change from equilibrium state to another one. This change in the state of a thermodynamic system is termed as thermodynamic process. For the analysis of a particular thermodynamic process, it becomes essential to know the variation of one thermodynamic variable with respect to another. The plot showing such variation is known as the **indicator diagram** for that process. To give you an idea, an indicator diagram for a thermodynamic process is shown below where the variation of volume with respect to pressure is plotted. (p_1, V_1) and (p_2, V_2) , respectively are the values of pressure and volume of the system at initial and final states.

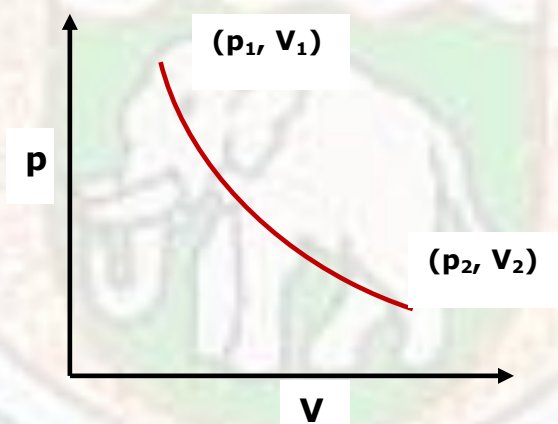


Figure 1.3: An indicator diagram

In the p-V indicator diagram (above), suppose the process is achieved in such a way that each point on the line joining initial and final state is also an equilibrium state of the system, then, ideally, the process may be retraced from final to initial state. On the other hand, the process may occur in such a way that it can not be retraced. So, depending on whether the process is retraceable or not, the thermodynamic processes are divided into two main categories which are discussed below.

1.5.1 Reversible and irreversible processes

A process in which the system and surroundings can be restored to the initial state from the final state without producing any changes in the thermodynamics properties of the universe is called a **reversible process**. It can be reversed completely without leaving

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behind any trace to show that the system had undergone thermodynamic change. Below is represented a reversible process on the indicator diagram. The system has undergone a change from state A to state B and it restored from state B to state A without any change in the universe.

It is worth to mention here that the reversible process is an **ideal** process and it can never be achieved in practice. However, we may approximate reversible process in practice by performing it extremely slowly. Expansion/compression of a spring very slowly, motion of simple pendulum suspended with a frictionless support *etc* may be approximated as reversible processes.

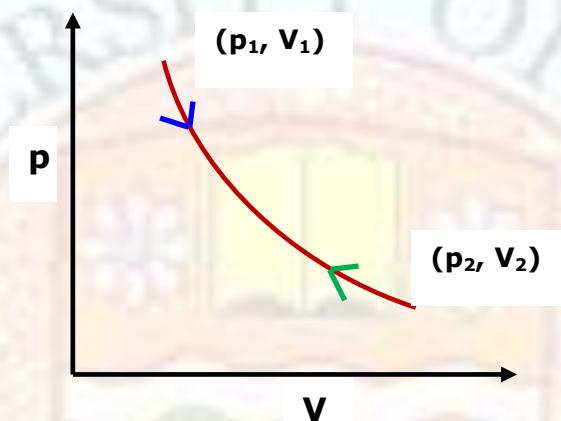


Figure 1.4: A reversible process

The natural processes such as heat flow from hot to cold body, flow of water from high level to low level *etc.* occur due to the finite gradient between the two states. These processes can not be retraced in backward direction naturally (with out any use of external means). All such natural processes which can not be retraced, from final to initial states, are known as **irreversible processes**. Below is a cartoon showing an irreversible process.

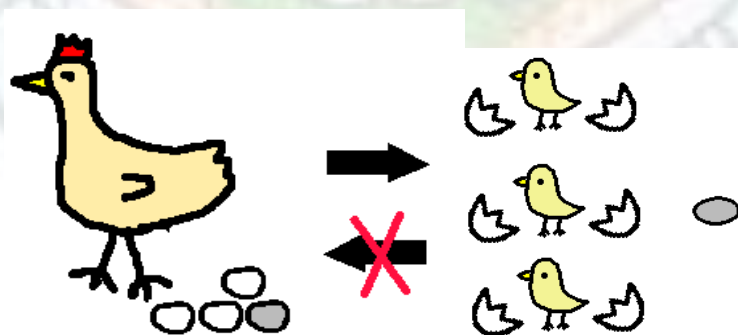


Figure 1.5: An irreversible process

1.5.2 Quasi-static process

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As discussed in the previous section that a reversible process may be approximated by carrying out the process extremely slowly. A process carried out very slowly in such a way that every state through which the system passes departs only infinitesimally from equilibrium is called as **quasi-static process**. Clearly, a quasi-static process may be thought of as a succession of thermodynamic equilibrium states. Any reversible process is necessarily a quasi-static one. However, some quasi-static processes are irreversible (if there is heat flowing in or out of the system).

1.5.3 Other processes

As discussed, the state of a thermodynamic system may be characterized by a number of thermodynamic variables. During a thermodynamic process, it may happen that some of these variables remain the same through out the process and hence, depending on the variables that do not change, the processes are defined as follows;

Isochoric processes: The process during which the volume of the system remains constant *e.g.* heating or the cooling of the contents of a sealed, inelastic container is an isochoric or an iso-volumetric or an isometric process.

Isobaric processes: The processes during which the pressure is kept constant *e.g.* melting of ice in air (the pressure *i.e.* atmospheric remains constant).

Adiabatic process: A process in which no thermal interaction takes place between the system and its surroundings is called as adiabatic process *e.g.* compression or expansion of a gas in a container with insulating walls.

Isothermal process: A process during which the temperature remains the same is called as isothermal process. The processes such as melting of ice and boiling of water occur at constant temperature and hence such processes are isothermal.

Besides above thermodynamic processes, some time a series of processes undergone by a system bring back it to its initial state. Such series of processes is said to constitute a **cyclic process**. Below is shown the p-V indicator diagrams of above discussed processes.

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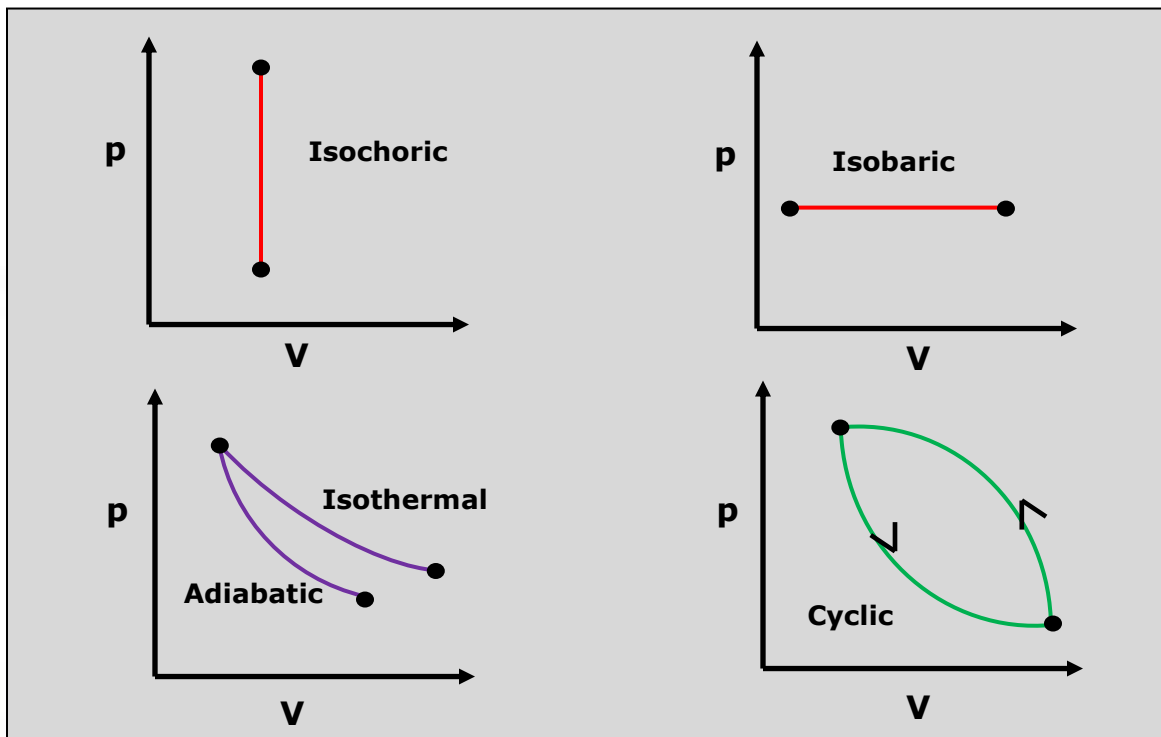


Figure 1.6: Representation of different processes on indicator diagram.

1.6 The Zeroth law: Concept of temperature:

To understand the concept of temperature, let us suppose two thermodynamic systems, each consisting of some fluid in a cylinder. Two identical mercury columns are attached in both the cylinders. At any instant, the height of the mercury in the columns will be different. Now, on putting both the cylinders in thermal contact with each other, a thermodynamic equilibrium is established simultaneously or successively and it is found that the height of the mercury in both the columns attains the same level. So, here the thermal equilibrium between the systems could be understood as the manifestation of a specified thermodynamic parameter which attains the same value when the systems are in thermal equilibrium. *This specified parameter is nothing but the **temperature** which may be defined as a property that determines whether or not a system is in thermal equilibrium with other systems.* Clearly, two bodies in thermal equilibrium will be at same temperature.

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Saha and Srivastava written about the measurement of temperature as "every physical quantity must be measurable in numerical terms". They presume temperature as a physical quantity and made a statement "If a body A is in temperature equilibrium with two bodies B and C, then B and C themselves will be in temperature equilibrium with each other". They postulated "Any of the physical properties of A which change with the application of heat may be observed and utilised for the measurement of temperature." However, the title '**the Zeroth law of thermodynamics**' was invented by **Ralph H.**



Ralph H. Fowler
(Image from Wikipedia)

The precise meaning of temperature is contained in the zeroth law of thermodynamics that may be stated as;

"If two systems are separately in thermal equilibrium with a third one, they will also be in thermal equilibrium with one another."

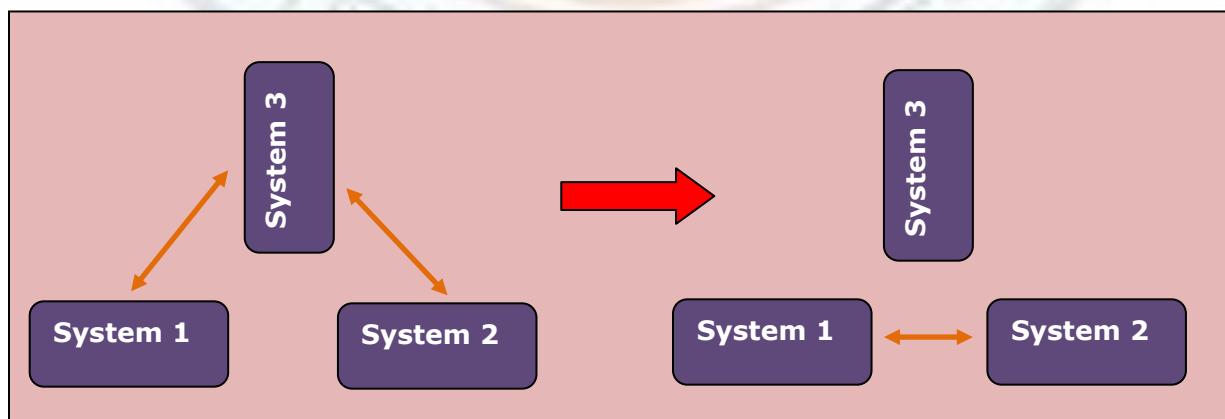
Or

"If a system A is in thermal equilibrium with a system B and if B is in thermal equilibrium with system C, then system A will be in thermal equilibrium with system C".

According to the above law, if systems 1 and 2 are separately in thermal equilibrium with system 3, then, systems 1 and 2 will also be in thermal equilibrium (Figure 1.7).

Clearly, the property that has the same value for the three systems is nothing but the temperature. Now, let us explain this concept in a more elegant fashion. For that, let us consider three isolated systems (say S1, S2, and S3), each of which is in equilibrium individually. Now, let these systems are characterized by thermodynamic variables (p_1, V_1) , (p_2, V_2) , and (p_3, V_3) and suppose we take system S3 as a reference. The thermal equilibrium between S1 and S3 may be expressed in functional form as

$$Y_{13}(p_1, V_1, p_3, V_3) = 0 \quad (1.1)$$



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Figure 1.7: Pictorial representation of the Zeroth law of thermodynamics.

Equation (1.1) expresses the definite relationship between the four variables *i.e.* $p_1, V_1, p_3,$ and V_3 and the fact that once any three of these variables get fixed, the fourth will be uniquely determined. A similar functional form may be written indicating the thermal equilibrium between the systems S2 and S3 as

$$Y_{23}(p_2, V_2, p_3, V_3) = 0 \quad (1.2)$$

The equations 1.1 and 1.2 may be solved for the variables p_3 or V_3 and the solution (say for p_3) may be expressed as

$$p_3 = Y'_{13}(p_1, V_1, V_3) \quad (1.3)$$

And

$$p_3 = Y'_{23}(p_2, V_2, V_3) \quad (1.4)$$

From equations 1.3 and 1.4, we have;

$$Y'_{13}(p_1, V_1, V_3) = Y'_{23}(p_2, V_2, V_3) \quad (1.5)$$

Relation (1.5) may be used to determine the value of the variable p_1 as;

$$p_1 = G(V_1, p_2, V_2, V_3) \quad (1.6)$$

Now, according to the Zeroth law of thermodynamics, systems S1 and S2 will be in thermal equilibrium with each other as S1 and S2 are in thermal equilibrium separately with S3. So, we may write for S1 and S2;

$$Y_{12}(p_1, V_1, p_2, V_2) = 0 \quad (1.7)$$

And, if we solve above equation for p_1 , then we have;

$$p_1 = Y'_{12}(p_2, V_1, V_2) \quad (1.8)$$

Equation (1.8) depicts that p_1 may be uniquely determined by $p_2, V_1,$ and V_2 , so that V_3 must be drop out from equation (1.6) and its earlier form *i.e.* (1.5). Taking into account this fact, equation (1.5) may now be expressed by a function ϕ with only two co-ordinates;

$$\phi_1(p_1, V_1) = \phi_2(p_2, V_2) \quad (1.9)$$

Equation (1.9) is the condition for thermal equilibrium between systems S1 and S2 and in general, we may write

$$\phi_1(p_1, V_1) = \phi_2(p_2, V_2) = \phi_3(p_3, V_3) = \text{Constant numeric value (known as temperature)} \quad (1.10)$$

Above equation reflects an important result *i.e.* if two or more systems are in thermal equilibrium with each other then, for each system their state variables p and V define a single valued function which has a common numerical value for all the systems. The common value of this function is known as **empirical temperature**. If the value of this function (*i.e.* temperature) for systems in thermal equilibrium be represented by θ , then we may write

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$$\phi(p, V) = \theta \quad (1.11)$$

Or, in more general form,

$$\phi(p, V, \theta) = 0 \quad (1.12)$$

Above equation is known as **equation of state**. Below are given the equation of states for some of the thermodynamic systems;

Table 1.2: Equation of states of some thermodynamic systems

S. NO.	Thermodynamic systems	Parametric form	Equation of states
1	Hydrostatic	$Y(p, V, T) = 0$	i) $PV = nRT$ (for ideal gas) ii) $\left(P + \frac{a}{V^2}\right)(V - b) = RT$ (for 1 mole of a real gas), a and b are Van der Waals constants.
2	Surface film	$Y(\sigma, T, A) = 0$	$\sigma = \sigma_0 \left(\frac{T_c - T}{T_c - T_0}\right)$
3	Dielectric solid	$Y(p_e, E, T) = 0$	$p_e = \left(a + \frac{b}{T}\right)E$, a and b are constants.
4	Paramagnetic substance	$Y(M, B, T) = 0$	$M = \frac{kB}{T}$
5	Electric cell	$Y(V_d, T, q) = 0$	$V_d = c_0 + c_1T + c_2T^2 + \dots$, c_i 's are constants

1.7 Measurement of temperature

Having an idea about what the temperature is?, Let us discuss how can we measure the temperature of a system or body. Though, we may be familiar to some of the means such as clinical thermometer by which the temperature is measured. It is the height of the mercury column that is calibrated to read the temperature of the body placed in contact with the clinical thermometers. However, there is certain limited range over which such thermometers may be employed. The higher values of the temperatures are not readable to such type of thermometers. So, depending on the range over which the measurement of temperature is required, the variation of different physical properties of a system in relation with the temperature are utilized. These common properties include length of the mercury column, volume of fluid, and pressure of a gas with fixed volume. Besides, above parameters, various other parameters such as electrical resistance of

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metal/semiconductors, thermoelectromotive force (emf), radiation emitted by black body, magnetic susceptibility of paramagnetic substances etc have been calibrated accordingly to estimate the temperature. Below are listed some common thermometers and their principles to measure the temperature.

Table 1.3: Some common thermometers and their principles for temperature measurement

S. No.	Utilized Thermodynamic property	Name of the thermometer	Principle
1	Volume	Constant pressure thermometer	Based on Charles's law , i.e. $V \propto T$, at constant pressure
2	Pressure	Constant volume gas thermometer	Based on Gay-Lussac's law i.e. $P \propto T$, at constant volume
3	Resistance	Resistance thermometer	The resistance of the metal rises with temperature, $R = R_0(1 + \alpha T + \alpha T^2)$
4	Thermo emf	Thermocouple	Based on Seebeck effect , $E = aT + bT^2$
5	Magnetic susceptibility	Susceptibility thermometer	Based on Curie's law i.e. Magnetic susceptibility $\propto T$
6	Emissive power	Radiation pyrometer	Based on Stefan's Law i.e. Emissive power $\propto T^4$

1.8 Scale of temperature

As discussed above, the measurement of the temperature is basically carried out by monitoring the changes in some thermodynamic property of a suitable substance by assigning a set of numbers to its values at different temperatures according to some well defined rule. For a given thermometer, the set of numbers assigned for the corresponding thermodynamic property at different temperatures is known as scale of temperature. The scale of temperature will be simpler if the variation of the thermodynamic property (utilized for thermometer) will be linear. Let for any thermometer, the thermodynamic property (say X) varies linearly with the temperature (θ). Suppose, at a given temperature $\theta(X)$, the value of X is X_θ then for linear variation, we may write;

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$$X_{\theta} = a_1\theta(X) + a_2 \quad (1.13)$$

Where a_1 and a_2 are constants.

The constant a_1 and a_2 may be determined by knowing the value of X at two different known/reference temperatures. The reference points may be arbitrarily chosen, however, the state of the system at these points must be reproducible. Being a standard system, the ice point and steam point of water have been referenced as 0°C and 100°C . So, with these values, we may easily obtain the values of the constants a_1 and a_2 (using equation (1.13)) as;

$$a_2 = X_0, \quad \text{and}$$
$$a_1 = \frac{X_{100} - X_0}{100}$$

By knowing the values of the constants a_1 and a_2 , we may determine the unknown temperature as;

$$\theta(X) = \frac{X_{\theta} - X_0}{X_{100} - X_0} \times 100$$

The temperature scale based on above equation is known as Celsius scale of temperature.

It has been found that the arbitrary chosen reference points in above case *i.e.* ice point and steam point of water can not be identically reproducible because of their high sensitivity to the atmospheric pressure, presence of impurities, nature of the containing material etc. This difficulty was addressed successfully by assigning **triple point** of water as a reference point and an arbitrary value **273.16K** was fixed for it. The ice point and steam point of water lies at 273.16K and 373.16K respectively on this scale. The name **absolute scale** of temperature was coined for this scale.

1.9 Summary

- **System:** A thermodynamic system may be defined as a certain portion of the universe selected for some investigation *e.g.* a gas, a vapor (steam), and a mixture etc.
- **Surroundings:** Everything outside the system that may affect its behavior is termed as surroundings.

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- **Universe:** The portion of space which contains both system and its surroundings is termed as universe.
- **Thermodynamic variables:** The set of measurable macroscopic quantities which specify the condition/state of the system at any given instant of time are known as thermodynamic variables.
- **Extensive and intensive variables:** The variables of a thermodynamic system in a given state are independent of the mass or the number of particles of the system, and then such variables will be called as intensive variables whereas the variables that are dependent on the system's mass or the number of its constituents particles are termed as extensive variables.
- **Thermodynamic equilibrium:** Thermodynamic equilibrium may be defined as a state of the system which exhibits mechanical, thermal and chemical equilibrium with its surroundings.
- **Quasi-static process:** A process carried out very slowly in such a way that every state through which the system passes departs only infinitesimally from equilibrium is called as quasi-static process.
- **Cyclic processes:** A series of processes undergone by a system bring back it to its initial state. Such series of processes is said to constitute a cyclic process.
- **The Zeroth law:** "If two systems are separately in thermal equilibrium with a third one, they will also be in thermal equilibrium with one another."
- **Triple point:** The temperature at which all the three phases i.e. ice, water, and water vapor co-exists in equilibrium is called as water triple point.

1.10 Exercises

Long answer type questions

- Q.1.** What are thermodynamic variables? Discuss with examples.
- Q.2.** State the Zeroth law of thermodynamics and hence give a concept of temperature.
- Q.3.** Distinguish between reversible and irreversible processes. Is it possible to realize reversibility in practice?
- Q.4.** Obtain general expression for the equation of states with the help of Zeroth law of thermodynamics.

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- Q.5.** Explain how temperature can be measured? Discuss the principles of temperature measurement for some of the common thermometer.
- Q.6.** What is absolute scale of temperature? Discuss in detail.

Short answer type questions

- Q.1.** What are intensive and extensive variables? Give two examples of each.
- Q.2.** Define reversible and irreversible processes with examples.
- Q.3.** Plot adiabatic and isothermal processes on indicator diagram.
- Q.4.** Define quasi-static process.
- Q.5.** What is scale of temperature? How is it different from the absolute scale?
- Q.6.** What is the working principle of thermocouple?
- Q.7.** On which principle, the radiation pyrometer works?
- Q.8.** Write down the equation of state for a paramagnetic substance.

Objective questions

- 1 An isolated system is one that
- can exchange heat and matter between system and its surroundings
 - can exchange heat but not the matter between system and its surroundings
 - can exchange matter but not the heat between system and its surroundings
 - can exchange neither heat nor the matter between system and its surroundings
- 2 Any system will be in thermodynamic equilibrium when it
- will be in only mechanical equilibrium
 - will be in mechanical and chemical equilibrium
 - will be in mechanical, chemical and thermal equilibrium
 - none of the above
- 3 The extensive variable is
- pressure,
 - volume,
 - electric field
 - potential difference
- 4 The intensive variable is
- surface tension
 - length
 - area
 - charge
- 5 The following thermometer is based on Stefan's law
- thermocouple
 - pyrometer
 - constant pressure thermometer

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(d) none of the above

6 The steam point on absolute scale is at

- (a) 273°C
- (b) 273.16K
- (c) 373.16°C
- (d) 373.16K

1.11 Glossary

Phase of the matter: Phase may be defined as a region of space throughout which all physical properties (such as density, index of refraction, magnetization and chemical composition etc) of a material are essentially uniform.

Surface tension: It may be understood as the tendency of the surface of a liquid to resist any external force.

Reaction rate (chemical): Reaction rate may be defined as the measure of the change in concentration (disappearance) of reactants or the change in concentration (appearance) of products per unit time.

Charles's law: According to this law, the volume of a given mass of an ideal gas is directly proportional to its temperature on the absolute temperature scale if pressure and the amount of gas remain constant.

Gay-Lussac's law: This law states that "The pressure of a gas of fixed mass and fixed volume is directly proportional to its absolute temperature".

Seebeck effect: When two junctions of some suitable metals are placed at different temperatures, an emf is induced between the junctions. The induced emf depends on the nature of the metals used and temperature difference between the junctions. This is known as Seebeck effect.

Curie's Law: The magnetization of paramagnetic material is almost directly proportional to an applied magnetic field. However, the magnetization reduces on increasing the temperature. According to Curie's law; for a fixed value of applied magnetic field, the magnetization of a paramagnetic material is inversely proportional to its temperature.

Stefan's Law: According to this law; the total energy radiated per unit surface area of a black body across all wavelengths per unit time is directly proportional to the fourth power of its temperature (in Kelvin).

1.12 References

Book cited:

Thermal Physics by Garg, Bansal and Ghosh (Tata McGra-Hill, 1993)

Further readings

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