

## INTRODUCTION

The word thermodynamics stems <sup>ينشأ</sup> from the Greek words *therme* (heat) and *dynamis* (force). Although various aspects of what is now known as thermodynamics have been of interest since antiquity, the formal study of thermodynamics began in the early nineteenth century through consideration of the motive power of *heat*: the capacity of hot bodies to produce *work*. Today the scope is larger, dealing generally with *energy* and with relationships among the *properties* of matter.

Thermodynamics is both a branch of physics and an engineering science. The scientist is normally interested in gaining a fundamental understanding of the physical and chemical behavior of fixed quantities of matter at rest and uses the principles of thermodynamics to relate the properties of matter. 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.

**Thermodynamics is the science that deals with the relationship of heat and mechanical energy and conversion of one into the other.**

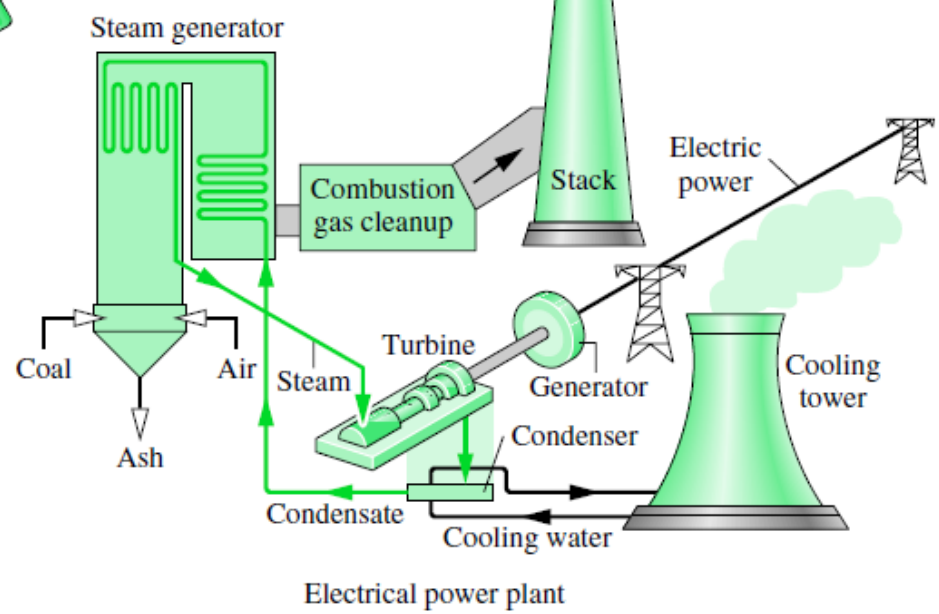
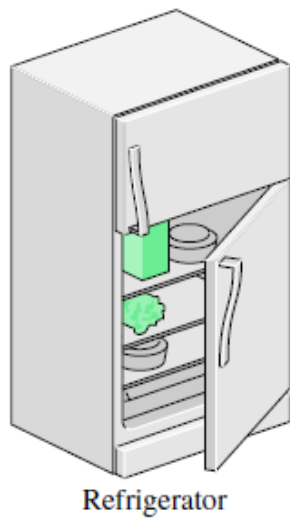
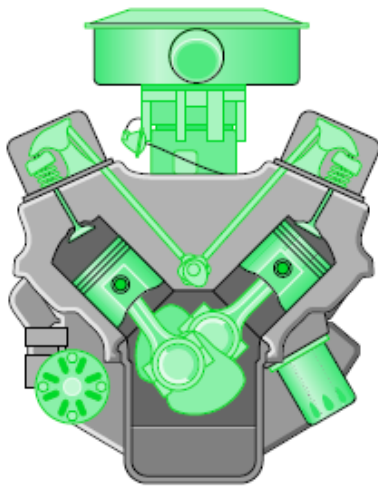
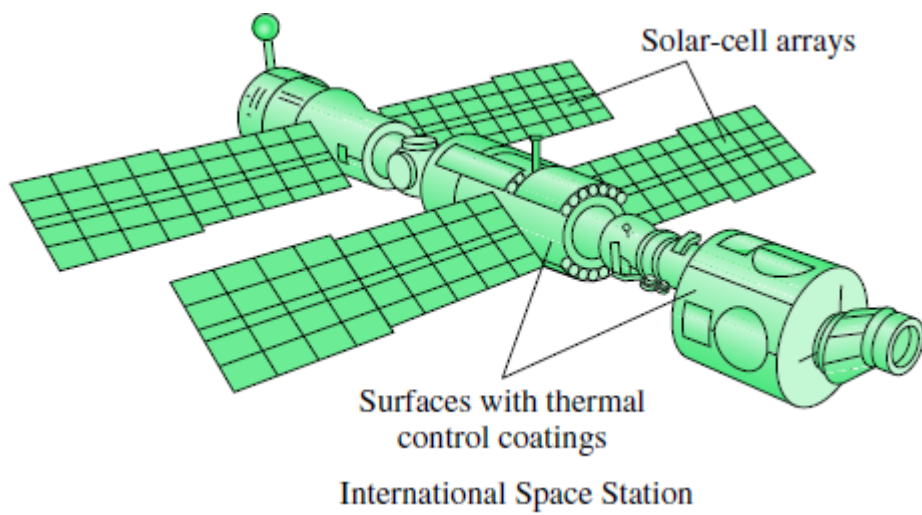
### Using Thermodynamics

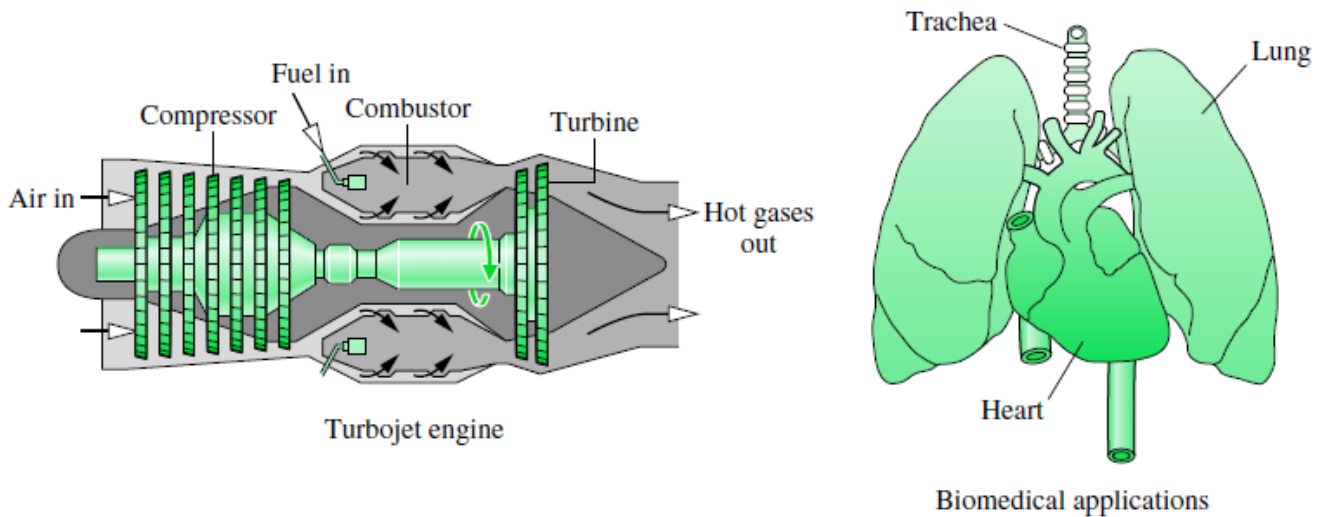
Engineers use principles drawn from thermodynamics and other engineering sciences, such as fluid mechanics and heat and mass transfer, to analyze and design things intended to meet human needs. The wide realm of application of these principles is suggested by Table 1.1, which lists a few of the areas where engineering thermodynamics is important. Engineers seek to achieve improved designs and better performance, as measured by factors such as an increase in the output of some desired product, a reduced input of a scarce <sup>النادرة</sup> resource, a reduction in total costs, or a lesser environmental impact. The principles of engineering thermodynamics play an important part in achieving these goals.

**TABLE 1.1** Selected Areas of Application of Engineering Thermodynamics

Automobile engines
Turbines
Compressors, pumps
Fossil- and nuclear-fueled power stations
Propulsion systems for aircraft and rockets
Combustion systems
Cryogenic systems, gas separation, and liquefaction
Heating, ventilating, and air-conditioning systems
• Vapor compression and absorption refrigeration
• Heat pumps
Cooling of electronic equipment
Alternative energy systems
• Fuel cells
• Thermoelectric and thermionic devices
• Magnetohydrodynamic (MHD) converters
• Solar-activated heating, cooling, and power generation
• Geothermal systems
• Ocean thermal, wave, and tidal power generation
• Wind power
Biomedical applications
• Life-support systems

- Artificial organs

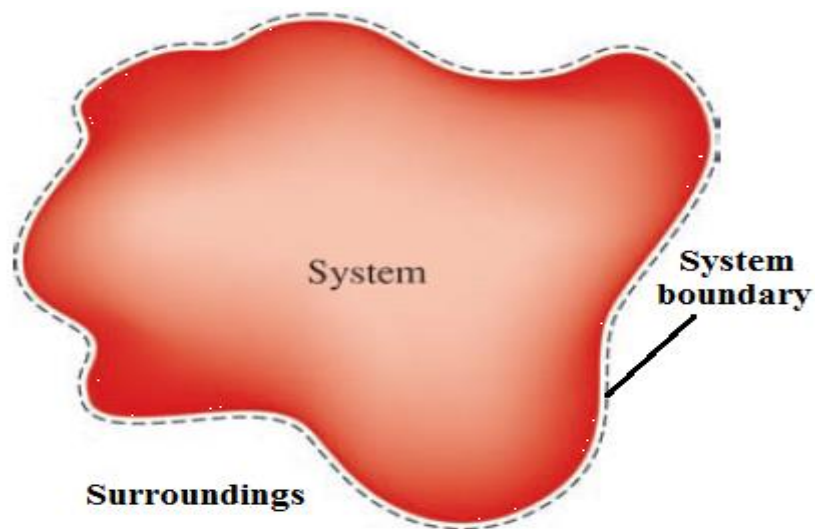




**FIGURE 1.1** Some Application of Engineering Thermodynamics

### The system

In a generic sense, a **system** is anything that we wish to analyze and distinguish from its **surroundings** or **environment**. To denote a system, all one needs to do is create a **boundary** between the system of interest and everything else, that is, the surroundings. The boundary may be a real surface or an imaginary construct indicated by a dashed line on a sketch. Figure 1.2 illustrates the separation of a system from its surroundings by a boundary.



**FIGURE 1.2** The system boundary separates a fixed mass, the system, from its surroundings.

A **system** is a specifically identified fixed mass of material separated from its surroundings by a real or imaginary boundary.

### TYPES OF SYSTEMS

Two basic kinds of systems are distinguished in this chapter see Fig.1.3 . These are referred to, respectively, as *closed systems* and *control volumes*. A **closed system** refers to a **fixed quantity of matter**, whereas a **control volume** is a **region of space through which mass may flow**.

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 its boundary. A special

type of closed system that does not interact in any way with its surroundings is called an *isolated system*.

A *control volume (open system)* is a region in space separated from its surroundings by a real or imaginary boundary, the *control surface*, across which mass may pass.

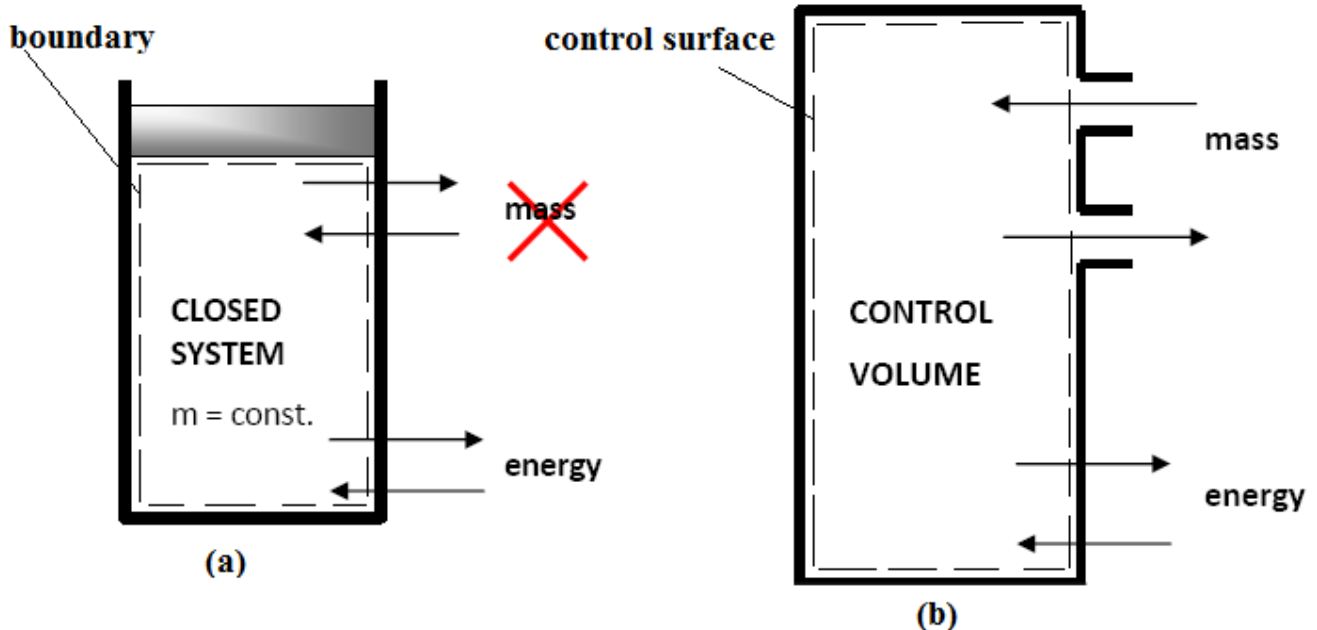


Figure 1.4 (a) Closed system, mass cannot cross the boundaries, but energy can, and the boundary may be fixed or moving, and real or imaginary (b) Control volume, both mass and energy can cross the boundaries.

### Describing Systems and Their Behavior

Engineers are interested in studying systems and how they interact with their surroundings. In this section, we introduce several terms and concepts used to describe systems and how they behave.

### MACROSCOPIC AND MICROSCOPIC VIEWS OF THERMODYNAMICS

Systems can be studied from a macroscopic or a microscopic point of view. **The macroscopic approach to thermodynamics is concerned with the gross or overall behavior. This is sometimes called *classical thermodynamics*.** No model of the structure of matter at the molecular, atomic, and subatomic levels is directly used in classical thermodynamics. Although the behavior of systems is affected by molecular structure, **classical thermodynamics allows important aspects of system behavior to be evaluated from observations of the overall system.**

**The microscopic approach to thermodynamics, known as *statistical thermodynamics*, is concerned directly with the structure of matter.** The objective of statistical thermodynamics is to characterize by statistical means the average behavior of the particles making up a system of interest and relate this information to the observed macroscopic behavior of the system.

For **applications involving lasers, plasmas, high-speed gas flows, chemical kinetics, very low temperatures (cryogenics), and others, the methods of statistical thermodynamics are essential.** Moreover, the microscopic approach is instrumental in developing certain data, for example, ideal gas specific heats.

For the great majority of engineering applications, classical thermodynamics not only provides a considerably more direct approach for analysis and design but also requires far fewer mathematical complications. For these reasons the macroscopic viewpoint is the one adopted in our study. When it

serves to promote understanding, however, concepts are interpreted from the microscopic point of view. Finally, relativity effects are not significant for the systems under consideration in our study.

## PROPERTY, STATE, AND PROCESS

To describe a system and predict its behavior requires knowledge of its properties and how those properties are related. A **property** is a macroscopic characteristic of a system such as mass, volume, energy, pressure, and temperature to which a numerical value can be assigned at a given time without knowledge of the previous behavior (*history*) of the system. Many other properties are considered during the course of our study of engineering thermodynamics.

Thermodynamics also deals with quantities that are not properties, such as mass flow rates and energy transfers by work and heat. Additional examples of quantities that are not properties are provided in subsequent chapters. A way to distinguish *non* properties from properties is given shortly.

The word **state** refers to the condition of a system as described by its properties. Since there are normally relations among the properties of a system, the state often can be specified by providing the values of a subset of the properties. All other properties can be determined in terms of these few.

A thermodynamic **state** of a system is defined by the values of all of the system thermodynamic properties.

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

(Any change a system undergoes from one state to another is called a *process*, and the series of states through which a system passes during a process is called a *path*. See Fig.1.5 )

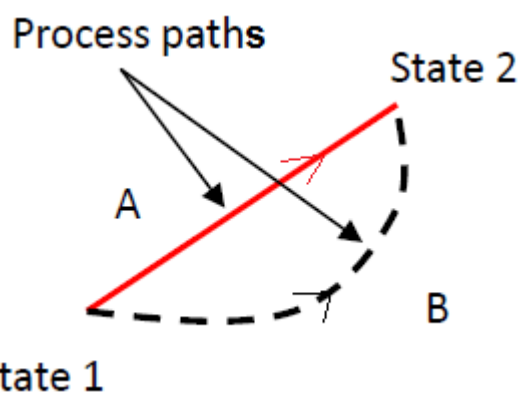


Fig. 1.5: To specify a process, initial and final states and path must be specified.

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 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.

A thermodynamic **cycle** consists of a sequence of processes in which the working fluid returns to its original thermodynamic state.

## EXTENSIVE AND INTENSIVE PROPERTIES

Thermodynamic properties can be placed in two general classes: extensive and intensive. 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, and several other properties introduced later are extensive. Extensive properties depend on the size or extent of a system. The extensive properties of a system can change with time, and many thermodynamic analyses consist mainly of carefully accounting for changes in extensive properties such as mass and energy as a system interacts with its surroundings.

**Intensive** properties are not additive in the sense previously considered. Their values are independent of the size or extent 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 at most with time. Specific volume, pressure, and temperature are important intensive properties; several other intensive properties are introduced in subsequent chapters.

*for example..* . To illustrate the difference between extensive and intensive properties, consider an amount of matter that is uniform in temperature, and imagine that it is composed of several parts, as illustrated in Fig. 1.6. The mass of the whole is the sum of the masses of the parts, and the overall volume is the sum of the volumes of the parts. However, the temperature of the whole is not the sum of the temperatures of the parts; it is the same for each part. Mass and volume are extensive, but temperature is intensive.

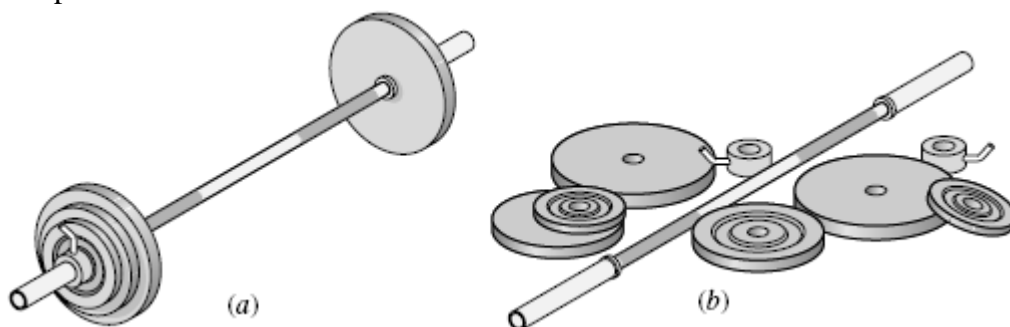


Figure 1.6 Explanation figure of extensive and intensive concept.

### 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 *vapor* (or equivalently all *gas*). A system can contain one or more phases. For example, a system of liquid water and water vapor (steam) contains *two* phases. When more than one phase is present, the phases are separated by *phase boundaries*. Note that gases, say oxygen and nitrogen, can be mixed in any proportion to form a *single* gas phase. Certain liquids, such as alcohol and water, can be mixed to form a *single* liquid phase. But liquids such as oil and water, which are not miscible, form *two* liquid phases.

A **pure substance** is one that is uniform and invariable in chemical composition. A pure substance can exist in more than one phase, but its chemical composition must be the same in each phase. For example, if liquid water and water vapor form a system with two phases, the system can be regarded as a pure substance because each phase has the same composition.

A uniform mixture of gases can be regarded as a pure substance provided it remains a gas and does not react chemically. A system consisting of air can be regarded as a pure substance as long as it is a

mixture of gases; but if a liquid phase should form on cooling, the liquid would have a different composition from the gas phase, and the system would no longer be considered a pure substance.

## EQUILIBRIUM

Classical thermodynamics places primary emphasis on equilibrium states and changes from one equilibrium state to another. Thus, the concept of *equilibrium* is fundamental. In mechanics, equilibrium means a condition of balance maintained by an equality of opposing forces. In thermodynamics, the concept is more far-reaching, including not only a balance of forces but also a balance of other influences. Each kind of influence refers to a particular aspect of thermodynamic, or complete, equilibrium. Accordingly, several types of equilibrium must exist individually to fulfill the condition of complete equilibrium; among these are mechanical, thermal, phase, and chemical equilibrium. Criteria for these four types of equilibrium are considered in subsequent discussions.

For the present, we may think of testing to see if a system is in thermodynamic equilibrium by the following procedure: Isolate the system from its surroundings and watch for changes in its observable properties. If there are no changes, we conclude that the system was 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 does not 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. Also, pressure can be regarded as uniform throughout as long as the effect of gravity is not significant; otherwise a pressure variation can exist, as in a vertical column of liquid.

## ACTUAL AND QUASIEQUILIBRIUM PROCESSES شبه او الى حد ما متزن

There is no requirement that a system undergoing an actual process be in equilibrium *during* the process. Some or all of the intervening الحاصلة states may be nonequilibrium states. For many such processes we are limited to knowing the state before the process occurs and the state after the process is completed. However, even if the intervening states of the system are not known, it is often possible to evaluate certain *overall* effects that occur during the process.

Processes are sometimes modeled as an idealized type of process called a *quasiequilibrium (or quasistatic) process*. A quasiequilibrium process is one in which the departure الانحراف from thermodynamic equilibrium is at most infinitesimal متناهي الصغر. All states through which the system passes in a quasiequilibrium process may be considered equilibrium states. Because nonequilibrium effects are inevitably امر حتمي present during actual processes, systems of engineering interest can at best approach, but never realize, a quasiequilibrium process.

Our interest in the quasiequilibrium process concept stems mainly from two considerations:

\_ Simple thermodynamic models giving at least *qualitative* information about the behavior of actual systems of interest often can be developed using the quasiequilibrium process concept. This is akin مماثل to the use of idealizations such as the point mass or the frictionless pulley in mechanics for the purpose of simplifying an analysis.

\_ The quasiequilibrium process concept is instrumental in deducing استدلالات relationships that exist among the properties of systems at equilibrium.

## Measuring Mass, Length, Time, and Force

When engineering calculations are performed, it is necessary to be concerned with the *units* of the physical quantities involved. A unit is any specified amount of a quantity by comparison with which any other quantity of the same kind is measured. For example, meters, centimeters, kilometers, feet, inches, and miles are all *units of length*. Seconds, minutes, and hours are alternative *time units*.

Because physical quantities are related by definitions and laws, a relatively small number of physical quantities suffice to conceive يعبر عنها of and measure all others. These may be called *primary dimensions*. The others may be measured in terms of the primary dimensions and are called *secondary*. For example, if length and time were regarded as primary, velocity and area would be secondary.

Two commonly used sets of primary dimensions that suffice for applications in *mechanics* are (1) mass, length, and time and (2) force, mass, length, and time. Additional primary dimensions are required when additional physical phenomena come under consideration.

Temperature is included for thermodynamics, and electric current is introduced for applications involving electricity. Once a set of primary dimensions is adopted, a **base unit** for each primary dimension is specified. Units for all other quantities are then derived in terms of the base units. Let us illustrate these ideas by considering briefly the SI system of units.

## SI Units

The system of units called SI, takes mass, length, and time as primary dimensions and regards force as secondary. SI is the abbreviation for Systeme International d' Unites (International System of Units), which is the legally accepted system in most countries. The conventions of the SI are published and controlled by an international treaty organization. The **SI base units** are listed in Table 1.2 and discussed in the following paragraphs. The SI base unit for temperature is the kelvin, K. The SI base unit of mass is the kilogram, kg. It is equal to the mass of a particular cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures near Paris. The mass standard for the United States is maintained by the National Institute of Standards and Technology. The kilogram is the only base unit still defined relative to a fabricated object.

**TABLE 1.2** Units and dimensions for Mass, Length, Time

Quantity	SI		
	Unit	Dimension	Symbol
mass	kilogram	M	kg
length	meter	L	m
time	second	t	s
temperature	Kelvin	T	K
electric current	Ampere	I	A
luminous intensity	candela	J	cd
amount of substance	mole	N	mol

The SI base unit of length is the meter (metre), m, defined as the length of the path traveled by light in a vacuum during a specified time interval. The base unit of time is the second, s. The second is defined as the duration of 9,192,631,770 cycles of the radiation associated with a specified transition of the



cesium atom. The SI unit of force, called the newton, is a secondary unit, defined in terms of the base units for mass, length, and time. Newton's second law of motion states that the net force acting on a body is proportional to the product of the mass and the acceleration, written  $F \propto ma$ . The newton is defined so that the proportionality constant in the expression is equal to unity. That is, Newton's second law is expressed as the equality

$$F = ma$$

The newton, N, is the force required to accelerate a mass of 1 kilogram at the rate of 1 meter per second per second. With Eq. 1.1

$$1N = (1kg) * \left(\frac{1m}{s^2}\right) = 1 kg.m/s^2$$

**for example..** to illustrate the use of the SI units introduced thus far, let us determine the weight in newton of an object whose mass is 1000 kg, at a place on the earth's surface where the acceleration due to gravity equals a *standard* value defined as 9.80665 m/s<sup>2</sup>. Recalling that the weight of an object refers to the force of gravity, and is calculated using the mass of the object,  $m$ , and the local acceleration of gravity,  $g$ , we get

$$F = mg = 1000kg * 9.80665 m/s^2 = 9806.65 kg.m/s^2$$

This force can be expressed in terms of the newton by using a *unit conversion factor*. That is

$$F = (9806.65 kg.m/s^2) * \left| \frac{1N}{1kg.m/s^2} \right| = 9806.65 N$$

Observe that in the calculation of force in newtons, the unit conversion factor is set off by a pair of vertical lines. This device is used throughout the text to identify unit conversions.

Since weight is calculated in terms of the mass and the local acceleration due to gravity, the weight of an object can vary because of the variation of the acceleration of gravity with location, but its mass remains constant. **for example..** if the object considered previously were on the surface of a planet at a point where the acceleration of gravity is, say, one-tenth of the value used in the above calculation, the mass would remain the same but the weight would be one-tenth of the calculated value.

SI units for other physical quantities are also derived in terms of the SI base units. Some of the derived units occur so frequently that they are given special names and symbols, such as the newton. SI and British units for quantities pertinent لها صلة to thermodynamics are given in Table 1.3.

**TABLE 1.3 quantities pertinent to thermodynamics**

Symbol	Quantity		* Units	
			SI	BU
A	Area	مساحة	m <sup>2</sup>	ft <sup>2</sup>
a	Acceleration	تسجيل	m/s <sup>2</sup>	ft/sec. <sup>2</sup>
C	Velocity	سرعة	m/s	ft/sec.
C	Specific heat	حرارة نوعية	J/kg.k	Btu/lbm.

D	Diameter	قطر دائرة	m	ft
E	Energy	طاقة	J=N.m	Ft.lb,Btu
F	Force	قوة	N=kg.m/s <sup>2</sup>	Lb <sub>f</sub> =slug.ft/sec <sup>2</sup>
g	Local acceleration of gravity	تعجيل ارضي	m/s <sup>2</sup>	ft/sec <sup>2</sup>
H	Enthalpy	انثالبي، طاقة السريان	kJ	Btu
h	Specific enthalpy	انثالبي نوعي	kJ/kg	Btu/lbm
J	Mechanical equivalent of heat	المكافئ الميكانيكي للحرارة	kcal=427kg.m	778,2ft.lbf/Btu
M	Molecular weight	الوزن الجزيئي	kg/kg.mol	Lbm/lbm.mole
m	Mass	الكتلة	kg	Slug,lbm
$\dot{m}$	Mass flow rate	المعدل الكتلي للجريان	kg/s	Slug/sec,lbm/sec
N	Mole	جزيء		
n	Polytropic index	الاس البولتروبي		
P	Pressure	الضغط	Pa = N/m <sup>2</sup>	Lb <sub>f</sub> /in <sup>2</sup> =psi
P	Power	القدرة	W = J/s	Ft.lb/s,h,p
Q	Heat	الحرارة	kJ	Btu
$\dot{Q}$	Heat rate	معدل الحرارة	kJ/s = kW	Btu/sec.
q	Heat per unit mass	حرارة لوحدة الكتلة	kJ/kg	Btu/Lbm
R	Gas Constant	ثابت الغاز	kJ/.kg.K	Btu/ Lb. F
$\bar{R}$	Universal Gas Constant	ثابت الغاز العام	8.314kJ/kmol.K	1545 ft.lbf/mole.R
S	Entropy	انتروبي	kJ / K	Btu /F
s	Specific Entropy	انتروبي نوعي	kJ / kg . k	Btu/Lbm.ft
T	Absolute Temperature	درجة حرارة مطلقة	K	F
T	Torque	عزم	N.m	Lbf . Ft
U	Internal Energy	طاقة داخلية	kJ	Btu
u	Specific Internal Energy	طاقة داخلية نوعية	kJ / kg	Btu / Lbm
V	Volume	حجم	m <sup>3</sup> , Liter	Ft <sup>3</sup>
W	Work	شغل	J= N.m	Ft . Lb
$\dot{W}$	Work Rate	معدل الشغل	kJ/s =kW	Lbf . Ft/s
w	Work per Unit mass	شغل لوحدة الكتلة	kJ/kg	Btu / Lbm

X	Displacement.	ازاحة	m	Ft
Z	Height	ارتفاع	m	Ft

Since it is frequently necessary to work with extremely large or small values when using the SI unit system, a set of standard prefixes is provided in Table 1.4 to simplify matters. For example, km denotes kilometer, that is,  $10^3$  m.

Table 1.4 SI Units Prefixes

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

### Measurable Properties: Specific Volume, Pressure and Temperature

Three intensive properties that are particularly important in engineering thermodynamics are specific volume, pressure, and temperature.

#### Specific Volume

The **specific volume**  $v$  is defined as the reciprocal of the density  $v=1/\rho$ . It is the volume per unit mass.

$$v = V/m \quad \rho = m/V$$

Like density, specific volume is an intensive property and may vary from point to point. SI units for density and specific volume are  $\text{kg/m}^3$  and  $\text{m}^3/\text{kg}$ , respectively. However, they are also often expressed, respectively, as  $\text{g/cm}^3$  and  $\text{cm}^3/\text{g}$ . In certain applications it is convenient to express properties such as a specific volume on a molar basis rather than on a mass basis. The amount of a substance can be given on a **molar basis** in terms of the kilomole (kmol) or the pound mole (lbmol), as appropriate. In either case we use

$$n = m/M$$

The number of kilomoles of a substance,  $n$ , is obtained by dividing the mass,  $m$ , in kilograms by the molecular weight,  $M$ , in kg/kmol. To signal that a property is on a molar basis, a bar is used over its symbol. Thus,  $\bar{v}$  signifies the volume per kmol. In this text, the units used for are  $\text{m}^3/\text{kmol}$ . And the relationship between  $\bar{v}$  and  $v$  is

$$\bar{v} = Mv$$

where  $M$  is the molecular weight in kg/kmol or lb/lbmol, as appropriate.

Sometimes the density of a substance is given relative to the density of a well-known substance. Then it is called specific gravity, or relative density, and is defined as the ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at  $4^\circ\text{C}$ , for which  $\rho_{\text{H}_2\text{O}} = 1000 \text{ kg/m}^3$ ). That is,

$$SG = \rho/\rho_{\text{H}_2\text{O}}$$

And SG is a dimensionless quantity.

## Pressure

Pressure  $p$  is the force exerted by a fluid per unit area.

$$p = \text{Force} / \text{Area}$$

For a fluid at rest, the pressure at a given point is the same in all directions. However, the pressure can vary from point to point within a fluid at rest; examples are the variation of atmospheric pressure with elevation and the pressure variation with depth in oceans, lakes, and other bodies of water.

### PRESSURE UNITS

The SI unit of pressure and stress is the pascal.

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

it is convenient to work with multiples of the pascal: the kPa, the bar, and the MPa.

$$1 \text{ MPa} = 10^6 \text{ Pa} = 10^6 \text{ N/m}^2, \quad 1 \text{ bar} = 10^5 \text{ Pa} = 10^5 \text{ N/m}^2,$$

$$\text{And } 1 \text{ kPa} = 10^3 \text{ Pa} = 10^3 \text{ N/m}^2$$

Although atmospheric pressure varies with location on the earth, a standard reference value can be defined and used to express other pressures.

$$1 \text{ standard atmosphere (atm)} = 1.01325 \times 10^5 \text{ N/m}^2$$

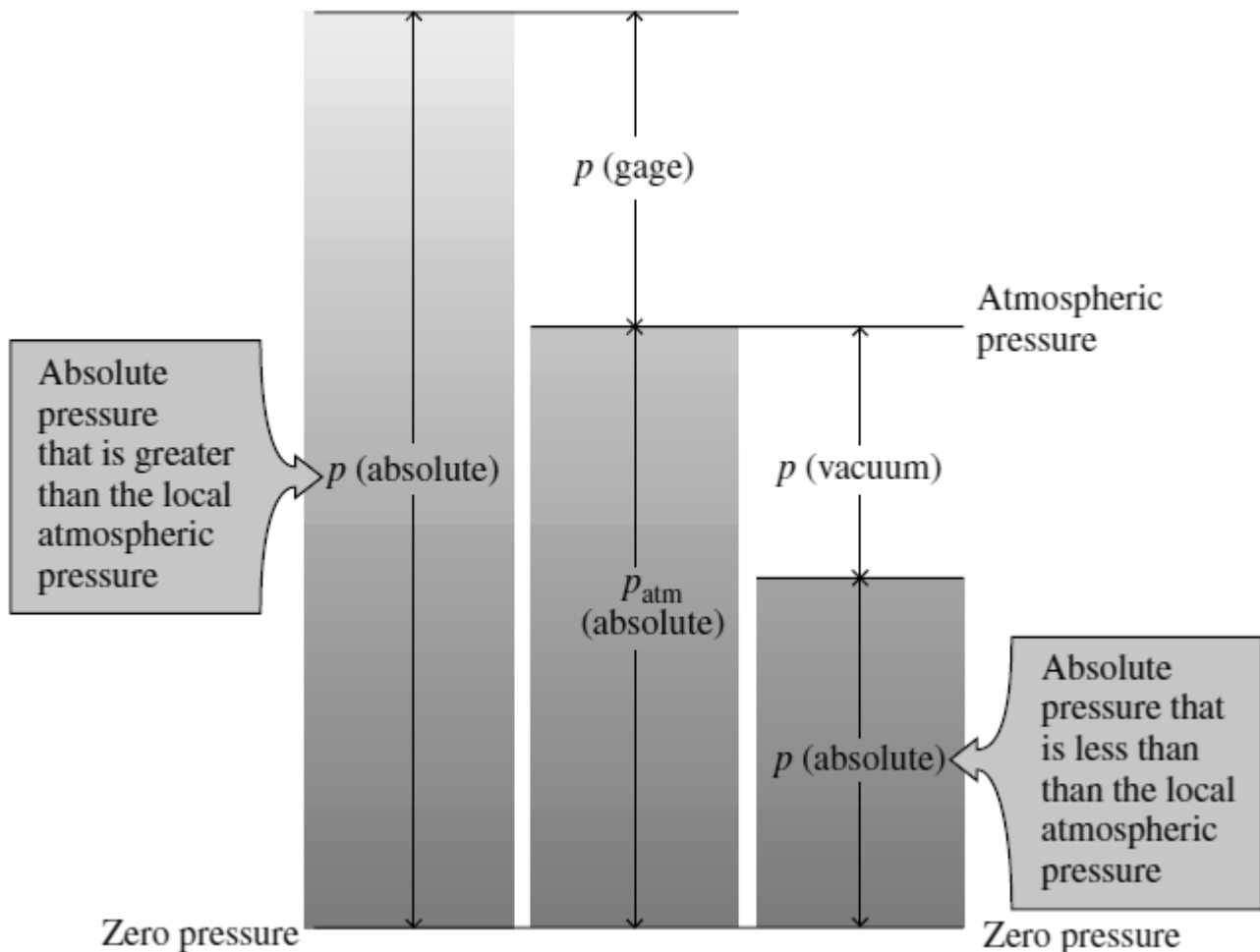
Pressure as discussed above is called ***absolute pressure***. Throughout this course the term pressure refers to absolute pressure unless explicitly stated otherwise. Although absolute pressures must be used in thermodynamic relations, pressure-measuring devices often indicate the *difference* between the absolute pressure in a system and the absolute pressure of the atmosphere existing outside the measuring device. The magnitude of the difference is called a ***gage pressure*** or a ***vacuum pressure***. The term gage pressure is applied when the pressure in the system is greater than the local atmospheric pressure,  $p_{\text{atm}}$ .

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

When the local atmospheric pressure is greater than the pressure in the system, the term vacuum pressure is used.

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

The relationship among the various ways of expressing pressure measurements is shown in Fig. 1.7.



**Figure 1.7** Relationships among the absolute, atmospheric, gage, and vacuum pressures.

## PRESSURE MEASUREMENT

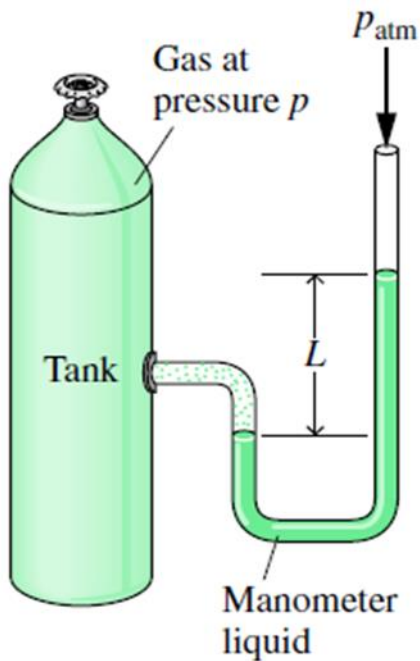
Two commonly used devices for measuring pressure are the manometer and the Bourdon tube. Manometers measure pressure differences in terms of the length of a column of liquid such as water, mercury, or oil. The manometer shown in Fig. 1.8 has one end open to the atmosphere and the other attached to a closed vessel containing a gas at uniform pressure. The difference between the gas pressure and that of the atmosphere is

$$p - p_{\text{atm}} = p(\text{gage}) \longrightarrow p(\text{gage}) = \text{force/area} = \text{weight of liquid column/area}$$

$$p(\text{gage}) = (\text{mass of liquid column} \cdot g) / \text{area} = ((\rho \cdot V) \text{ of liquid column} \cdot g) / \text{area}$$

$$\text{but } V \text{ of liquid column} = L \cdot \text{area}$$

$$\text{then } p(\text{gage}) = \rho g (\text{area}) L / \text{area}$$



**Figure 1.8** Pressure measurement by a manometer.

where  $\rho$  is the density of the manometer liquid,  $g$  the acceleration of gravity, and  $L$  the difference in the liquid levels. For short columns of liquid,  $\rho$  and  $g$  may be taken as constant. Because of this proportionality between pressure difference and manometer fluid length, pressures are often expressed in terms of millimeters of mercury, inches of water, and so on.

A Bourdon tube gage is shown in Fig. 1.9. 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 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.

Pressure can be measured by other means as well. An important class of sensors utilizes the *piezoelectric* effect: A charge is generated within certain solid materials when they are deformed.

This mechanical input /electrical output provides the basis for pressure measurement as well as displacement and force measurements. Another important type of sensor employs a diaphragm that deflects when a force is applied, altering an inductance, resistance, or capacitance. Figure 1.10 shows a piezoelectric pressure sensor together with an automatic data acquisition system.

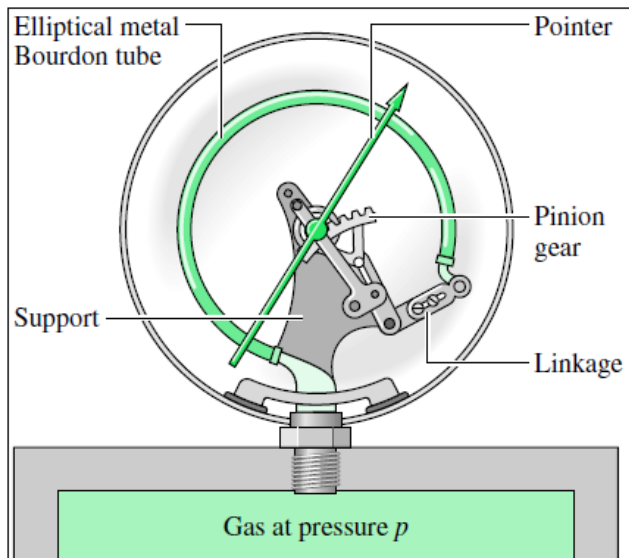


Fig. 1.9 Bourdon gauge

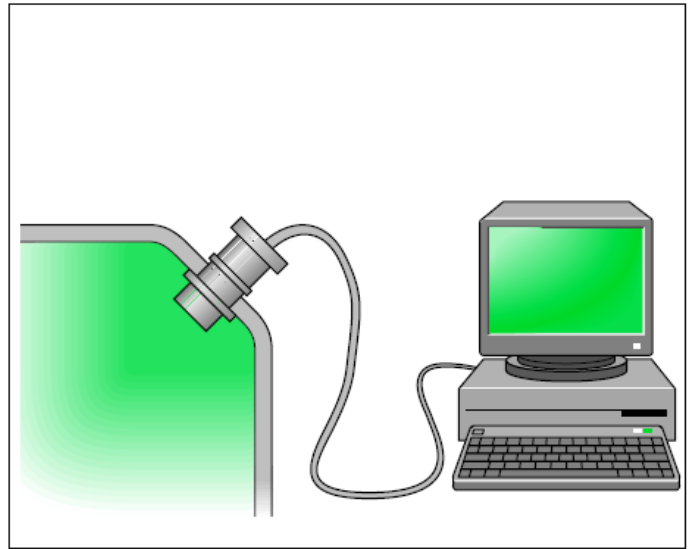


Fig. 1.10 piezoelectric pressure sensor

The traditional device that measures blood pressure using mercury in a manometer called Sphygmomanometer. Pressures are recorded in "millimetres of mercury". see Fig. 1.11a



Fig. 1.11a Sphygmomanometer

### The Inclined Manometer

This type of manometer uses for very small pressure differences (less than 50mm H<sub>2</sub>O) where the inclined scale by angle ( $\alpha$ ) with the horizon increases the illustration of pressure reading. See figure 1.11b.

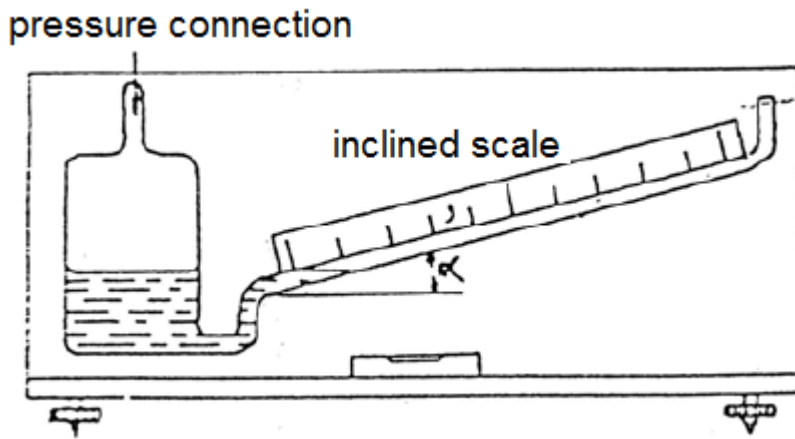


Figure 1.11b The inclined manometer

## Measuring Temperature

In this section the intensive property temperature is considered along with means for measuring it. Like force, a concept of temperature originates with our sense perceptions. It is rooted in the notion of the “hotness” or “coldness” of a body. We use our sense of touch to distinguish hot bodies from cold bodies and to arrange bodies in their order of “hotness,” deciding that 1 is hotter than 2, 2 hotter than 3, and so on. But however sensitive the human body may be, we are unable to gauge this quality precisely. Accordingly, thermometers and temperature scales have been devised to measure it.

## Thermal Equilibrium

A system is said to be in thermal equilibrium if the state of all bodies composing a thermodynamic state does not change for a long period of time. If there is no external spontaneous تلقائي factor a system cannot be out of the state of equilibrium

However, it is possible to arrive at an objective understanding of *equality* of temperature by using the fact that when the temperature of a body changes, other properties also change. To illustrate this, **consider two copper blocks**, and suppose that our senses tell us that one is warmer than the other. If the blocks were brought into contact and isolated from their surroundings, they would interact in a way that can be described as a ***thermal (heat) interaction***.

During this interaction, it would be observed that the volume of the warmer block decreases somewhat with time, while the volume of the colder block increases with time. Eventually, no further changes in volume would be observed, and the blocks would feel equally warm. Similarly, we would be able to observe that the electrical resistance of the warmer block decreases with time, and that of the colder block increases with time; eventually the electrical resistances would become constant also. When all changes in such observable properties cease تتوقف, the interaction is at an end.



The two blocks are then in **thermal equilibrium**. Considerations such as these lead us to infer للاستدلال that the blocks have a physical property that determines whether they will be in thermal equilibrium. This property is called **temperature**, and we may postulate وضع استنتاج اساسي that when the two blocks are in thermal equilibrium, their temperatures are equal.

The *rate* at which the blocks approach thermal equilibrium with one another can be slowed بتبطيئه by separating them with a thick layer of polystyrene foam, rock wool, cork, or other insulating material. Although the rate at which equilibrium is approached can be reduced, no actual material can prevent the blocks from interacting until they attain the same temperature. However, by extrapolating الاستقراء from experience, an *ideal* insulator can be imagined that would preclude يعوق them from interacting thermally. An ideal insulator is called an **adiabatic wall**. When a system undergoes a process while enclosed by an adiabatic wall, it experiences no thermal interaction with its surroundings. Such a process is called an **adiabatic process**. A process that occurs at constant temperature is an **isothermal process**. An adiabatic process is not necessarily an isothermal process, nor is an isothermal process necessarily adiabatic. It is a matter of experience that when two bodies are in thermal equilibrium with a third body, they are in thermal equilibrium with one another. This statement, which is sometimes called the **zeroth law of thermodynamics**, is tacitly ضمنا assumed in every measurement of temperature.

## ZEROth LAW OF THERMODYNAMICS

The **Zeroth Law of Thermodynamics states that: If two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other** (Fig. 1.12). This obvious جلية واضحة fact cannot be concluded from the other laws of thermodynamics, and it serves as a basis of temperature measurement.

Thus, if we want to know if two bodies are at the same temperature, it is not necessary to bring them into contact and see whether their observable properties change with time, as described previously. By replacing the third body with a **thermometer**, the zeroth law can be restated **two bodies are in thermal equilibrium if both have the same temperature reading even if they are not in contact**

The zeroth law was first formulated and labeled by R.H. Fowler in 1931.

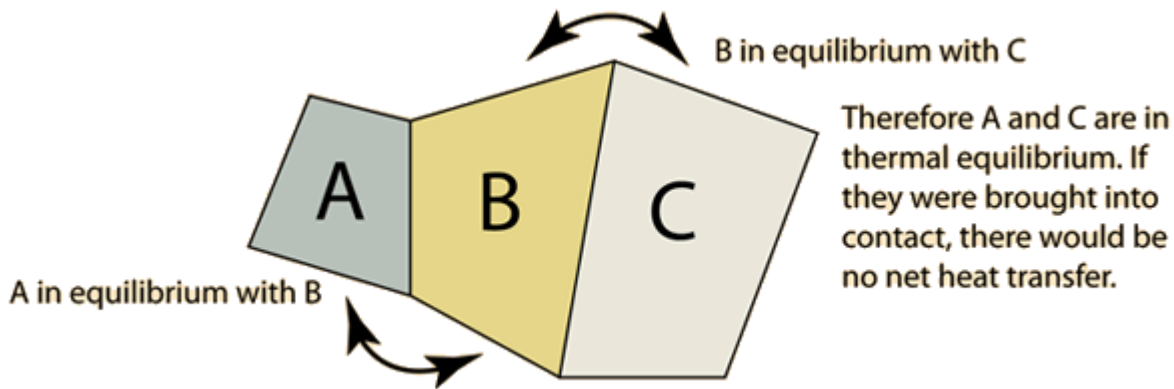


Fig. 1.12 Zeroth Law of Thermodynamics

## 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 **تظهر** 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. 1.13a, which consists of a glass capillary tube connected to a bulb filled with a liquid such as alcohol and sealed at the other end. The space above the liquid is occupied by the vapor of the liquid or an inert **خامل، غير فعال** gas. As temperature increases, the liquid expands in volume and rises 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. Although this type of thermometer is commonly used for ordinary temperature measurements, it is not well suited for applications where extreme accuracy is required.

## OTHER TEMPERATURE SENSORS

Sensors known as **thermocouples** are based on the principle that when two dissimilar metals are joined, an electromotive force (emf) that is primarily a function of temperature will exist in a circuit. In certain thermocouples, one thermocouple wire is platinum of a specified purity and the other is an alloy of platinum and rhodium. Thermocouples also utilize copper and constantan (an alloy of copper and nickel), iron and constantan, as well as several other pairs of materials. **Electrical-resistance** sensors are another important class of temperature measurement devices. These sensors are based on the fact that the electrical resistance of various materials changes in a predictable manner with temperature. The materials used for this purpose are normally conductors (such as platinum, nickel, or copper) or semiconductors. Devices using conductors are known as **resistance temperature detectors**.

The present generation of liquid-in-glass fever thermometers for home use contains patented liquid mixtures that are nontoxic, safe alternatives to mercury. Battery-powered digital thermometers also are common today. These devices use the fact that electrical resistance changes predictably with temperature to safely check for a fever see Fig. 1.13(b)

Semiconductor types are called **thermistors**. A variety of instruments measure temperature by sensing radiation, such as the ear thermometer shown in Fig. 1.13(c). They are known by terms such as **radiation thermometers** and **optical pyrometers**. This type of thermometer differs from those previously considered in that it does not actually come in contact with the body whose temperature is to be determined, an advantage when dealing with moving objects or bodies at extremely high temperatures. All of these temperature sensors can be used together with automatic data acquisition.

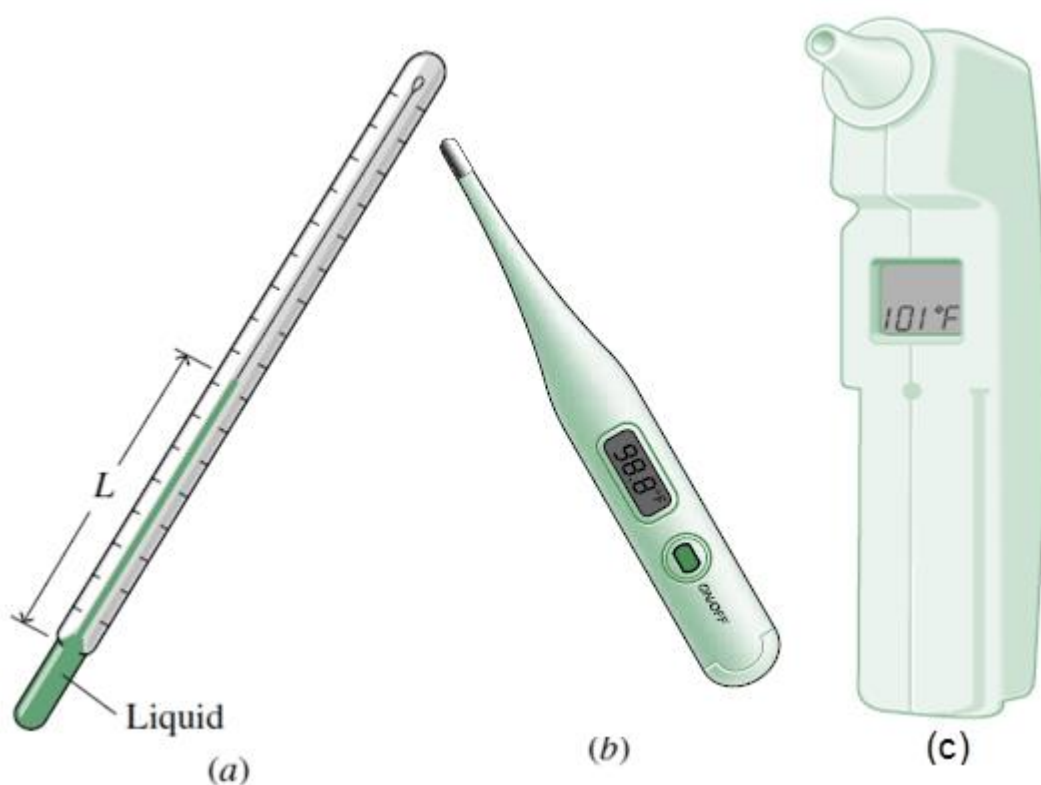
The constant-volume gas thermometer shown in Fig. 1.14 is so exceptional in terms of precision and accuracy that it has been adopted internationally as the standard instrument for calibrating other thermometers. The thermometric substance is the gas (normally hydrogen or helium), and the thermometric 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 an open-tube mercury manometer. As temperature increases, the gas expands, forcing mercury up in the open tube.

The gas is kept at constant volume by raising or lowering the reservoir. The gas thermometer is used as a standard worldwide by bureaus of standards and research laboratories. However, because gas thermometers require elaborate apparatus and are large, slowly responding devices that demand painstaking اجتهاد experimental procedures, smaller, more rapidly responding thermometers are used for most temperature measurements and they are calibrated (directly or indirectly) against gas thermometers.

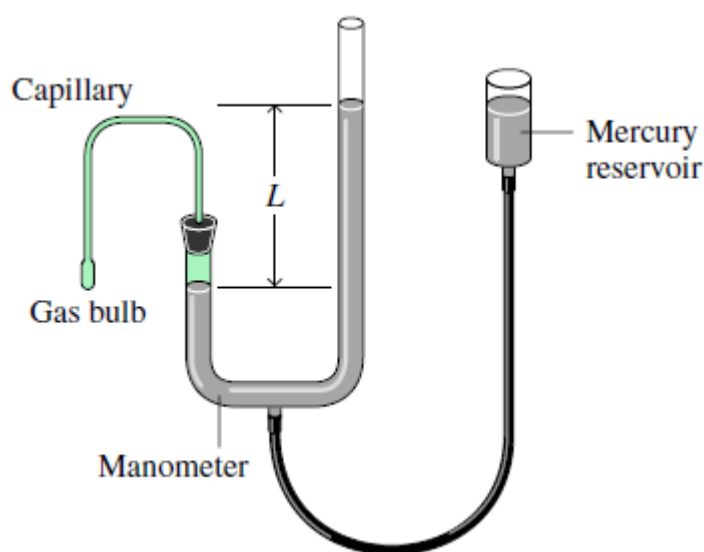
## **Kelvin Scale**

***Absolute temperature is the temperature measured from a point where the molecules of a substance have so called 'zero energy'.***

Empirical means of measuring temperature such as considered in above have inherent limitations. **for example..** . The tendency of the liquid in a liquid-in-glass thermometer to freeze at low temperatures imposes a lower limit on the range of temperatures that can be measured. At high temperatures liquids vaporize, and therefore these temperatures also cannot be determined by a liquid-in-glass thermometer. Accordingly, several *different* thermometers might be required to cover a wide temperature interval.



**Figure 1.13** Thermometers. (a) Liquid-in-glass. (b) New digital home and medical usage thermometer (c) Infrared sensing ear thermometer.



**Figure 1.14** Constant-volume gas thermometer.

In view of the limitations of empirical means for measuring temperature, it is desirable to have a procedure for assigning temperature values that does not depend on the properties of any particular substance or class of substances. Such a scale is called a *thermodynamic* temperature scale. The **Kelvin scale** is an absolute thermodynamic temperature scale that provides a continuous definition of temperature, valid over all ranges of temperature.

Empirical measures of temperature, with different thermometers, can be related to the Kelvin scale. To develop the Kelvin scale, it is necessary to use the conservation of energy principle and the second law of thermodynamics; (discussed at next) we note here that the Kelvin scale has a zero of 0 K, and lower temperatures than this are not defined.

The Kelvin scale and the gas scale are defined by the following equation:

$$T (^{\circ}\text{C}) = a + bp$$

where  $a$  and  $b$  are constants can be experimentally determined by measuring the pressures and temperatures of two reproducible points of the gases such as (ice and steam points) considering that only one straight line pass through these point on the  $p$  and  $T$  diagram. Repeating same procedure on different types and amount of gases, the value of the constant  $a$  (which corresponding to the zero absolute pressure is determined to be  $-273.15^{\circ}\text{C}$ . That is on the  $p$  and  $T$  diagram all the straight lines passing through the data points in this case will intersect the temperature axis at  $-273.15^{\circ}\text{C}$  when extrapolated as shown in Fig. 1.15

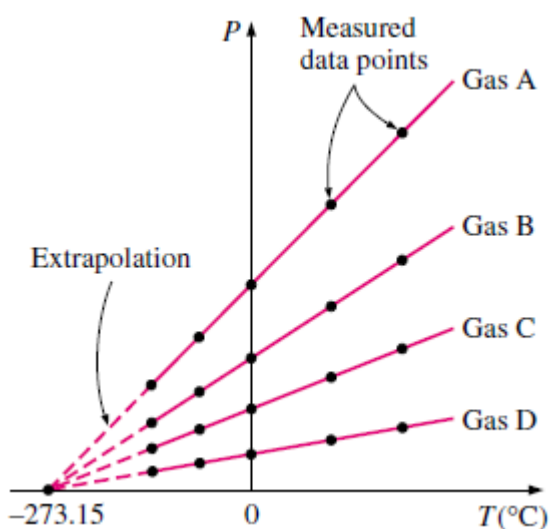


Figure 1.15  $p$   $T$  diagram of different gases

### Celsius Scale

Temperature scales are defined by the numerical value assigned to a *standard fixed point*. By international agreement the standard fixed point is the easily reproducible **triple point of water**: the state of equilibrium between steam, ice, and liquid water. As a matter of convenience, the temperature at this standard fixed point is defined as 273.16 Kelvins, abbreviated as 273.15 K. This makes the temperature interval from the *ice point* (The state of equilibrium between ice and air-saturated water at a pressure of 1 atm.) (273.15 K) to the *steam point* (The state of equilibrium between steam and liquid water at a pressure of 1 atm.) equal to 373.15 K and thus in agreement over the interval

with the Celsius scale discussed next, which assigns 100 Celsius degrees to it. The kelvin is the SI base unit for temperature.

The **Celsius temperature scale** (formerly called the centigrade 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 see Fig. 1.16. 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

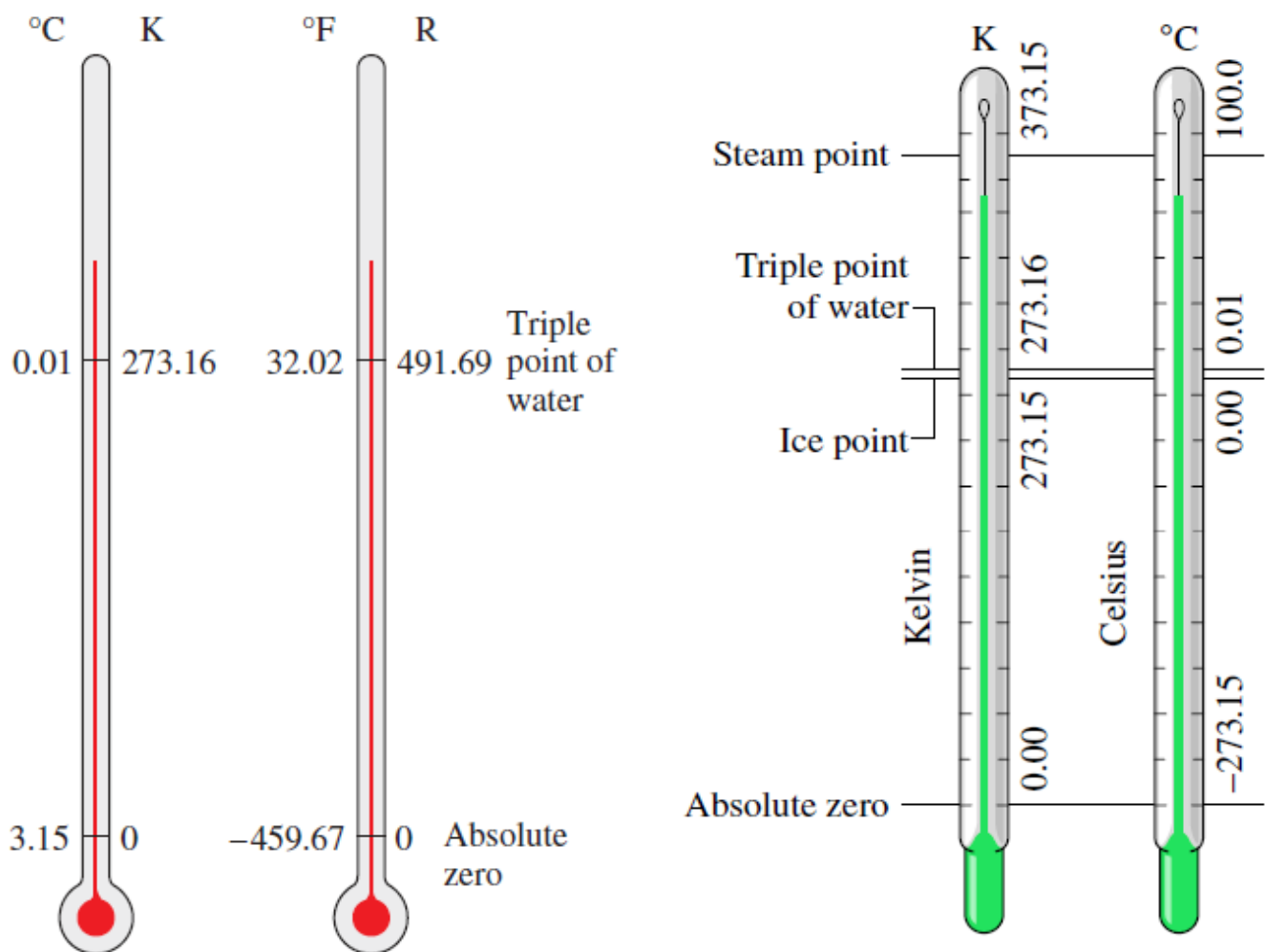
$$T(^{\circ}\text{C}) = T(\text{K}) - 273.15$$

In English units Fahrenheit scale (F) used where freezing occurs at  $32^{\circ}\text{F}$  and boiling at  $212^{\circ}\text{F}$ .

$$T(^{\circ}\text{C}) = \frac{5}{9}(T(^{\circ}\text{F}) - 32) \quad \text{and} \quad T(^{\circ}\text{F}) = \frac{9}{5}T(^{\circ}\text{C}) + 32$$

The Rankine temperature scale designated by  $^{\circ}\text{R}$  is used as absolute temperature scale in English unit.

$$T(^{\circ}\text{R}) = T(^{\circ}\text{F}) + 459.67 \quad \text{and} \quad T(^{\circ}\text{R}) = 1.8 T(\text{K})$$



**Figure 1.16** Comparison of temperature scales.

## **Working substance**

Is the substance to and from which heat and work is transferred while undergoing a process or a thermodynamic cycle.

## **Types of Systems**

Based on the types of exchange which take place يحصل or don't take place, five dominant classes of systems may be defined: There are:

**Isolated Systems** – matter and energy may not cross the boundary.

**Adiabatic Systems** – heat may not cross the boundary.

**Diathermic Systems** - heat may cross boundary.

**Closed Systems** – matter may not cross the boundary, (may be any of the above).

**Open Systems** – heat, work, and matter may cross the boundary.

For isolated systems, as time goes by, internal differences in the system tend to even out; pressures and temperatures tend to equalize, as do density differences. A system, in which all equalizing processes have gone practically to completion, is considered to be in a state of thermodynamic equilibrium.

## **Types of Process**

Several processes are described by the fact that one property remains constant. The prefix iso- is used to describe such processes. A process is said to be reversible if both the system and its surroundings can be restored to their respective initial states by reversing the direction of the process.

**Reversible:** if the process happens slow enough to be reversed.

**Irreversible:** if the process cannot be reversed (like most processes).

**Isobaric:** process done at constant pressure

**Isochoric:** process done at constant volume

**Isothermal:** process done at constant temperature

**Adiabatic:** process where  $q=0$

**Cyclic:** process where initial state = final state