

1 INTRODUCTORY CONCEPTS AND DEFINITIONS

1.0 INTRODUCTION

Thermodynamics is an engineering science topic, which deals with the science of “motion” (*dynamics*) and/or the transformation of “heat” (*thermo*) and energy into various other energy – containing. The flow of energy is of great importance to engineers involved in the design of power generation and process industries. The formal study of thermodynamics began in the eighteenth century through consideration of the motive power of *heat*: the capacity of hot bodies to produce work. Today the scope is larger, generally dealing with *energy* and with relationships among the *properties* of matter.

Thermodynamics is both a branch of physics and an engineering science. Engineers are generally interested in studying *systems* and how they interact with their *surroundings*. To facilitate this, engineers extend the subject of thermodynamics to the study of systems through which matter flows.

Engineers use principles drawn from thermodynamics and other engineering sciences, such fluid mechanics and heat and mass transfer, to analyse and design things intended to meet human needs. The wide realm of the application of these principles is suggested by Table 1.1, which lists a few areas where engineering thermodynamics is important.

The objective of this chapter is to introduce you to some of the fundamental concepts and definitions that are used in our study of engineering thermodynamics.

Table 1.1 Selected areas of application of engineering thermodynamics

Automotive engines
Turbines, Compressors, pumps
Fossil- and nuclear-fuelled power stations
Propulsions systems for aircraft and rockets
Combustions systems
Gas separation and liquefaction
Heating, ventilating and air-conditioning
Vapour compressors and absorption refrigeration
Heat pumps
Alternate energy systems
Fuel cells
Geothermal systems
Ocean thermal, wave, and tidal power
Wind power
Biomedical applications
Life support systems
Artificial organs

LIMITATIONS OF THERMODYNAMICS

It is not possible to determine the rates of transport processes using thermodynamics analysis alone. For example, thermodynamics demonstrates that heat flows from higher to lower temperatures, but does not provide a relation for the heat transfer rate. Rate processes are discussed in texts pertaining to heat, mass and momentum transport.

1.1 THERMODYNAMIC SYSTEMS

System

In thermodynamics the term *system* is used to identify a region containing energy/and/or matter that is separated from its *surroundings* by arbitrarily imposed walls or boundaries. Once the system is defined and the relevant interactions with other systems are identified, one or more physical laws or relations are applied.

The system is whatever we want to study. We may want to study a quantity of matter contained within a closed, rigid-tank, or we may want to consider something such as a gas pipeline through which matter flows. Note that even vacuum which devoid of matter, may be the focus of interest. The composition of matter inside a system may be fixed or may be changing through chemical or nuclear reactions. The shape or volume of the system being analysed is not necessarily constant, as when a piston compresses a gas in a cylinder or a balloon is being inflated.

Surrounding

The portions of matter or space which are external to the system and which either affect or is affected by the system are the surroundings.

Boundary

A boundary is a closed surface, either real or imaginary, surrounding a system through which energy and mass may enter or leave the system and which separates the system from its surroundings. The boundary may be rigid in which case it cannot be deformed and has a fixed shape. *Permeable* and process boundaries allow mass transfer to occur. Mass transfer cannot occur across *impermeable* boundaries. A *diathermal* boundary allows heat transfer to occur across it as in the case of thin metal walls. Heat transfer cannot occur across the *adiabatic* boundary. In this case, the boundary is impermeable to heat flux, e.g. as in the case of a Thermos Flask.

A *moveable/deformable* boundary is capable of performing “boundary work”. No boundary work transfer can occur across a rigid *boundary*. However, energy transfer can occur via shaft work, e.g., through the stirring of fluid in a blender.

Surroundings

Everything external to the system is considered to be part of the system’s *surroundings*. The system is distinguished from its surroundings by a specified boundary, which may be at rest or in motion. The interactions between the system and its surroundings take place across the boundary.

A simple system is one which is macroscopically homogeneous and isotropic and involves a single work mode. The term macroscopically homogeneous implies that properties such as the density are uniform over a large dimensionally region several times larger than the mean free path during a relatively large time period.

An isotropic system is one in which the properties do not vary with direction, e.g., a cylindrical metal block is homogeneous in terms of density and isotropic, since its thermal conductivity is identical in the radial and axial directions.

A simple *compressible* system utilises the modes of compression and/or expansion, and is devoid of body forces due to gravity, electrical and magnetic fields, inertia, and capillary effects. Therefore, it involves only volumetric changes in the work term.

Example 1: Suppose we are interested in the behaviour of air when it is heated or compressed: Figure 1.1 shows the sketch of the experimental set-up, which could be used to carry out the study. The system is the 1.0 kg of air, the surroundings comprise the cylinder walls and the areas adjacent to it from where heat may be supplied, and the inner surface of the piston. Note that one side of the boundary, namely the surface of the piston, is deformable while the others are rigid. Also the boundary is *diathermal* as it allows heat to be transferred to the system. The boundaries are usually indicated with dotted lines as shown.

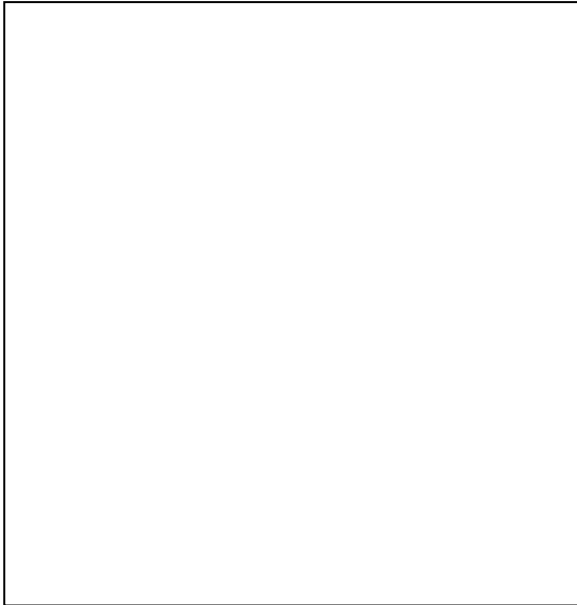


Figure 1.1 Thermodynamic system

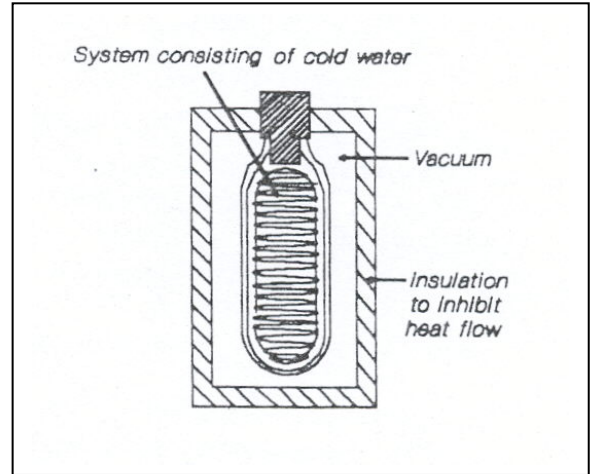


Figure 1.2 Thermos flask

1.1.1 Types of systems

Depending on the nature boundary, two kinds of systems are distinguished. These are referred to, respectively, as *closed systems* (fixed mass system or control mass system) and the *open systems* (control volume system).

Closed system

A closed system is defined when a particular quantity of matter is under study. A closed system always contains the same matter. There can be no transfer of mass across the boundary. A closed system may exchange only heat and work with the surroundings. Figure 1.1 shows an example of a closed system. A special type of a closed system that does not interact in any way with its surroundings is called an *isolated system* since the boundaries of such a closed system does not allow either heat, work or matter to flow. An example of an isolated system is shown in Figure 1.2.

Open system

An open system is a region in space defined by a boundary across which heat, work and matter may flow. Note that when the region within a prescribed boundary is studied the region is called a control volume (open system). A schematic diagram of an engine (open system) is shown in Figure 1.3. The dashed line defines a control volume that surrounds the engine. Observe that air, fuel, and exhaust gases cross the boundary. In addition, we have heat flow to the cooling water and work output from the crankshaft to the drive wheel.

Figure 1.4 a, b show examples of open systems. In figure 1.4a, the system is water which flows through a region containing a water wheel. As the water turns the wheel, work flows

across the boundaries of the open system in the form of the shaft rotating. The water is the source of the shaft work. The boundaries of the system are fixed.

Fig. 1.4b consists of food being cooked on a simple stove: work is transferred to the system (the food in this case) from the stirrer whilst heat is supplied by means of wood fuel. Matter in the form of water or dough could be added and steam (matter accompanied by heat loss) leaves the system.

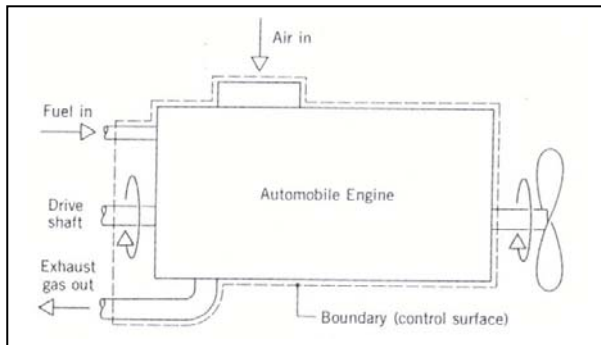


Figure 1.3 An open system (an automobile engine)

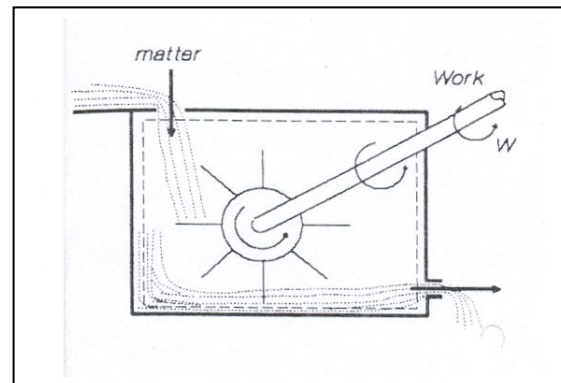
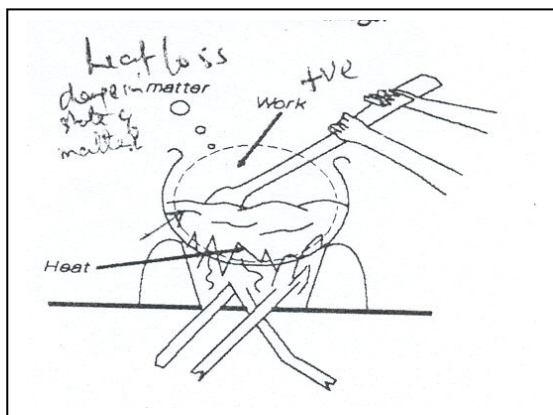


Figure 1.4. An open system (Food being cooked)

Concluding remarks.

Note that the definition of a system depends entirely on the observer's interest. Consider the case of a hot block of metal being dropped into a bowl of cold water, as shown in Figure 1.5.

If the interest is in the cooling of the block, then we choose it as the system and perhaps insert a thermometer into it to measure its temperature. On the other hand, if we are interested in the heating of the water, then we select it (cold water) as the system and insert the thermometer in the water. If we consider the block, water and container as the system then we shall have a system, which is isolated from the surroundings.

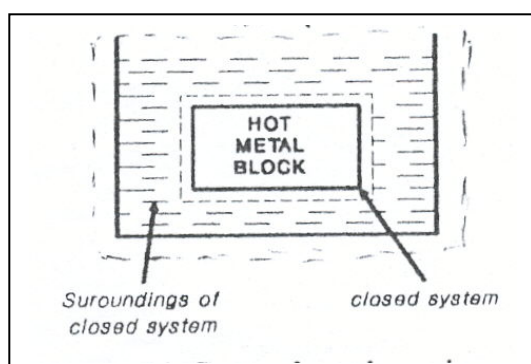


Figure 1.5. System depends on the observer

1.1.2 Macroscopic and microscopic views of thermodynamics

Systems may be studied from the macroscopic or microscopic views. The macroscopic approach to thermodynamics is concerned with the gross or overall behaviour. This attention is sometimes called classical thermodynamics. The microscopic approach, known as statistical thermodynamics, is concerned directly with the structure of matter. The macroscopic viewpoint is what is generally adopted in engineering thermodynamics but for understanding concepts are interpreted from the microscopic viewpoint.

1.2 PROPERTY, STATE, PROCESS, AND CYCLE

Property

To describe a system and predict its behaviour requires the knowledge of its properties and how these properties are related. *Properties* are macroscopic characteristics of a system such as mass, volume, energy, pressure, and temperature to which numerical values can be assigned at a given time without knowledge of the *history* of the system.

If X is a property then its value is independent of path, hence,

$$\int_1^2 dx = X_2 - X_1$$

- The above statement suggests that a property must be: macroscopic, measurable, have a single value that does not depend on how the condition of that property was attained.

Thermodynamics also deals with quantities that are not properties such as work and heat. A way to distinguish properties from non-properties will follow in due course.

State

The word state refers to the condition of a system as described by its properties. Providing values of a subset of the properties can often specify the state. The state can be specified by two thermodynamic properties. You should note that a doctor needs a few macroscopic measurements (temperature and pressure) to determine the patient's medical condition or state.

When a thermodynamic system is in motion the mechanical state, as specified by the velocity and position coordinates relative to a fixed point, must be specified. In the hydro-electric plant, for example, the source of energy is the potential energy of water in the dam or the kinetic energy of a river.

Process

When any of the properties of a system change, the state changes and the system is said to have undergone a *process*. A process is a transformation from one state to another.

If a system exhibits the same values of its properties at two different times, it is in the same state at those times. A system is said to be at *steady state* if none of its properties change with time.

Thermodynamic cycle

A *thermodynamic cycle* is a sequence of processes that begins and ends at the same state. At the conclusion of a cycle all properties have the same values they had at the beginning. Consequently, over the cycle the system experiences no net change of the state. Cycles that are repeated periodically play prominent roles in many areas of application. For example, steam circulating through an electrical power plant executes a cycle.

At a given state each property has a definite value that can be assigned without knowledge of how the system arrived at that state. Therefore, the change in the value of a property as the system is altered from one state to another is determined solely by two end states and is independent of the particular way the change of state occurred. The change is independent of the details or history of the process. Conversely, we can say that if the value of a quantity is independent of the process between two states then that quantity is the change in a property.

- A necessary and sufficient test for whether a quantity is a property or not

A quantity is a property if, and only if, its change in value between states is independent of that process. That is, if the value of a particular quantity depends on the details of the process, and not solely on the end states, that quantity cannot be a property.

1.2.1 Extensive and Intensive Properties

A property is called *extensive* if its value for an overall system is the sum of its values for the parts into which the system is divided. Mass, volume, energy are all examples of extensive properties. Extensive properties depend on the size or extent of a system. The extensive properties of a system can change with time as the system interacts with its surroundings.

Intensive properties are not additive. Their values are independent of the size or extent of change of a system and may vary from place to place within the system at any moment. Thus, intensive properties may be functions of both position and time, whereas extensive properties vary most with time. Specific volume, pressure and temperature are all intensive properties.

1.2.2 Phase and Pure Substance

The term *phase* refers to a quantity of matter that is homogeneous throughout in both chemical composition and physical structure. Homogeneity in physical structure means that the matter is all *solid*, or all *liquid*, or all *vapour* (or equivalently all gas).

A system can contain one or more phases. For example, a system of liquid water and water vapour contains *two* phases. When more than one phase is present, the phases are separated by *phase boundaries*. Gases like say oxygen and nitrogen can be mixed in any proportion to form a single phase. Oil and water, which are not miscible, form *two* liquid phases.

1.2.3 Equilibrium

If we isolate a system from its surroundings and watch for changes in its observable properties and there are no changes it may be concluded that the system is in equilibrium at the moment it was isolated. The system can be said to be at an *equilibrium state*.

When a system is isolated, it cannot interact with its surroundings; however, its state can change as a consequence of spontaneous events occurring internally as its intensive properties such as temperature and pressure, tend toward uniform values. When all such changes cease, the system is in equilibrium.

Hence, for a system to be in equilibrium it must be a single phase or consist of a number of phases that have no tendency to change their conditions when the overall system is isolated from its surroundings. At equilibrium, temperature is uniform throughout the system. Pressure can be regarded to uniform if gravity is neglected, otherwise pressure variation can exist, as in vertical column of liquid.

1.3 UNITS FOR MASS, LENGTH, TIME, AND FORCE

SI units: SI is the abbreviation for Systeme International d'Unites (International System of Units).

Table 1.2 SI Units for Mass, Length, Time, and Force

Quantity	Unit	Symbol
mass	kilogram	kg
length	metre	m
time	second	s
force	Newton	N

Table 1.3 SI Unit prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{12}	tera	T	10^{-2}	centi	c
10^9	giga	G	10^{-3}	milli	m
10^6	mega	M	10^{-6}	micro	μ
10^3	kilo	k	10^{-9}	nano	n
10^2	hecto	h	10^{-12}	pico	p

1.4 SPECIFIC VOLUME AND PRESSURE

The density, or local mass per unit volume, is an intensive property that may vary from point to point within a system. Thus, the mass associated with a particular volume V is determined in principle by integration $m = \int_V \rho dV$ and *not* simply as the product of density and volume.

The specific volume v is defined as the reciprocal of density, $v = 1/\rho$. It is the mass per unit mass. Like density, specific volume is an intensive property and may vary from point to point. SI units for density and specific volume are kg/m^3 and m^3/kg , respectively. However, they can be written in other units as well.

The thermodynamic pressure, P , of a system is defined as the total normal force, per unit area, exerted by the system within and at the boundary. In solids, the pressure is referred to as the normal stress.

The SI unit of pressure and stress is the pascal (Pa).

$$1 \text{ pasacl} = 1 \text{ N/m}^2$$

It is however convenient to work with multiples of the pascal: the kilopascal, the bar, and the megapascal.

$$\begin{aligned} 1 \text{ kPa} &= 10^3 \text{ N/m}^2 \\ 1 \text{ bar} &= 10^5 \text{ N/m}^2 \\ 1 \text{ MPa} &= 10^6 \text{ N/m}^2 \end{aligned}$$

Another unit of pressure that continues to be used is the atmosphere (atm.).

$1 \text{ atm} = 101\,325 \text{ Pa} = 1.013\,25 \text{ bar} = 760 \text{ mm Hg}$

The 760 mm Hg refers to the height of mercury column that the atmosphere can support; the force per unit area exerted by the mercury column is the atmospheric pressure.

The pressure of a system is usually measured relative to the atmosphere, and it is called “gauge pressure”. The pressure used in thermodynamics is the absolute pressure and is defined by:

$$\text{Absolute pressure} = \text{gauge pressure} + \text{atmospheric pressure}$$

Gauge pressure below atmospheric pressure is gauge negative and is referred to as vacuum pressure.

$$p(\text{vacuum}) = p_{\text{atm}}(\text{absolute}) - p(\text{absolute})$$

The relationships among the various ways of expressing pressure measurements is shown in Fig. 1.6.

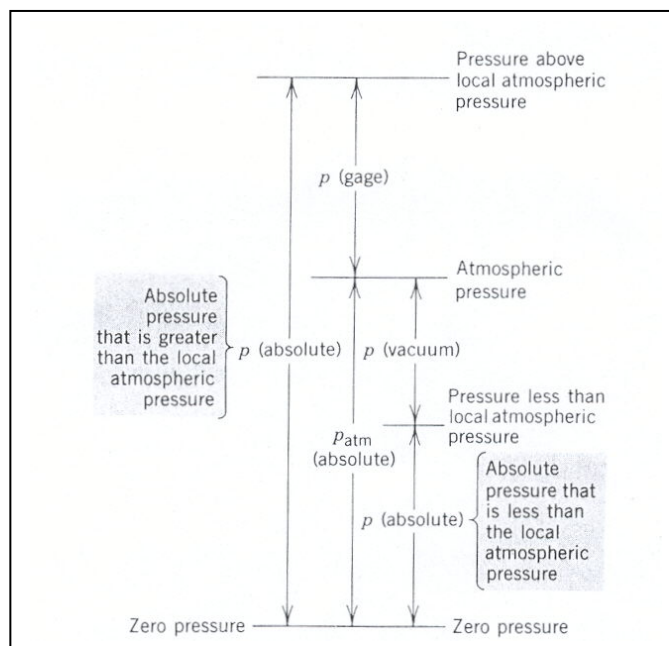
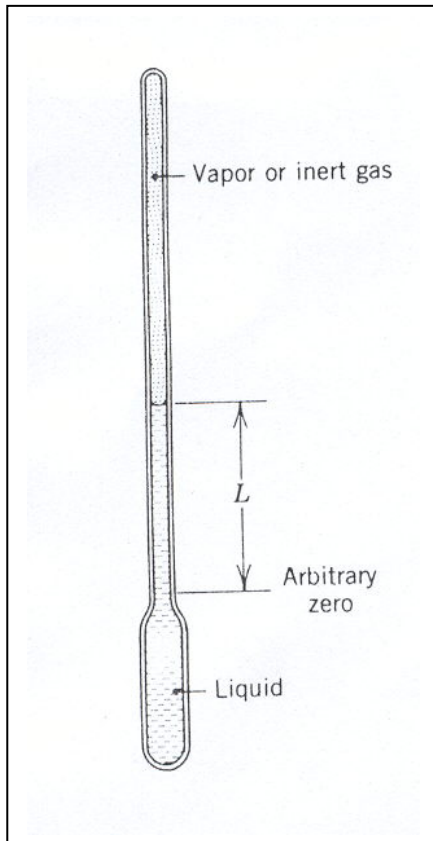


Fig. 1.6 Relationships between the absolute, atmospheric, gauge, and vacuum pressures.

Pressure Measurement

Two commonly used devices for measuring pressure are the manometer and the Bourdon tube. Manometers measure pressure differences in terms of the length of a column of liquid such as water, mercury, or oil. The manometer shown in Fig. 1.7 has one end open to the atmosphere and the other attached to a closed vessel containing a gas at uniform pressure. The difference between the gas pressure and that of the atmosphere is



$$p = p_{atm} - \rho g L$$

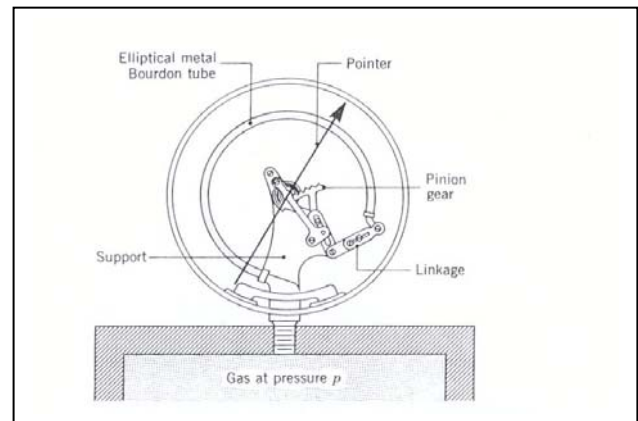


Figure 1.8 Bourdon tube

Fig. 1.7 Pressure measurement by a monometer

A Bourdon tube gauge is shown in Fig. 1.8. The figure shows a curved tube having an elliptical cross section with one end attached to the pressure to be measured and the other end connected to a pointer by a mechanism. When the fluid under pressure fills the tube, the elliptical section tends to become circular, and the tube straightens. This motion is transmitted by the mechanism to the pointer. By calibrating the deflection of the pointer for known pressures, a graduated scale can be determined from which any applied pressure can be read in suitable units. Because of its construction, the Bourdon tube measures the pressure relative to the pressure of the surroundings existing at the instrument. Accordingly, the dial reads zero when the inside and outside of the tube are at the same pressure.

1.5 TEMPERATURE

If two bodies are kept together for a sufficiently long period, experience shows that the bodies appear to attain the same degree of hotness and the changes in their resistance also cease. This state is defined as the state of thermal equilibrium, and the two bodies are then said to have the same temperature. Temperature is, therefore, *a property of a system which determines whether or not they are in thermal equilibrium with other systems or their surroundings.*

1.5.1 Zeroth Law of Thermodynamics

It states that two systems in thermal equilibrium with a third system individually are in equilibrium with each other. The law is tacitly assumed in every measurement of temperature. Thus, if we want to know if two bodies are at the same temperature, it is not necessary to bring them together and see whether their observable properties change with time. It is necessary

only to see if they are individually in thermal equilibrium with the third body. The third body is usually a *thermometer*.

1.5.2 Thermometers

Any body with at least one measurable property that changes as its temperature changes can be used as a thermometer. Such a property is called a *thermometric* property. The particular substance that exhibits changes in the thermometric property is known as a *thermometric* substance.

A familiar device for temperature measurement is the liquid-in-glass thermometer pictured in Fig. 1.9, which consists of a glass capillary tube connected to a bulb filled with a liquid such as mercury or alcohol and sealed at the other hand. The space above the liquid is occupied by vapour of the liquid or an inert gas. As temperature increases, the liquid expands in volume and rise in the capillary. The length L of the liquid in the capillary depends on the temperature. Accordingly, the liquid is the thermometric substance and L is the thermometric property.

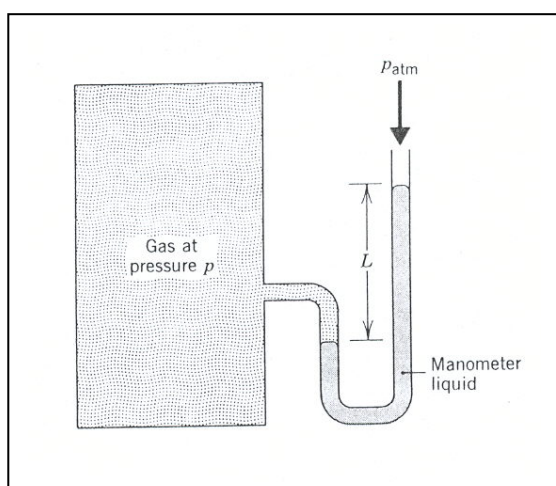


Fig. 1.9 Liquid-in-glass thermometer

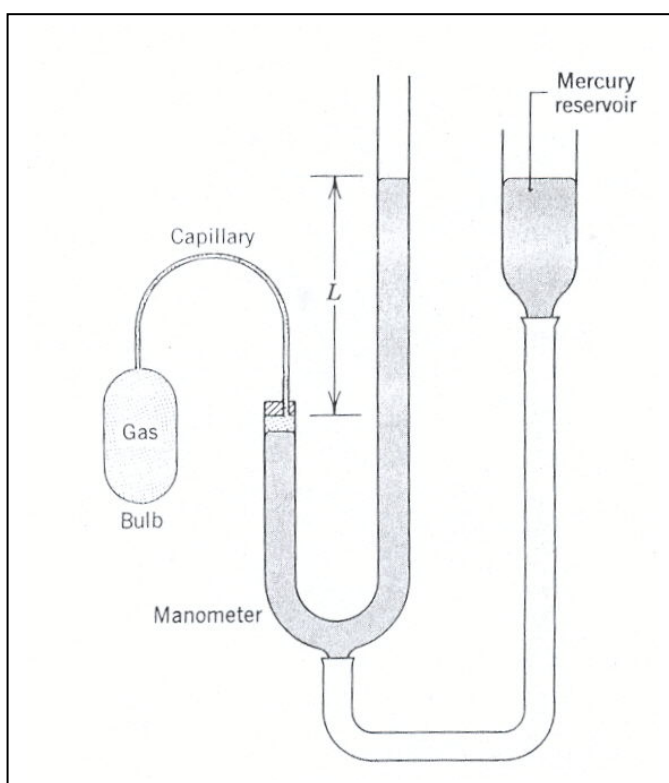


Figure 1.10 Constant-volume gas thermometer

The gas thermometer shown in Fig. 1.10 is so exceptional in terms of precision and accuracy that it has been adopted internationally as the standard instrument for calibrating other thermometers. The thermometric substance is the gas, and the thermometric property is the pressure exerted by the gas. As shown in the figure, the gas is contained in a bulb, and the pressure exerted by it is measured by open-tube mercury thermometer. As the temperature increases, the gas expands, forcing the mercury up in the open tube. The gas is kept at constant volume by raising or lowering the reservoir. Gas thermometers require elaborate apparatus and

are large, and hence they are responding devices that demand painstaking experimental procedures.

Thermocouples

Sensors known as thermocouples are based on the principle that when two dissimilar metals are joined, a thermal electromotive force, t_{emf} , that is primarily a function of temperature will exist in a circuit. If two different metals, or semiconductors, are connected with their junctions held at different temperatures, as shown in Fig. 1.11, the thermal electromotive force develops. The relationship between the thermal electromotive force and temperature may be represented by the cubic equation:

$$t_{emf} = a + bt + ct^2 + dt^3$$

where a, b, c, and d are constants which depend on the materials. An example of a suitable pair is copper-constantan. Thermocouples are suitable for measuring temperatures which are changing rapidly with time.

In the above example the thermometer is the thermocouple and the thermometric property is the thermal electromotive force.

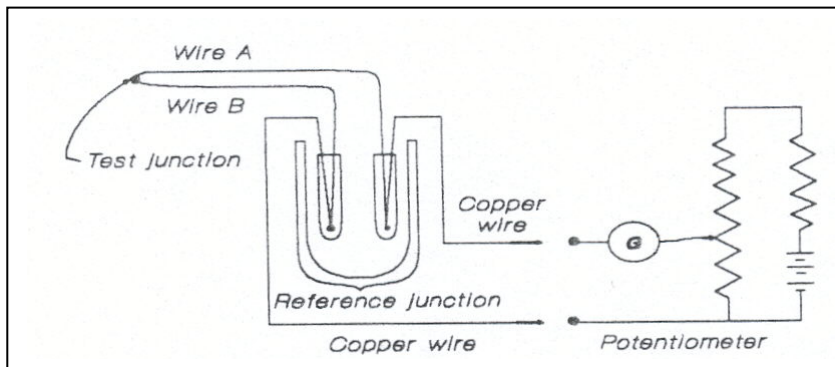


Fig. 1.11 Thermocouple of wires A and B

Absolute Temperature Scale and calibration of Thermometers

An absolute temperature scale may be established as follows:

Let X represent the value of a thermometric property. Then for a given thermal equilibrium state between the system and the thermometer we choose a linear temperature relation such that $T(X) = aX$, where a is a constant.

We therefore choose two arbitrary temperatures by the relation:

$$\frac{T(X_1)}{T(X_2)} = \frac{X_1}{X_2}$$

To ensure that temperatures measured by different thermometers are comparable, an internationally accepted reference system is used to calibrate all thermometers. The temperature at which ice, liquid water and water vapour coexist in equilibrium, called the triple point of water, is chosen as the fixed-point for all thermometers and the temperature is arbitrarily chosen as 273.16 K. Since all thermometers will indicate different values of temperatures for systems, which are not at the triple point because of the different characteristics of the thermometric properties, the temperature at other point is calculated as follows:

$$T(X) = 273.16 \frac{X}{X_0}$$

where X_0 is the value of the thermometric property at the fixed point and X that at the temperature T .

1.5.4 Celsius, Rankine, and Fahrenheit Scales

The Celsius temperature scale uses the unit degree Celsius ($^{\circ}\text{C}$), which has the same magnitude as the Kelvin. Thus, temperature differences are identical on both scales. However, the zero point on the Celsius scale is shifted to 273.15 K, as shown by the following relationship between the Celsius temperature and the Kelvin temperature

$$T(^{\circ}\text{C}) = T(\text{K}) - 273.15 \quad (1)$$

Thus, from equation (1) we see that on the Celsius scale the triple point of water is 0.01°C and 0 K corresponds to -273.15°C .

The temperature of at the steam point, 373.15 K is 100.00°C . Accordingly, there are 100 Celsius degrees in this interval of 100 kelvins.

The Rankine scale, the unit of which is the degree rankine ($^{\circ}\text{R}$), is proportional to the Kelvin temperature according to

$$T(^{\circ}\text{R}) = 1.8 T(\text{K}) \quad (2)$$

The Rankine scale is also an absolute temperature scale.

The Fahrenheit scale is related to the Rankine scale by the relation

$$T(^{\circ}\text{F}) = T(^{\circ}\text{R}) - 459.67 \quad (3)$$

Substituting Eqs. 1 and 2 into Eq. 3, it follows that

$$T(^{\circ}\text{F}) = 1.8T(^{\circ}\text{C}) + 32 \quad (4)$$

Equation (4) shows that the Fahrenheit temperature of the ice point ($^{\circ}\text{C}$) is 32°F and the steam point (100°C) is 212°F .

TUTORIAL PROBLEMS

1. Determine the weight, in newtons, of an object whose mass is 10 kg at a location where the acceleration due to gravity is 9.81 m/s^2 .
2. An object occupies a volume of 25 ft^3 and weighs 20 lbf at a location where the acceleration of gravity is 31.0 ft/s^2 . Determine its weight, in lbf, and its average density, in lbf/ft^3 , on the moon, where $g = 5.57 \text{ ft/s}^2$.
3. A spring stretches 0.2 cm per Newton of applied force. An object is suspended from the spring and a deflection of 3 cm is observed. If $g = 9.81 \text{ m/s}^2$, what is the mass of the object, in kg?
4. The following table lists temperatures and specific volumes of water at two pressures.

P = 0.1 MPa		P = 0.12 MPa	
T/($^{\circ}\text{C}$)	V/ m^3kg	T/($^{\circ}\text{C}$)	V/ m^3kg
200	2.172	200	1.808
240	2.359	240	1.965
280	2.546	280	2.120

Data encountered in solving problems often do not exactly on the grid values provided by property tables and linear interpolation between adjacent tables entries becomes necessary. Using the data provided, estimate

- (a) the specific volume at $T = 200^{\circ}\text{C}$, $p = 0.113 \text{ MPa}$.
- (b) the temperature at $p = 0.12 \text{ MPa}$, $v = 1.85 \text{ m}^3/\text{kg}$ in $^{\circ}\text{C}$
- (c) the temperature at $p = 0.11 \text{ MPa}$, $v = 2.20 \text{ m}^3/\text{kg}$, in K
5. Write out the meanings of the following terms: system, control volume, property, intensive property, equilibrium state, process, thermodynamic cycle, phase, adiabatic process, closed system, isolated system, steady state, extensive property, pure substance, Zeroth law of thermodynamics.
6. Determine the gauge pressure, in bars, equivalent to a manometer reading 1 cm of
 - (a) water (density = 1000 kg/m^3).
 - (b) Mercury (the density of mercury is 13.59 times that of water).
7. Determine the absolute pressure exerted on an object submerged 1000 m below the surface of the sea, in bars. The density of seawater is 1020 kg/m^3 and the acceleration of gravity is 9.7 m/s^2 . The local atmospheric pressure is 0.98 bar.
8. Convert the following temperatures from $^{\circ}\text{F}$ to $^{\circ}\text{C}$:
 - (a) 70°F
 - (b) 0°F
 - (c) -30°F
 - (d) 500°F
 - (e) 212°F

A. ANSWER TRUE OR FALSE in Questions 9 – 14.

9. When a System undergoes a thermodynamics cycle, the change in internal energy is positive

10. A perpetual motion machine of the first kind is possible to invent
 11. For a closed system undergoing a constant pressure process the heat transfer is given by the change in the enthalpy of the system.
 12. For a closed system undergoing an adiabatic process, there is decrease in the internal energy of the system.
 13. Enthalpy is particularly important for open systems.
 14. Heat, work and internal energy have the same units and therefore they are all properties of thermodynamics systems.
- B. Each line in the table 1 below gives information about the same process for a closed system. Every entry has the same energy units. Fill in the blank spaces in the table for the different paths of that process for Q7 to Q12.

PATH	Q	W	U_1	U_2	ΔU
A	+50	-20	30		
B		-30			
C		-40			
D		-50			
E		-60			

- C. Select from Table 2 the letter corresponding to the expression that best completes each of the following statements.
15. The internal energy of an remains unchanged
 16. According to the First Law of Thermodynamics, the total amount of energy is ----- in all transformations and transfers.
 13. The objective of a ----- is to provide energy for industrial processes or dwelling units at elevated temperatures.
 14. The thermal efficiency of a power cycle can never be ----- than unity (100%)
 15. The value of ----- depends on the details of the process and not just the end states.
 16. The performance of a ----- can be described as the ratio of the amount of energy received by a system undergoing a cycle from a cold space to the net work transfer of energy into the system to accomplish this effect.
 17. For a simple compressible substance undergoing an ----- process the energy transfer by heat is equal to the change in enthalpy.
 18. ----- is the capacity to do work.

TABLE 2

A.	Energy	F.	Heat pump	K.	Closed system
B.	Work	G.	Refrigeration cycle	L.	Isolated system
C.	Less	H.	Power cycle	M.	Conserved
D.	Greater	I.	Internal energy	N.	Isothermal
E.	Adiabatic process	J.	Reversible process	O.	Property