INTRODUCTION

Aero-hydro-mechanics is that part of science which deals with the following :

(*i*) The laws of motion and equilibrium of fluid and gases.

(*ii*) The interaction of fluids or gases and the moving bodies in them and or their surfaces being surrounded by them.

(*iii*) The interaction of fluids or gases and body surrounded by them.

In many cases laws of motion of fluid and gases are the same and therefore mechanics of fluid and gases can be combined together. However, besides the common laws of motion of fluid and gases, there are different laws for fluid and for gases.

Mechanics of gases differ from the mechanics of fluid especially when gas moves with high velocity (nearer to or more than sound velocities). Part of aeromechanics which deals with study of high speed (gases having lesser density) is known as 'Gas Dynamics'. The science dealing with studies of interactions of forces between the gaseous medium and the moving body in it, usually used in aviation and rocket buildings is known as 'Aerodynamics'.

The science of gas dynamics deals primarily with the motion of gases and its consequent effects. Gas dynamics differs from classical fluid dynamics. Although both of them deal with fluid motion, in fluid dynamics thermal or chemical effects are usually excluded.

Gas dynamics deals with the motion of gas as a mass or continum. It does not study behaviour of the constituent molecules of gas. However, at very high altitudes, the concept of Classical Gas Dynamics' may be inadequate, because owing to the reduced pressure, the mean free path between molecules increases so much that the behaviour of individual molecules cannot be neglected. The more rarefied is a gas, longer is the mean free path. Dynamics of rarefied gases may be studied by applying principles of gas dynamics. Kinetic theory and statistical mechanics form the basis for newer science called rarefied gas dynamics or super aerodynamics.

In 18th century, Leonard Euler (1707-1783) and Daniel Bernoulli (1700-1783) laid foundation of aero-hydro-mechanics. Euler formulated the general equation of fluid motion and gas motion and law of conservation of mass. He investigated many problems of fluid resistance and used the results of his investigations in solving the practical problems of ship buildings and construction of hydraulic machines.

Bernoulli used the terminology "Hydro-dynamics" and through his research work formulated "Law of conservation of acting forces". He established relationship between pressure and kinetic energy of the fluid which is now known as the Bernoulli's equation. Similarly, he investigated many problems on "the fluid pressures upon thin plates".

However, for a long time, up to the end of 19th century, aerohydro-dynamics developed very slowly because the practical problems were very less. Hydraulics, marine science etc. could not develop due to the resistance offered by the medium on the moving body. More complex problems of distribution of action of forces along the surface of the body, moving in the fluid or gas, arouse quite late when it became necessary to calculate the strength of the apparatus flying in the air. Thus until the aviation came into existence, practical problems developed very little and consequently, investigations in the field of aero-hydro-mechanics.

On the other hand, theories developed were not related to practical problems and were contradictory to the practical results. Thus, the investigators sometimes did not believe their own conclusions. For example, the paradox of Euler-D'Alembert.

Only in the later half of 19th century after the invention of Reynold regarding the conditions of transition of laminar flow in turbulent and after the formation of theory of similarity, many scientists in the field of hydro-mechanics understood that without theory, unsolved experimental problems and generalisation of their results, could not be scientifically investigated.

More intensive development in aero-hydro-mechanics took place in the beginning of 20th century due to development in aviation technology which pushed forward the science to face a series of problems. One of these problems put forward by aviation before the aero-hydro-mechanics was the problem of lifting forces. Without these forces, which balance the weight of the flying apparatus, it was not possible to have horizontal flight of the apparatus, heavier than air. Hence, investigation of problems associated with lift forces was very important for aviation.

Even long ago, till the first flight of an object, heavier than air, flight of birds remained a question for the human intelligence. For the first time, the problem of lifting forces was noticed by an Italian painter-cum-scientist Leonardo-Da-Vinchi. He suggested (1505 AC) that the reason of the force which held the birds in the air was due to the quick hammering of their wings. There were a few more hypotheses regarding the flight of birds.

From the time of Euler, more convincing theories were developed about the fluid and gaseous medium contrary to Newton's theory. According to Euler fluid or gas is considered to be continuous and easily deformable material.

Zukovski gave equation for the lifting forces (1847-1921) in 1904 on the airwings.

At present aero-hydro-mechanics is useful for designing flight apparatus, hydraulic and gas turbines, pumps, compressors, propellers and hydro-technical equipments etc.

Flow of a gas may be compressible or incompressible. If density of a gas remains constant at every section of flow-channel or duct etc. during its motion, then such a flow is called incompressible flow. Cases where there are changes in density of a flowing gas at various flow sections then such a flow is designated as compressible flow. In general, gases are highly compressible at moderate and high speeds of flow.

Although applications of gas dynamics are wide and varied, most of the engineers are interested in gas flows in engines, between turbine blades, in wind tunnels, in jet and rocket propulsion systems etc. Also, the transport of gas at low speeds over very long distances, where compressibility cannot be neglected, is another field of gas dynamics.

Majority of practical engineering problems deal with steady flow in which the properties of a gas at any flow section remain independent of time and even if flow is unsteady ; many problems ; specially in one-dimensional flow, can be solved with the equations obtained for steady flow without much error. A flow is called one-dimensional if the fluid properties are uniform over each cross-section of the pipe or duct etc. with the implication that the fluid properties are functions of distance along the flow alone. Even if non-uniform sections may exist in between uniform sections under study, the one-dimensional analysis is still applicable, provided suitable average values can be defined. This would require that the change in flow area is slow and the radius of curvature of flow-axis is large compared with any dimension of the pipe or duct etc. normal to the flow.

Flow of gas through a channel etc. becomes two-dimensional when any dimension of a channel etc., normal to the axis of flow is significant as compared to the dimension of pipe etc. along the flow-axis. The component of velocity of flow in the normal direction also influences the fluid properties over each cross-section of the channel etc.

Three-dimensional flow of gas through a channel etc. is obtained when velocity of flow has its components along the three-major axes of the channel and the properties of gas varies from section to section of the channel.

In analysing any flow characteristics or properties, the following basic equations are used :

(*i*) Equation of state.
(*ii*) The principle of conservation of mass.
(*iii*) The principle of conservation of momentum.
(Newton's second law of motion)
(*iv*) The principle of conservation of energy.
(The first law of thermodynamics) and
(*v*) The concept of entropy.
(The second law of thermodynamics)

1

Basic Concepts

1·1. Thermodynamics

Thermodynamics is that branch of science which deals with energy transfer and its interactions between material systems. Due to energy transfer the physical properties of substances change. As a matter of fact, thermodynamics deals with the transformation of energy of all kinds from one form to another, but mainly two forms of energy *i.e.* heat and work.

Observations of common experience have been formulated into four laws of thermodynamics, which govern the principles of energy conversion. These laws are known as the zeroth law, the first law, the second law and the third law.

There is a wide range of application of thermodynamics in engineering. It is used in design of thermal prime movers, such as, steam engines, steam turbines, internal combustion engines and gas turbines. It is used in fuel cells, thermoelectric and thermionic generators. The laws of thermodynamics are used in air conditioning, refrigeration, jet propulsion and compressors etc.

Thermodynamics is classified as macroscopic thermodynamics-generally called classical thermodynamics and microscopic thermodynamics, called statistical thermodynamics. In a macroscopic thermodynamics, a certain quantity of matter is considered without taking into account its individual molecular activities. Thus, only the effects of the action of many molecules are considered in a macroscopic thermodynamics. These effects can be easily sensed by human being. In a microscopic thermodynamics matter is considered as myriads of molecules. Specially in a gas, each molecule has a certain position, velocity and energy at a particular instant which change very frequently as a result of collisions. Therefore, when the behaviour of a gas is taken as sum of the behaviour of each molecule and a study is made then it is known as microscopic or statistical thermodynamics. In this book only subjects or macroscopic or classical thermodynamics will be studied.

1.2. Dimensions and Units

Measureable quantities or characteristics of an object such as its mass, length, time or temperature etc. are described by dimensions.

A unit is a standard for measuring the dimension or quantity.

As per the information from International Organisation for Standardization (ISO) there are seven basic units from which many quantities can be derived either in the form of products or quotient of these basic units : namely metre (length), kilogram (mass) second (time), ampere (electric current), kelvin (temperature), candela (luminous intensity) and mole (amount of substance).

These basic units are defined as below :

1. **Metre (m).** This is the length between two marks on platinum-iridium bar at 0°C which is kept in a vault at the International bureau of weights and measures at Sevres france.

The metre length is redefined as the length equal to 1650763.73 wave lengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the Kryton – 86 atom.

2. **Kilogram (kg).** The kilogram is the unit of mass. It is equal to the mass of lump or platinum-iridium kept at Sevres france and declared International prototype of the kilogram.

3. **Second (S).** The unit of time is the second. It is equal to 1/86400 part of the mean solar day. The second is also the duration of 9192631770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the Caesium – 133 atom.

4. **Ampere (A).** The ampere is that constant current which if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed one metre a part in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.

5. **Kelvin (K).** The kelvin is the unit of thermodynamic temperature and is equal to $\frac{1}{273.15}$ of the thermodynamic tempature of the triple point of water.

6. **Candela (cd).** The Candela is the luminous intensity in the perpendicular direction of a surface of $\frac{1}{600000}$ square metre of a black body at the temperature of freezing platinum under a pressure of 101325 newtons per square metre.

7. **Mole (Mole).** The Mole is defined as an amount of substance of a system which contains as many elementary units as there are carbon atoms in 0.012 kg of the pure nuclide carbon – 12.

The supplementary base units—radian and steradian are defined below :

Radian (plane angle). The angle subtended at the centre of a sphere of radius 1 metre by an area of 1 square metre on the surface. Steradian (Solid angle). The angle subtended by an area on another area.

1.3. Derivation of Important Engineering Units

1. **Force.** Force is one of the most important quantity from engineer's point of view. According to Sir Isaac Newton, the force is proportional to the rate of change of momentum. Mathematically force is expressed as below :

$$F \propto \frac{mu'-mu}{t}$$

$$\propto \frac{m(u-u)}{t}$$

$$\propto ma$$

or $$F = kma \qquad \ldots(i)$$

where k is the proportionality constant.

a = rate of change of velocity *i.e.* acceleration. The SI system of units is rationalized because for any one physical quantity, only one measurement unit is essential and its entire structure is derived from the seven arbitrarily defined basic units. The system of unit is coherent if the product or quotient of any two unit quantities in the system is the unit of the resultant quantity. Hence, the unit of derived quantity (*i*) is obtained from unit values *i.e.* the proportionality constant k shall be unity. So we get

$$F = ma$$

or 1 unit of force = 1 unit of mass (1 kg) 1 unit of acceleration $\left[\frac{1\,m}{s^2}\right]$

$$= 1\text{kgm/s}^2$$

The unit of force is called "NEWTON"

Hence 1 Newton = 1 N = 1 kg m/s^2.

A newton is hence defined as the force which when acting on 1 kilogram mass gives an acceleration of 1 metre per second per second to that mass.

The value of acceleration due to gravity varies from one place to another depending upon the position on earth's surface.

But for all practical purposes a standard value of 9.81 m/s^2 is accepted for it. So if a mass of 1 kilogram is allowed to fall freely, the force experienced by it would be :

$$F = \mathrm{m\,a} = \mathrm{m\,g} \qquad (g = \text{acceleration due to gravity})$$

let $g = 9.81\ \mathrm{m/s^2}$

or $F = 1\ \mathrm{kg}\ 9.81\ \mathrm{m/s^2} = 9.81\ \mathrm{kg\ m/s^2}$

1 kgf = 9.81 N (newtons).

2. **Pressure or stress.** Pressure or stress is stated as the force per unit area and expressed as below :

or $$P = \frac{F}{A} = \frac{N}{m^2} \text{ or } \mathrm{N/m^2}.$$

Pascal is the unit of stress or pressure and is equal to lthe newtons per square metre. Since this unit is very small, generally kN/m^2 and MN/m^2 are used in practice as units of pressure or stress.

3. **Work and energy.** Joule is unit of work which is defined as the work done when a point being acted upon by a force of one newton moves to a distance of one metre in the direction of force *i.e.*

Work done = Force × distance moved

= Newton × metre =Nm.

$$\text{One newton metre} = 1\ \mathrm{Nm} = 1\ (\mathrm{kg/s^2})\ (\mathrm{m}) = 1\ \mathrm{kg}\ \frac{m^2}{s^2} = 1\ \mathrm{J}$$

Also unit of energy is the joule :

$$\text{kinetic energy} = \frac{1}{2} mu^2 \left\{ kg \frac{m^2}{s^2} \right\}$$

$$\text{Potential energy} = \mathrm{mgh} \left(kg \frac{m^2}{s^2} \right)$$

Unit of energy is = J (joule)

4. **Power.** The power of a system is its capacity to do maximum work. The unit of power is watt (W) which is defined as the joule (work done) per second.

$$\text{Power} = \frac{\text{Work done}}{\text{time}}$$

$$P = \frac{J}{s} = W = Watt \left[kg \frac{m^2}{s^3} \right]$$

In engineering use, watt is a small unit; hence kilowatt (kW) and megawatt (MW) are generally used.

5. **Temperature.** The unit for temperature in SI unit is the kelvin (K) although the degree Centigrade (°C) unit is invariably used for temperature.

$$1°\text{C} = 273\ K$$

Another unit of temperature the degree fahrenheit (°F) can be converted to degrees centigrade or degree celsius by the following relation :

$$\text{degrees F} = \frac{9 \text{ degrees C}}{5} + 32$$

Thus the basic units of importance to the Mechanical Engineers are newton, joule, watt and kelvin (N, J, W, K).

1.4. Thermodynamic System

A quantity of matter under consideration or study from thermodynamic point of view is known as a thermodynamic system. A thermodynamic system can be defined as a specified region in which change of energy or mass or both takes place. (Fig. 1.1).

1.5. Surroundings, Boundary and Universe

(*i*) **Surroundings.** Space or matter outside of a themodynamic system is called surroundings or environment. (Fig. 1.1).

(*ii*) **Boundary.** Between a thermodynamic system and its surroundings there exits a boundary. (Fig. 1.1.).

(*iii*) **Universe.** A system and its surroundings together form a universe.

1.6. Kinds of Thermodynamic Systems

There are three kinds of thermodynamic systems, namely :

(*a*) a closed system, (*b*) an open system and

(*c*) an isolated system.

(*a*) **A Closed System.** It is a system of which the mass remains constant. (Fig. 1.2.). There is no transfer of mass across the system boundary, but

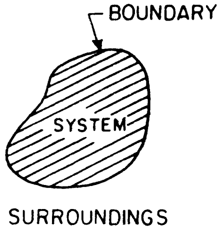


Fig. 1.1. A thermodynamic system.

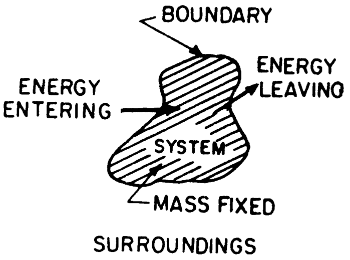


Fig. 1.2. A closed system.

there may be transfer of energy between the system and its surroundings. A certain quantity of steam in a steam engine confined between its cylinder and piston is an example of a closed system. The steam can be expanded or compressed as it is closed from all sides. Thus, boundary of a closed system may change with the transfer of mass.

(*b*) **An Open System.** In as open system the transfer of mass takes place between the system and its surroundings. Also transfer of energy may take place (Fig. 1.3.).

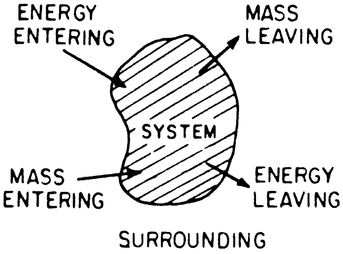


Fig. 1.3. An open system.

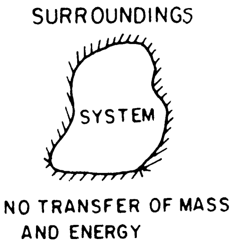


Fig. 1.4. An isolated system.

Examples of open systems are—air compressors, turbines, nozzles, diffusers and engines etc.

In an open system, the analysis is centred around a region in space through which the mass flows. Such a region is named as a control volume bounded by a surface called the control surface. Mass as well as energy may cross the control surface.

(*c*) **An Isolated System.** A system in which there is no transfer of mass and no transfer of energy between it and its surroundings, is known as an isolated system (Fig. 1.4.). In other words, there is no interaction between the system and its surroundings. Its example is space.

1.7. Thermodynamic Properties

There are certain characteristics of a system which describe its physical conditions. These characteristics are pressure, volume, temperature, internal energy, enthalpy, etc., and are called thermodynamic properties. A property can be determined by examining the system under study without any reference to the previous history of the system. For example, the pressure can be measured without any previous knowledge of pressure change which the system might have undergone.

Properties are grouped into two categories. They are :

(*i*) intensive properties and (*ii*) extensive properties.

(*i*) **Intensive Properties.** Properties which are independent of the mass of a system are called intensive properties. Pressure, temperature, specific volume and specific internal energy, specific entropy are the examples of intensive properties of a system.

(*ii*) **Extensive Properties.** Properties which are dependent upon the mass of a system are called extensive properties. The magnitude of an extensive property depends upon the mass of a system. Volume, internal energy, enthalpy and entropy are the examples of extensive properties of a system. The ratio of an extensive property to the mass of a system is called the specific value of that property. For example, if the total volume of a system is V and its mass is m, then specific volume or volume per unit mass of a system is given by

$$v = \frac{V}{m} \quad \text{...(1.1)}$$

Similarly, specific internal energy is given by

$$u = \frac{U}{m} \quad \text{...(1.2)}$$

Generally, capital letters denote extensive properties and small letters represent specific values of these properties.

Properties can be further classified as (*i*) internal properties and (*ii*) external or mechanical properties. Internal properties are the characteristics of a system within the equilibrium system. They are mass, composition, temperature, internal energy etc. External properties are the characteristics of either the motion or the position of the system in a field of force. They are kinetic energy, potential energy, electrical potential etc.

Thermodynamic properties of a system are point functions. Their values depend only on the state of the system and not upon the manner in which the state has reached. If a property of a system is represented by f, then df will be an exact differential *i.e.*,

$$\int_1^2 df = f_2 - f_1 \quad \text{...(1.3)}$$

1.8. State, Path, Process and Cycle

State. The properties of a system can be used as coordinates to describe the condition of the system. This condition is known as a state of the system. Any operation in which one or more of the properties of a system change then its state also changes (Fig. 1.5).

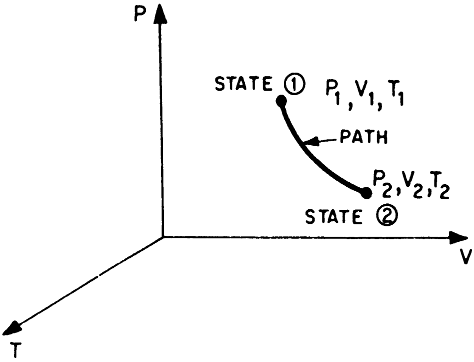
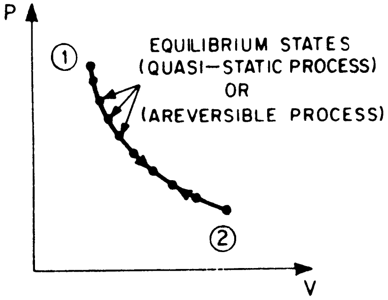


Fig. 1.5. *P.V.T.* coordinates and change of state.

Path. The successsion of state passed through during a change of state forms the path of the change of state.

Process. When a path is completely specified then the change of state is called a process. When a system undergoes a process then atleast one of its properties must change.

Reversible process. A thermodynamic process is called a reversible process when a system passes through a continous series of equilibrium states. In a reversible process (Fig. 1.6) any energy transferred would have to be transferred reversibly. In fact, a reversible process can be obtained when



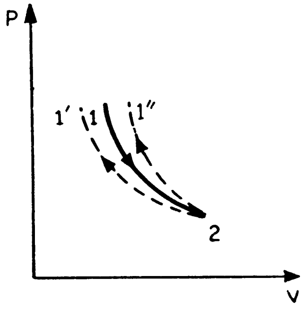


Fig. 1.6. A reversible process. Fig. 1.7. An irreversible process.

the process is quasistatic *i.e.* nearly static (Fig. 1.6). When a reversible process from state point 2 (Fig. 1.6) is reversed then the system attains its initial state 1 (Fig. 1.6). The equilibrium states coincide with the previous equilibrium states and energy transferred or transformed during the process is restored in the system and the surroundings. Examples of reversible processes are frictionless relative motion, frictionless adiabatic expansion and compression, polytropic and isothermal expansion and comression processes etc. A reversible process is possible in an ideal gas.

Irreversible process. A process in which energy transfer is not reversible is called an irreversible process. In an irreversible process, a system passes through a sequence of non-equilibrium states and if it is reversed,the system will not attain its initial state (Fig. 1.7). When a system undergoes an irreversible process, then it passes through a sequence of non-equilibrium states during the process and these states can not be shown on any property diagram because each property has not a unique value in the entire system. The end states of an irreversible process are considered as states of equilibrium. Sometiemes, an irreversible process is shown by broken lines. (Fig. 1.8).

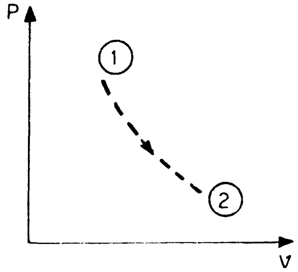


Fig. 1.8. An irreversible process.

Fluid flow with friction, heat transfer by convection and turbulent flow are some of the examples of irreversible processes.

Kinds of processes. The following are the thermodynamic processes :

(*i*) Isobaric process (constant pressure process)

(*ii*) Isochoric process (constant volume process)

(*iii*) Isothermal process (constant temperature process)

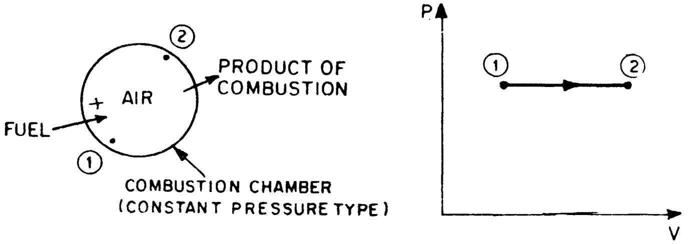
(*iv*) Isentropic process (constant entropy process)

(*v*) Isenthalpic (throttling) process (constant enthalpy process)

(*vi*) Adiabatic process (PV^γ = constant)

(*vii*) Polytropic process (PV^n = constant).

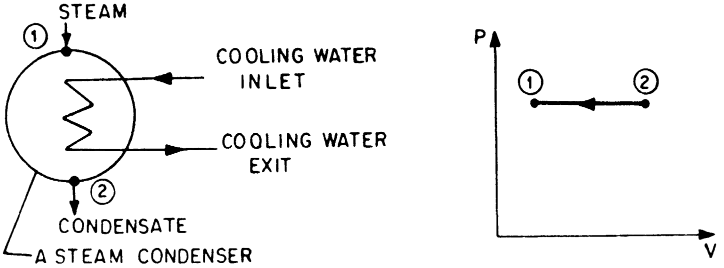
(*i*) **Isobaric process.** In an isobaric (constant pressure) process thermal energy level of a system can be raised by burning fuel in constant pressure combustion chamber Fig. 1.9 (*a*). The process is shown in Fig. 1.9 (*b*).



(*a*) Heat addition in isobaric process. (*b*) *P-V.* diagram

Fig. 1.9

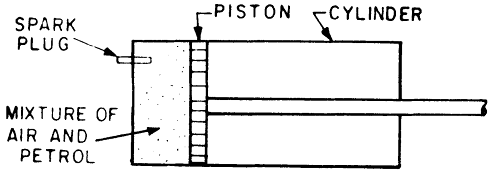
Similarly, isobaric heat rejection can be obtained in a steam condenser, Fig. 1.10 (*a*). The process of cooling during this process is shown in Fig. 1.10 (*b*).



(*a*) Heat rejection in isobaric process. (*b*) P.V. diagram.

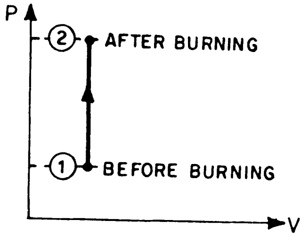
Fig. 1.10

(*ii*) **Isochoric process.** In an isochoric (constant volume) process, energy transfer can be obtained at constant volume. For example, in a petrol engine, heat addition takes place at constant volume (Fig. 1.10) by burning mixture of air and petrol in its cylinder by a spark plug. The process in *P-V* diagram is shown in Fig. 1.11 *(b)*



(*a*)

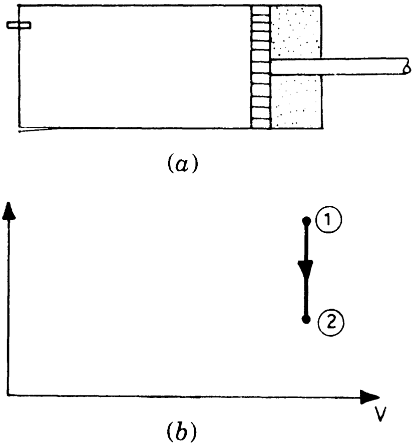
Fig. 1.11



(*b*)

Fig. 1.11

Similarly, isochoric heat rejection can be obtained in the petrol engine at its exhaust stroke Fig. 1.12 (*a*). Its P – V diagram is shown in Fig. 1.12 (*b*).



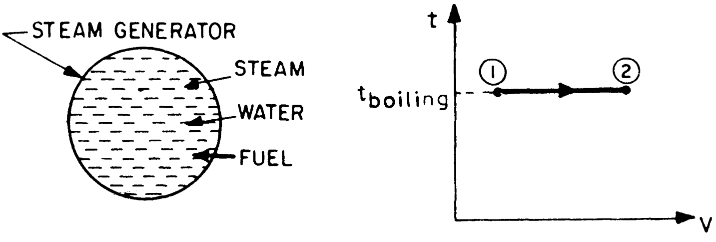
(*a*)

(*b*)

Fig. 1.12

(*iii*) **Isothermal process.** It is a constant temperature thermodynamic process *i.e.* during this process energy transfer takes place at constant temperature. For example, in a steam generator (boiler) heat is added to liquid water at its boiling temperature to convert into steam Fig. 1.13 (*a*) by burning fuel in furnace. The process is shown in *t* - V diagram in Fig. 1.13 (*b*).

One of the examles of heat rejection during an isothermal process is the condensation of steam into liquid water in a steam condenser at condensation temperature of steam, Fig. 1.14 (*a*). The process is shown in *t*-*V* diagram in Fig. 1.14 (*b*)

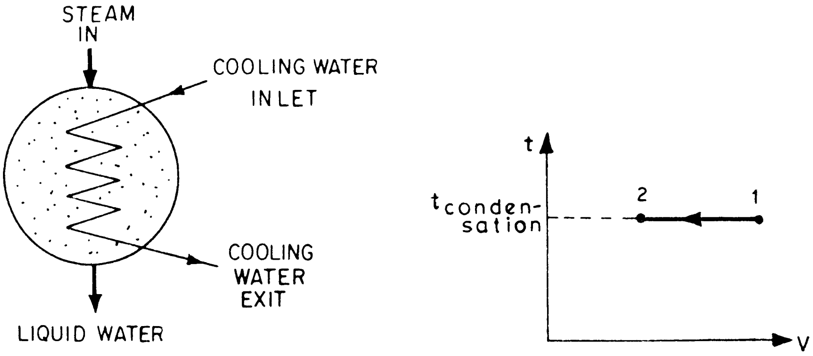


(*a*)

(*b*)

State (1) : Liquid water
State (2) : Steam

Fig. 1.13



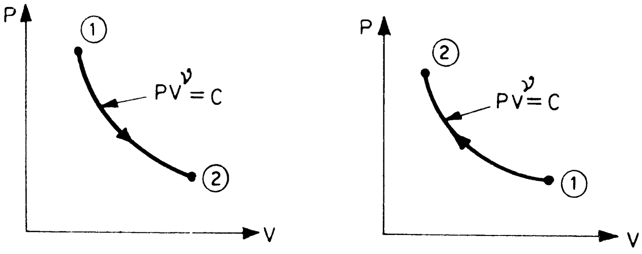
(a) (b)

State (1) : Steam

State (2) : Liquid water

Fig. 1.14

(*iv*) **Isentropic process.** During an isentropic process heat is neither added into a system nor rejected from a system. This process is also called as an adiabatic process without internal friction between the layers of fluid comprising a system. This is an ideal (theoretical) process. This process takes place in petrol engines, diesel engines, steam turbines and gas turbines etc. during expansion process of the system. It is shown in Fig. 1.15 (*a*) in *p*-*V* diagram. Isentropic compression process takes place in air compressors and pumps etc. Fig. 1.15 (*b*) shows its *p*-*V* diagram.



(*a*) Isentropic expansion process. (*b*) Insentropic compression process.

Fig. 1.15

(*v*) **Isenthalpic process.**It is a constant enthalpy process and is also called as a throttling process. An isenthalpic process occurs when a thermodynamic system passes through a narrow path inside an insulated pipe or a duct or a channel Fig. 1.16 (*a*). One of the examples is the flow of steam through a throttle valve of a steam engine. At the end of an isenthalpic process, pressure and temperature decreases, enthalpy remains constant and entropy increases Fig. 1.16 (*b*).

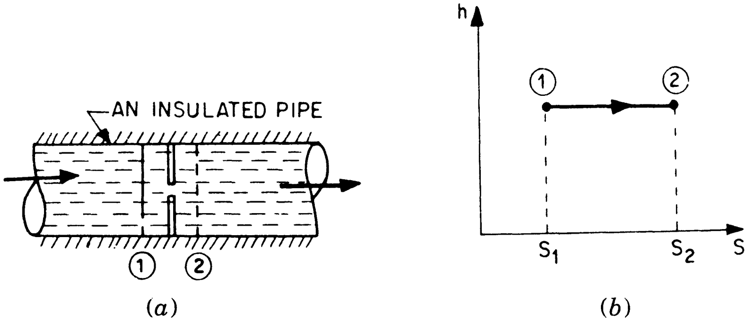
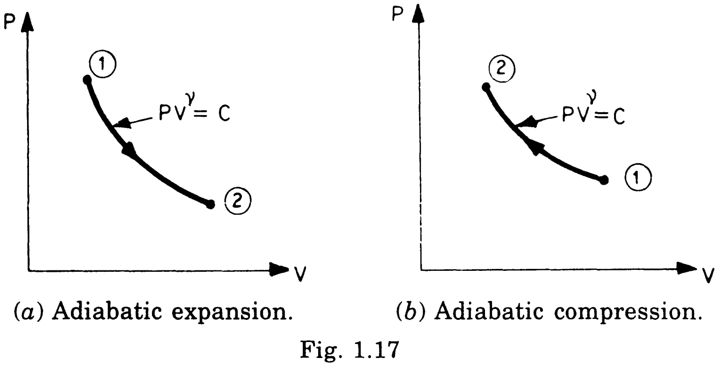


Fig. 1.16

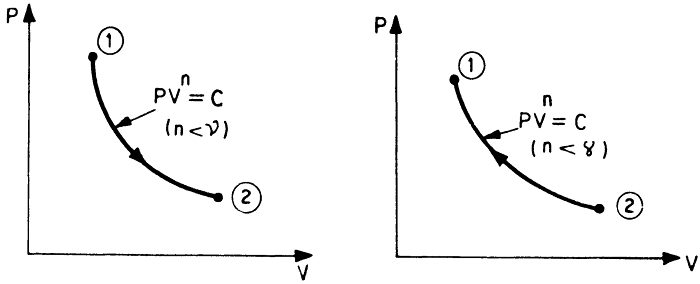
(*vi*) **Adiabatic process.** During an adiabatic process heat transfer between a system and its surroundings is zero as in case of an isentropic process. But in an adiabatic process internal friction between the layers of the fluid (system) exists.In practice, expansion and compression processes in petrol engines, diesel engines turbines and gas turbines unit are adiabatic processes as shown in Fig. 1.17 (*a*) and 1.17 (*b*).



(*a*) Adiabatic expansion. (*b*) Adiabatic compression.

Fig. 1.17

(*vii*) **Polytropic process.** During a polytropic process, heat transfer between a system and its susrroundings takes place. For example, when a gas or steam expands in a gas turbine or a steam turbine from a higher temperature then if the casing is not perfectly insulated, then due to temperature difference between the gas or steam and the surroundings loss of heat will take place (heat transfer from the system to the surroundings), and the index of expansion 'n' will be less than 'γ' Fig. 1.18 (*a*).



(*a*) Polytropic expansion (*b*) Polytropic compression.

Fig. 1.18

Similarly, during a compression process in an air compressor, heat transfer takes place from the air to the surroundings through fins or cooling water and the index of compression 'n' will be less than 'γ' Fig. 1.18 (*b*).

Cycle. A thermodynamic cycle is defined as a combination of a number of processes (at least two processes) that a system undergoes through them having state changes in such a way that it attains its initial (original) state (Fig. 1.19).

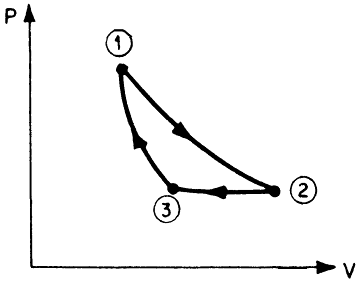


Fig. 1.19. 1-2-3-is a cycle.

1.9. Phase, Homogeneous and Heterogeneous System

Phase. When a quantity of matter is uniform in physical structure and chemical composition throughout, then the matter is called a single phase.There are three phases of a substance, namely–solid, liquid and vapour or gas.

Homogeneous system. When a system is in a single phase *i.e.* it is either solid, liquid or gas, then such a system is called a homogeneous system. For example, a mixture of dry air and water vapour, a mixture of liquid water and ammonia, a mixture of liquid water and nitric acid, tea or coffee. These mixtures have uniform physical structures and chemical compositions.

Heterogeneous system. When a system is in more than one phases, then it is called a heterogeneous system. A heterogeneous system may have any combination of phases of a particular substance *i.e.* a system may be in solid and liquid phases or liquid and gas phases, or solid and gas phases or in all the three phases *i.e.* solid, liquid and vapour or gas. The examples of heterogeneous systems are listed below :

(*i*) a mixture of solid and liquid-ice and liquid water together

(*ii*) a mixture of liquid and vapour phases—liquid water and steam together

(*iii*) mixture of vapour and solid phases-steam and ice together

Also, a heterogeneous system has a non-uniform physical structure and chemical composition. For example—a mixture of oil and water.

1.10. Thermodynamic Equilibrium

When there is no change in any thermodynamic properties of a system, when it is isolated from its surroundings, then such a system is said to be in a thermodynamic equilibrium.

In an isolated system, its properties like pressure and temperature may vary with time initially, but gradually the rate of change will become lesser and lesser until no further change will occur. This final steady state of an isolated system is a state of thermodynamic equilibrium. Thus, it can be said that an isolated system always reaches a state of thermodynamic equilibrium in course of time and can never depart from it spontaneously.

Thermodynamic equilibrium is a complete equilibrium *i.e.* the following three types of equilibrium exist in a system :

(*i*) mechanical equilibrium;

(*ii*) thermal equilibrium; and

(*iii*) chemical equilibrium.

(*i*) **Mechanical equilibrium.** A thermodynamic system is said to be in mechanical equilibrium when there is no unbalanced force within the system and also between the system and its surroundings. As soon as any unbalanced force exists in the system or between the system and its surroundings, the change of state will occur till mechanical equilibrium is attained.

(*ii*) **Thermal equilibrium.** When there is no temperature difference between any two points in a system *i.e.* there is a uniformity of temperature in the system then the system, is in thermal equilibrium.

(*iii*) **Chemical equilibrium.** When there is no chemical reaction taking place in any part of a system, then the system is in chemical equilibrium.

When, in a system, any one of the above equilibria is absent, then the system is said to be in a non-equilibrium state. When a system undergoes a change of state in a non-equilibrium condition, then the system can not be described by thermodynamic properties which represent the system as a whole. Thus, thermodynamic properties are used only for thermodynamic equilibrium states and are used as coordinates to describe a system.

1.11. Quasi-Static Process

When a system in thermodydnamic equilibrium state passes through a process in such a way that every state in the process is in thermodynamic equilibrium or has a deviation by only infinitesimal quantity, then the process is known as a quasi-static process as shown in Fig. 1.20. In fact, all reversible processes are quasi-static processes.

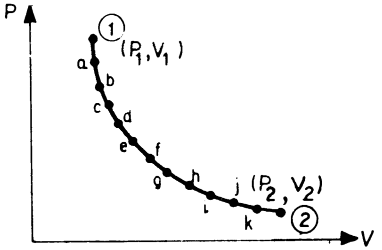


Fig. 1.20. Processes 1-2; Quasi-static states *a*, *b*, *c*,.....*k* in thermodynamic equilibrium.

1.12. Energy

Energy is the capacity to exert forces through a distance *i.e.* capacity to do work. It is a scalar quanity which can not be observed but can be recorded and evaluated by indirect measurements.

Forms of Energy

(*i*) **Potential energy.** Energy stored in a system due to its elevation is known as potential energy. For example—potential energy of a system having mass '*m*' at an elevation *Z* above a datum of zero potential will be

$$(\text{P.E.})_Z = mgZ \qquad ...(1.4)$$

Potential energy (P.E.) of a system is an external form of energy.

(*ii*) **Kinetic energy.** Energy possessed by a system due to its velocity is called kinetic erergy. If '*m*' is the mass of a system and '*C*' is its velocity, then

$$\text{Kinetic energy (K.E.)} = \frac{m}{2}c^2 \qquad ...(1.5)$$

Kinetic energy of a system is also an external form of energy.

(*iii*) **Internal energy.** Internal energy is an energy stored in a system due to its temperature elevation. Internal energy is an extensive property of a system [Art. 1.6 (ii)]. Mathematically, internal energy for a gas is written as

$$U = mC_v t \qquad ...(1.6)$$

where U = Internal energy
m = Mass of a system (gas)
C_v = Specific heat capacity at constant volume
t = Temperature in degree.

(*iv*) **Flow energy.** Energy due to transfer of mass across the boundary of a system is known as flow energy. For example : if a system of mass 'm' and specific volume 'v' flows across the boundary of the system at a pressure 'P' as shown in Fig. 1.21, then. Fig. 1.21. Flow energy.

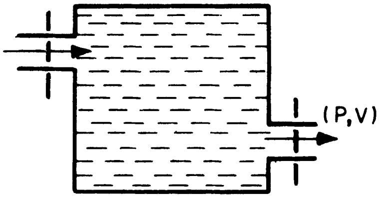


Fig. 1.21. Flow energy (*PV*).

Flow energy

$$= P\,.\,(mv) = PV \qquad ...(1.7)$$

where V = Total vlume of a system flowing across the boundary.

In integral form, flow energy is written as

$$\text{Flow energy} = \int_1^2 V dp \qquad ...(1.8)$$

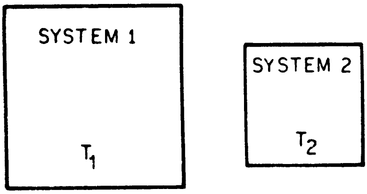
(*v*) **Transient energy.** Energy which flows across the system bounary like heat and work is known as transient energy.

1.13. Heat

When two systems 1 and 2, having different temperatures T_1 and T_2 (let $T_1 > T_2$) respectively are brought near to each other then energy transfer, without transfer of mass, across the boundaries of the systems take place due to temperature difference between them. Energy flows from a system at higher temperature (T_1) to a system at lower temperature (T_2). Such energy is known as *heat.*

Energy transfer ceases as soon as both the systems attain a common temperature (T). Thus, heat is a transient quantity. It occurs only during a transfer of energy due to temperature difference as shown in Fig. 1.22.

Heat, being a transient quantity, is not possessed by a system and hence it is not considered as a themodynamic property of a system. As the amount of heat transfer depends upon the



$T_1 > T_2$ (initially)

$$\left.\begin{array}{l} T_1 \to T \\ T_2 \to T \end{array}\right\} \text{(after some time)}$$

Fig. 1.22

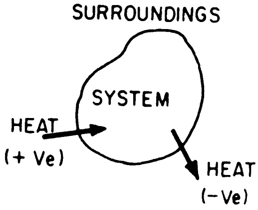


Fig. 1.23

modes of heat transfer either by conduction, convection or by radiation it is considered as a path function. Heat is taken as a positive quantity when a system recieves it from its surroundings and it is a negative quantity when the surroundings receive heat from a system as shown in Fig. 1.23.

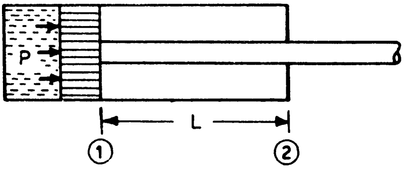
1. 14. Work

In mechanics, work is defined as a product of a force acting on a body and the distance through which the force moves the body along its direction.

Work = (Force) × (distance) ...(1.9)

= $(F) \times (L)$ ...(1.10)

But, in thermodynamics, this definition of work is not sufficient, because in thermodynamics energy transfer between a system and its surroundings is in the form of heat and work. Therfore, in thermodynamics, work is defined as an energy transferred, without transfer of mass, across the boundary of a system because of an intensive property difference, other than temerature, that exists between them. For example : Let a certain quantity of gas in a cylinder of an engine be initially at a pressure '*P*' and volume V_1 at state 1 as shown in Fig. 1.24. Let the piston move out to a new position at state-2, where pressurre remains as '*P*'and volume increases to V_2.



State 1 : p, V_1
State 2 : p, V_2

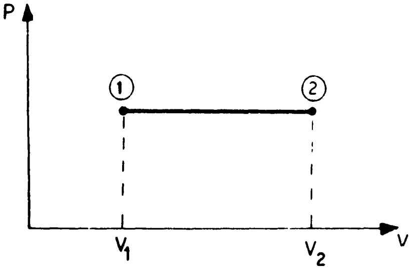


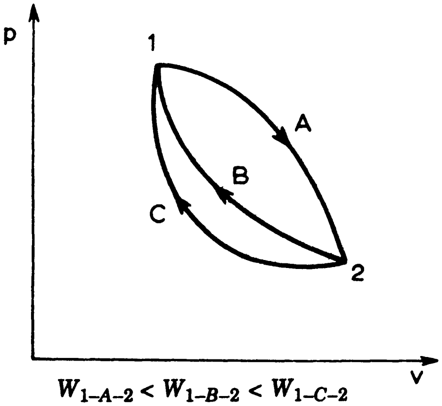
Fig. 1.24

When the piston has a surface area *'A'* and a stroke (displacememnt) *L*, then work done will be the products of *P*, *A* and *L*, *i.e.*,

Work done = P.A.L. = $P. (V_2 - V_1)$ ...(1.11)

As long as a system has a displacement, there is a work. The moment, displacement of a system stops, the work ceases. Thus, work, like heat, is a transient quantity and is not possessed by a system. Therefore, work is not a thermodynamic property of a system. Also, magnitude of work done between two state points of a system depends upon the kind of process which takes place between the states 1 and 2 as shown in Fig. 1.25. Hence, work is a path function.

When work is done by a system in its surroundings, then it is taken as a positive work. When work is done on a system by its surroundings, then it is taken as a negative quantity as shown in Fig. 1.26.



$W_{1-A-2} < W_{1-B-2} < W_{1-C-2}$

Fig. 1.25

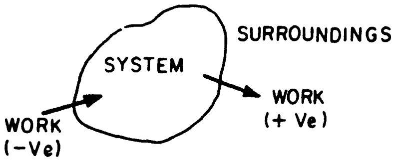


Fig. 1.26.

1.15. Temperature and Zeroth Law of Thermodynamics

1.15.1. Temperature

Temperature is an intensive property of a thermodynamic system. Temperature is considered as an indicator of hotness. Temperature is a result of activity of molecules of a system. Higher temperature means higher kinetic energy of molecules. Temperature is used in determining whether a system is in thermal equilibrium with other systems. When two systems having different temperatures are brought closer to each other or in contact with each other, then after some time they attain a common temperature and are in thermal equilibrium with each other.

1.15.2. Zeroth Law of Thermodynamics

When a system *A* is in thermal equilibrium with a system *C* and a system *B* is in thermal equilibrium with the system *C* then the system *A* is also in thermal equilibrium with the system *B* as shown in Fig. 1.27. Thus, it can be stated that "when two systems are each in thermal equilibrium with a third system separately, then the two systems are also in thermal equilibrium with each other". This is known as Zeroth Law of thermodynamics.

This law of thermodynamics is a basis of measurement of temperature. The third system *C* is a thermometer. With a thermometer it is possible to know whether two or more than two systems are in thermal equilibrium with each other without bringing them in contact with each other.

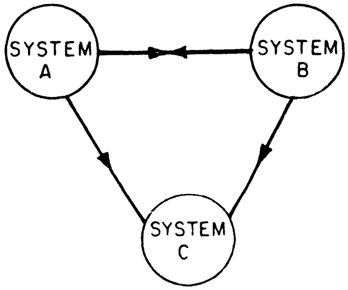


Fig. 1.27

1.16. Measurement of Temperature

To obtain a quantitative value of temperature, a system is used which contains a substance whose physical characteristics changes with temperature. The selected system is called a thermometer and the physical characteristics is called thermometric property. A very common thermometer is made of an evacuated capillary tube which contains a small amount of mercury. The rise of mercury column in the tube is used as its thermometric property.

In general, the following thermometers are used with thermometric properties shown against each of them.

	Thermometer	*Thermometric property*
(*i*)	Mercury-in-glass thermometer	Length
(*ii*)	Constant volume gas thermometer	Pressure
(*iii*)	Constant Pressure gas thermometer	Volume
(*iv*)	Electrical resistance thermometer	Resistance
(*v*)	Thermocouple	Thermal e.m.f.
(*vi*)	Radiation pyrometer	Thermal radiation
(*vii*)	Optical pyrometer	Monochromatic radiation.

1.16.1. Temperature Scales

The scale used for measuring temperature is the celsius scale which is written as 0°C.

Before 1954, the Celsius scale was based on two fixed points namely the ice point and the steam point. The ice point is the temperature of a mixture of ice and water which is in thermal equilibrium with saturated air at a pressure of 100 kN/m^2. The steam point is the temperature of water and steam which are in thermal equilibrium at a pressure of 100 kN/m^2. These two points are 0°C and 100°C on the Celsius scale.

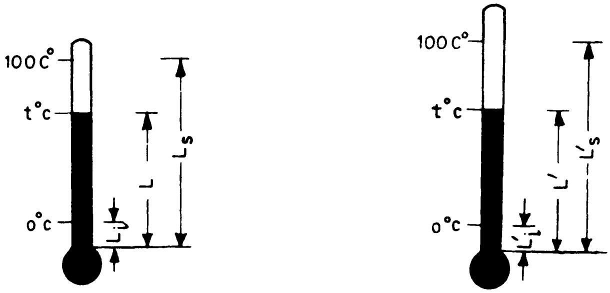


Fig. 1.28 (*a*) Liquid thermometer with a liquid *A*. (*b*) Liquid thermometer with a liquid *B*

Let the ice point (0°C) be L_i and the steam point (100°C) be L_s on the temperature scale shown in Fig. 1.28 (*a*) and t°C is represented by length L where liquid A is used with length as a thermometric property, then

$$t°\text{C} = 100\,\frac{L - L_i}{L_s - L_i} \qquad \ldots(1.12)$$

Similarly, if another liquid B is used in another thermometer as shown in Fig. 1.28 (*b*) having ice point as L_i' and steam point as

L_s' then if this thermometer is brought in contact with a system which has t°C obtained from the thermometer with liquid A, we get

$$t'\,°\mathrm{C} = 100\,\frac{L' - L_i'}{L_s' - L_i'} \qquad ...(1.13)$$

If the expansion coefficients of liquid A and B are different, then mathematical values of t and t' will be different though they represent the temperature of the same temperature. The use of two fixed points was not found satisfactory due to difficulty of achieving equilibrium between a pure ice and saturated air with pure water, and due to extreme sensitiveness of the steam point to the change in pressure. Hence, this method is not in use now.

After 1954, only one fixed point is in use. It is the triple point of water at which ice, liquid water and water vapour exist together in thermal equilibrium. Its value is assigned as 0.01°C.

The absolute scale related to the Celsius scale is known as Kelvin Scale (after Lord Kelvin, 1821—1907) and is designated K. The relation between Kelvin scale and Celsius scale is given as

$$K = °\mathrm{C} + 273.15 \qquad ...(1.14)$$

If triple point of water is written as t_t and the thermometric property as x_t and a system is brought in contact with the triple point of water, then the following relation is obtained :

$$t_t = a x_t$$

$$\therefore \quad a = \left(\frac{t_t}{x_t}\right) = \frac{(273.15 + 0.01)}{x_t} = \frac{273.16}{x_t} \qquad ...(1.15)$$

therefore,

$$t = x = \frac{273.16}{x_t}\,x$$

$$= 273.16\,\frac{x}{x_t} \qquad ...(1.16)$$

According to the Eq. (1.16) the temperature recorded by different thermometers will be as given below :

(*i*) Liquid in glass thermometer $t(L) = 273.16\,\frac{L}{L_t}$

(*ii*) Constant volume gas thermometer $t(p) = 273.16\,\frac{P}{P_t}$

(*iii*) Constant pressure gas thermometer $t\,(V) = 273.16\,\frac{V}{V_t}$

(*iv*) Thermocouple $t(E) = 273.16\,\frac{\varepsilon}{\varepsilon_t}$

(*v*) Electric resistance thermometer $t\ (R) = 273.16\ \dfrac{R}{R_t}$

It is observed that if the temperature of a system is measured with these thermometers simultaneously then there is a considerable difference among the readings. But if different gas thermometers are used then the difference of readings is the smallest. Hence a gas is used as a standard thermometric substance.

1.17. Gas Thermometers

Gas thermometers are based on the fact that as the pressure of a gas approaches zero, its equation of state approaches the ideal gas equation of state,

$$Pv = RT \qquad \text{...(1.17)}$$

or

$$\left(\frac{Pv}{T}\right)_{p\to 0} = \text{Constant} \qquad \text{...(1.18)}$$

From the Eq. (1.18) the product Pv of a gas is a function of temperature only and is independent of the thermometeric property.

There are two ways of measuring temperature with gas thermometers.

(*i*) Temperature can be measured by a gas thermometer by keeping the pressure of the gas constant and measuring the variation of volume. The change of volume of the gas will be directly proportional to the change of temperature-equation (1.18). Such a gas thermometer is known as a constant pressure gas thermometer.

(*ii*) A gas thermometer can be made for measuring temperature by keeping volume constant. The variation of pressure at constant volume will be proportional to changes in temperatures. Such thermometers are known as constant volume gas thermometers.

1.17.1. A constant pressure gas thermometer

A constant pressure gas thermometer is not very common in use because it is very difficult to measure small change of volume at a constant pressure due to a small change of temperature.

A *constant volume gas thermometer* is often used because it is easier to measure change of pressure due to change of temperature at a constant volume.

1.17.2. A constant volume gas thermometer

A schematic diagram of a constant volume gas thermometer is shown in Fig. 1.29. It consists of a gas bulb, a capillary tube and a mercury column.

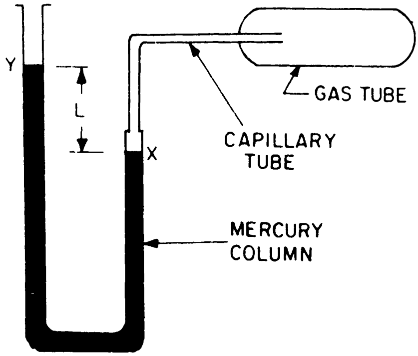


Fig. 1.29. A constant volume gas thermometer.

The gas bulb is brought in contact with the system, the temperature of which is to be measured. The mercury column is adjusted so that the level of mercury stands at the reference mark *X*. Thus the volume of the gas is maintained constant. The gas in the capillary tube is assumed to have the same temperature as the gas in the bulb. The pressure of the gas, which is indicated by the height of the mercury column is a measure of the temperature *T*.

When the gas bulb is brought at the triple point of water (273.16 K) at pressure P_{tp} then the temperature T can be calculated from the following relation :

$$\frac{T}{T_{tp}} = \left(\frac{P}{P_{tp}}\right)_{P_{tp}\to 0} \qquad \text{...(1.19)}$$

or

$$T = T_{tp}\left(\frac{P}{P_{tp}}\right)_{P_{tp}\to 0} = 273.16\left(\frac{P}{P_{tp}}\right)_{P_{tp}\to 0} \qquad \text{...(1.20)}$$

The temperature T so obtained is considered as the ideal gas temperature and is equal to the thermodynamic temperature.

A series of measurements is made by varying the quantity of gas in the gas bulb so that different values for triple point pressures (P_{tp}) and any other temperature are obtained. When an indicated temperature T_i is plotted against the pressure of the gas with the gas bulb at the triple point of water, a curve as shown in Fig. 1.30 is obtained.

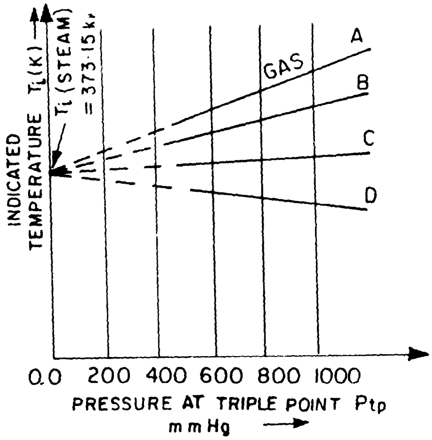


Fig. 1.30.

When a curve obtained for a gas *A, B, C or D* is extrapolated to zero pressure, the correct ideal gas temperature is obtained. All these curves *A, B, C, D* result from different gases, but they will all indicate the same temperature at zero pressure.

Different range of temperatures can be measured by a constant volume gas thermometer by using different gases. The ranges of temperatures which can be measured by using different gases are given in Table 1.1.

Table 1.1

Gas	*Temperature range °C*
Helium	below –200
Hydrogen	–200 to 500
Nitrogen	upto 1500

1.18. Electrical Resistance Thermometer

Change of resistance of a metallic wire due to change of temperature is taken as a thermometric property in an electrical resistance thermometer (Fig. 1.31). Platinum wire is generally used in this thermometer. A very high temperature can be measured with a very high degree of accuracy due to which a platinum resistance thermometer *is used as a standard* for calibration of other thermometers also.

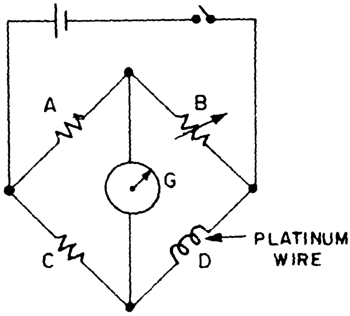


Fig. 1.31. Platinum resistance thermometer.

An elelctrical resistance thermometer works on the principle of a wheatstone bridge. Any temperature t can be obtained from the following relation :

$$R_t = R_o = (1 + at + bt^2 + ct^2 + ...) \qquad ...(1.21)$$

where R_t = resistance of wire at t° C, Ω

R_o = resistance of wire at 0°C, Ω

a, b, c = constants of the wire used.

Its range of temperature is from – 200°C to 1000°C for which the accuracy of the thermometer is very high.

1.19. Thermocouples

When two wires of different metals are joined at two points and one of the junctions is kept in a higher temperature (Fig. 1.32) and the other junction of these wires is put in a lower temperature, then according to the seeback effect, a net e.m.f. is setup which causes a current to flow in the circuit due to the temperature difference. Thus e.m.f. generated is a thermometric property of the circuit.

The e.m.f. procuced due to temperature difference between the two junctions of the wire 1 and 2 can be measured by a micro voltmeter G to a very high degree of accuracy.

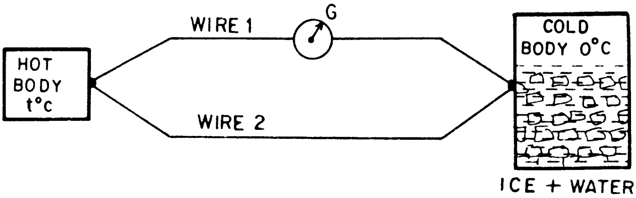


Fig. 1.32. A thermocouple.

Thermocouples are calibrated by measuring e.m.f. produced at different known temperatures and by taking 0°C (temperature of ice + water mixture) as a reference temperature for the thermocouples. The results of such calibrations can be given by the following equation :

$$\varepsilon = a + bt + ct^2 + dt^3 \qquad ...(1.22)$$

where ϵ = e.m.f.

a, b, c, d = constant for each thermocouple

t = temperature of hot body, °C.

Different metals are used for different ranges of temperatures to be measured. Some of them are mentioned below in Table 1.2.

Table 1.2

	Metals	*Range of temperatures*
1.	Iron and constantum	upto 250—300°C
2.	Iron and Nickel	250—550°C
3.	Nickel and chromium	500—1500°C
4.	Platinum and rhodium	800—1600°C
5.	Rhodium and iridium	1000—2000°C
6.	Iridium and rubidium	1500—2500°C
7.	Tungsten and moledium	2000—3000°C

1.20 Radiation Pyrometer

In a radiation pyrometer the heating effect of energy radiated from a system of high temperature is used as a thermometric property and is an index of its temperature. The salient feature of a radiation pyrometer is shown in Fig. 1.33.

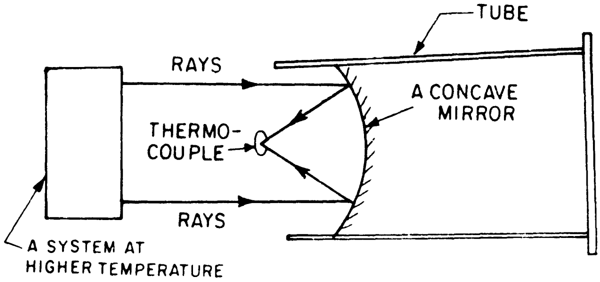


Fig. 1.33. A radiation pyrometer.

A radiation pyrometer contains a concave mirror fixed in a tube. The radiation rays radiated from the system, whose temperature is to be measured, concentrate on a thermocouple which is connected to a temperature measuring device. Generally, temperatures higher than 300—400°C are measured by such pyrometers.

1.21. Optical Pyrometer

In an optical pyrometer, monochromatic radiation from a system, whose temperature is to be measured, is used as a thermometric property to measure the temperature. An optical pyrometer consists of a telescope which contains a small electric filament lamp and a variable resistance in the filament circuit. (Fig. 1.34).

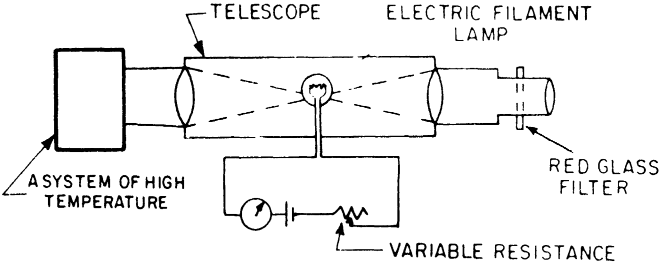


Fig. 1.34. An optical pyrometer.

A high temperature system is seen through a telescope and the image of the filament is superimposed on the system. The temperature of the filament is varied by a variable resistance till the image of the filament merges into the image of the high temperature system. At this condition the temperatures of the system and the filament are equal. By calibrating the variable resistance the temperature of the system is determined. This pyrometer is used for measuring temperatures higher than 600°C.

1.22. International Temperature Scale

Temperature of fixed points of certain substances have been accepted as international temperature scale by the International Committee of Weights and Measures. This international temperature Scale is similar to Celcius Scale. Scientific and industrial instruments are easily calibrated with this scale. Temperatures of fixed points at atmospheric pressure are given in Table 1.3.

Table 1.3

S. No.	*Fixed point*	*Temperature°C*
1.	Boiling point of oxygen, *i.e.* temperature of equilibrium between liquid and vapour oxygen	–182.97
2.	Triple point of water, *i.e.* temperature of equilibrium between ice and air saturated water	0.01
3.	Boiling point of water, *i.e.* temperature of equilibrium between liquid water and its vapour.	100.00
4.	Boiling point of sulphur, *i.e.* temperature of equilibrium between liquid sulphur and its vapour.	444.60
5.	Boiling point of silver, *i.e.* temperature of equilibrium between solid silver and liquid silver.	960.80
6.	Boiling point of gold, *i.e.* temperature of equilibrium between solid gold and liquid gold.	1063.00

The temperatures between oxygen point to gold point are divided into the following three parts :

(*i*) From – 182.97°C to 0°C

For measuring temperatures between –182.97°C to 0°C, a platinum resistance thermometer, having diameter of platinum wire between 0.05 mm to 0.2 mm, is used. The temperature is obtained from the following relation

$$R_t = R_o\,[1 + At + Bt^2 + C\,(t - 100)t^3] \qquad ...(1.23)$$

where R_0 = resistance at the ice point.

A, B, C = constants determined by calibration at the steam point, sulphur point and oxygen point respectively.

(*ii*) From 0°C to 660°C

A platinum resistance thermometer is used for measuring the temperatures between 0°C to 660°C by using the following relation.

$$R_t = R_o\,(1 + At + Bt^2) \qquad ...(1.24)$$

where R_o A and B are the constants at ice point, steam point and sulphur point.

(*iii*) From 660°C to 1063°C

For measuring temperatures between 660°C to 1063°C, a thermocouple comprising of a platinum wire and a platinum-rhodium wire, is used with one junction kept at 0°C. The temperature is obtained from the following equation.

$$\Sigma = a + bt + ct^2 \qquad ...(1.25)$$

where a, b, c = constants obtained at antimony point, silver point and gold point respectively.

To measure temperatures above 1063°C, an optical pyrometer is used. The intensity of radiation J is compared with the intensity of radiation of the same wave length emitted by a black body at the gold point J_{Au}. The following formula is used

$$\frac{J}{J_{Au}} = \frac{\exp\left\{C_2 l/(t_{Au +} T_o)\lambda\right\} - 1}{\exp\left\{C_2/(t + T_o)\,\lambda\right\} - 1} \qquad ...(1.26)$$

where C_2 = 1.438, cm- K

T_0 = ice point temperature, K.

λ = wave length, cm.

1.23. SOLVED PROBLEM

Problem 1.1. *The length of the mercury column in a certain mercury in-glass thermometer is 5.0 cm when the thermometer is at the ice point and is 25.0 cm when the thermometer is at the steam* *point. Consider this length as the thermometer property X and let t be the temperature on a linear celcius scale as determind by this thermometer.*

Suppose we were to define a celcius temperature t by the quadratic equation,*

$$t^* = ax^2 + b$$

where t = 0 at the ice point and t* = 100° at the steam point. Calculate the temperature t* when t = 50°.*

Solution. Given : Hg column 5 cm at ice point = L_i

Hg column 25 cm at steam point = L_s

X – Thermometer property $t^* = ax^2 + b$

To find : tem. t^* at $t = 50°C$.

$$t = 100\,\frac{L - L_i}{L_s - L_i}$$

Equation at ice point, $0 = ax^2 + b$

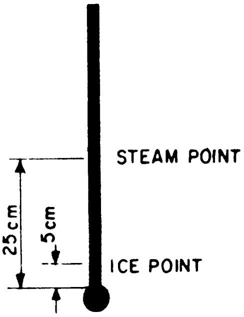
or $\quad 0 = a\,(5)^3 + b \qquad ...(1)$

Equation at steam point,

$$100 = ax^2 + b$$

$$100 = a\,(25)^2 + b \qquad ...(2)$$

from eqns. (1) and (2), $a = \frac{1}{6},\ b = -\left(\frac{25}{6}\right)$



$\therefore \quad t^*$ at $\quad X = 5 + \frac{(25-5)}{2} = 15$ cm

$$t^* = \frac{1}{6}\,(15)^2 - \frac{25}{6} = \mathbf{33.33°.\ Ans.}$$

1.24. EXERCISES

(A) Objective Types

1. Which one of the following may be variable in a closed system
   (*a*) mass of a system
   (*b*) boundary (control volume) of a system
   (*c*) mass as well as control volume of a system
   (*d*) none of these.

Ans. (*b*)

2. Which one of the following is true in an open system
   (*a*) only mass of the system remains constant
   (*b*) only control volume (boundary) of the system remains constant.

(*c*) only control volume of the system varies

(*d*) mass as well as control volume of the system vary.

Ans. (*b*)

3. A thermodynamic system is considered to be an isolated one if

(*a*) mass transfer and entropy change are zero.

(*b*) entropy change and energy transfer are zero.

(*c*) energy transfer and mass trnsfer are zero.

(*d*) mass transfer and volume change are zero.

Ans. (*c*)

4. Which one of the following is an irreversible process

(*a*) an isothermal process (*b*) an isentropic process

(*c*) an isobaric process (*d*) an isenthalpic

Ans. (*d*)

5. Which one of the following is a process without heat transfer between a system and its surroundings

(*a*) an adiabatic process (*b*) a polytropic process

(*c*) an isochoric process (*d*) an isothermal process.

Ans. (*a*)

6. On which one of the following, internal energy of a system depends upon

(*a*) mass and temperature (*b*) temperature and pressure

(*c*) pressure and volume (*d*) volume and mass.

Ans. (*a*)

7. Heat is energy transfer that is

(*a*) not accounted for in microsopic evaluation of energy transfer as work

(*b*) macroscopic work that is hidden from direct microscopic view

(*c*) associated with transfer of mass across the boundary of a system

(*d*) not a transient quantity and is independent of mass.

Ans. (*a*)

8. Which one of the following statement related to heat is true

(*a*) heat is an extensive property of a matter

(*b*) heat is an intensive property of matter

(*c*) heat is a transient phenomenon

(*d*) heat is expressed as a point function.

Ans. (*c*)

9. Which one of the following statement is related to work

(*a*) work is a path function

(*b*) work is a non-transient phenomenon

(*c*) work is associated with change in mass

(*d*) work is a point function.

Ans. (*a*)

10. Work is defined as

(*a*) energy transfer with transfer of mass across the boundary of a system

(*b*) energy transfer without transfer of mass across the boundary of a system

(*c*) energy transfer because of temperature difference between the surroundings and the system

(*d*) interaction between a system and its surroundings without having sole effect of raising of a weight.

Ans. (*b*)

11. Which one of the following is a unit of work

(*a*) kW (*b*) kWh

(*c*) kW/h (*d*) kJ/s.

Ans. (*b*)

12. Which one of the following statements is related to concept of temperature

(*a*) an intensive property of a system which determines whether the system is in equilibrium or not

(*b*) an extensive property of a system which determines whether the system is in thermal equilibrium or not

(*c*) a transient quantity gained by a system due to vibration of its molecules

(*d*) a transient quantity gained by system due to its elevation.

Ans. (*a*)

13. Which one of the following statement defines the Zeroth law of thermodynamics

(*a*) when two systems are in thermal equilibrium then the third system will also be in thermal equilibrium

(*b*) when two systems are in thermal equilibrium with the third system then all the systems are in thermal equilibrium.

(*c*) when two systems are in thermal equilibrium with the third system separately then the two systems are in thermal equilibrium

(*d*) all of them

Ans. (*c*)

(B) Descriptive Types

14. Discuss macroscopic and microscopic points of view of thermodynamics

15. Explain a thermodynamic system

16. Define :

(*i*) a closed system

(*ii*) an open system

(*iii*) an isolated system and give examples.

17. Discuss homogeneous and heterogeneous systems.

18. Define :

(*i*) non-flow work and flow work

(*ii*) extensive properties and intensive properties

(*iii*) boundary and surroundings of a system

19. Define the terms state, property, process and cycle of a thermodynamic system.

20. Discuss the concept of thermodynamic equilibrium.

21. Explain "internal energy", "heat" and "work".

22. Explain the Zeroth law of thermodynamics.

23. Explain "reversible and irreversible" processes.

24. Explain the concept of temperature.

25. Describe a method of making a temperature scale and establish relationship between °F and °C.

26. Describe a constant volume gas thermometer.

27. Describe a radiation pyrometer and an optical pyrometer.

28. Describe "International temperature scale".

(C) Numericals

29. In a certain mercury in glass thermometer the length of the mercury column is 30 cm when the thermometer is at the ice point. It is 15.0 cm at the steam point. Considering this length as a thermometric property L and t as the temperature on a linear celsius scale, determined by this thermometer, calculate the temperature t^* when $t = 30°$ by using the quadratic equation

$$t^* = aL^2 + b$$

where $t^* = 0°$ at the ice point and $t^* = 100°$ at the steam point. Also draw a graph between t^* and t.

30. In the above exercise if a logarithmic celcius temperature scale is defined by the equation

$$t^* = a \ln L + b$$

then calculate t^* when $t = 30°$ and draw graph between t^* and t.

...(11.6)

31. A thermometer is calibrated by using ice point and steam point temperatures as 0° and 100° respectively, and a scale is obtained by

$$t = 100\left\{In\frac{L}{L_i}\ \text{In}\ \frac{L_s}{L_i}\right\}$$

Show that the thermometric function chosen to establish the scale is

$$t = a\ \text{In}\ L + b$$

32. Suppose a temperataure scale is chosen in exponentional form between 0° and 100° as

$$t = ae^x + b$$

then what shall be temperature on this new scale which will correspond to – 40°C.

33. When a reference junction of a thermocouple is kept at the ice point and the test junction is at a temperature t in celcius scale, the e.m.f. generated in the thermocouple is given by

$$E = at + bt^2$$

where $a = 0.2$ m V/ deg

$b = 5 \times 10^{-4}$ mV/deg^2

(*i*) Calculate the e.m.f. when t = – 100°C, 0°C, 100°C, 200°C, 300°C and 400°C and draw graph between ε and t

(*ii*) When e.m.f. is taken as a thermometric property and temperature scale t^* is defined by the linear equation

$$t^* = a\varepsilon + b$$

where t^* = 0° at the ice point and t^* = 100° at the steam point.

Calculate the values of a and b and draw a graph between ε and t^*.

(*iii*) Calculate the values of t^* for t = – 100°C, 0°C, 100°C, 200°C and 300°C and draw a graph between t^* and t. Also, compare the celsius scale with the t^* scale.