

## INTRODUCTION

The word thermodynamics stems **ينشأ** 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 **النادرة** 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

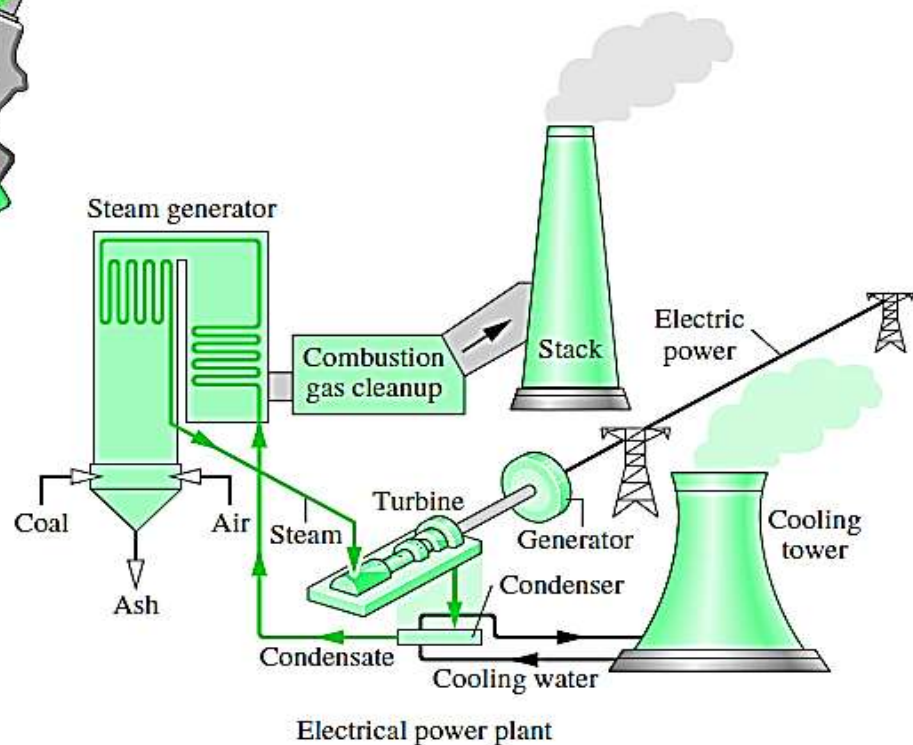
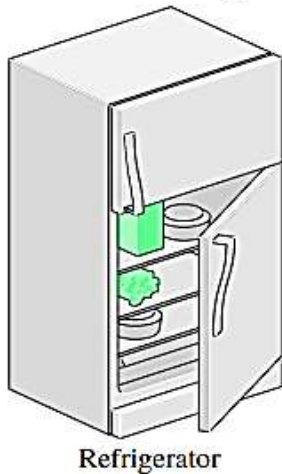
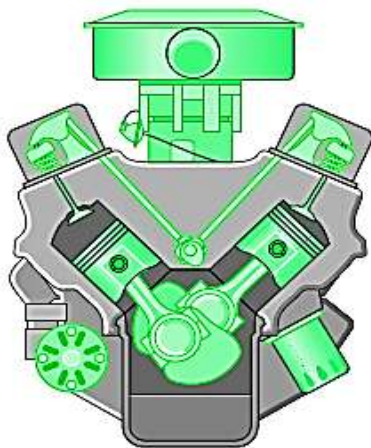
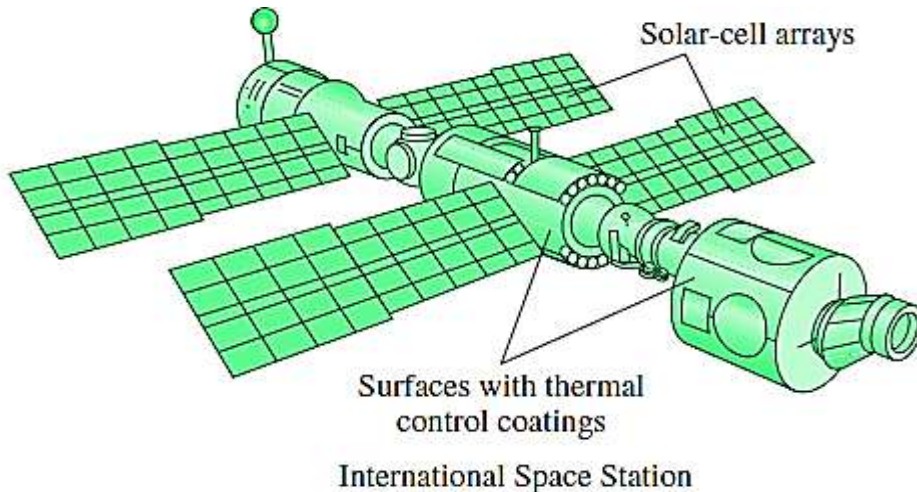
Cooling of electronic equipment

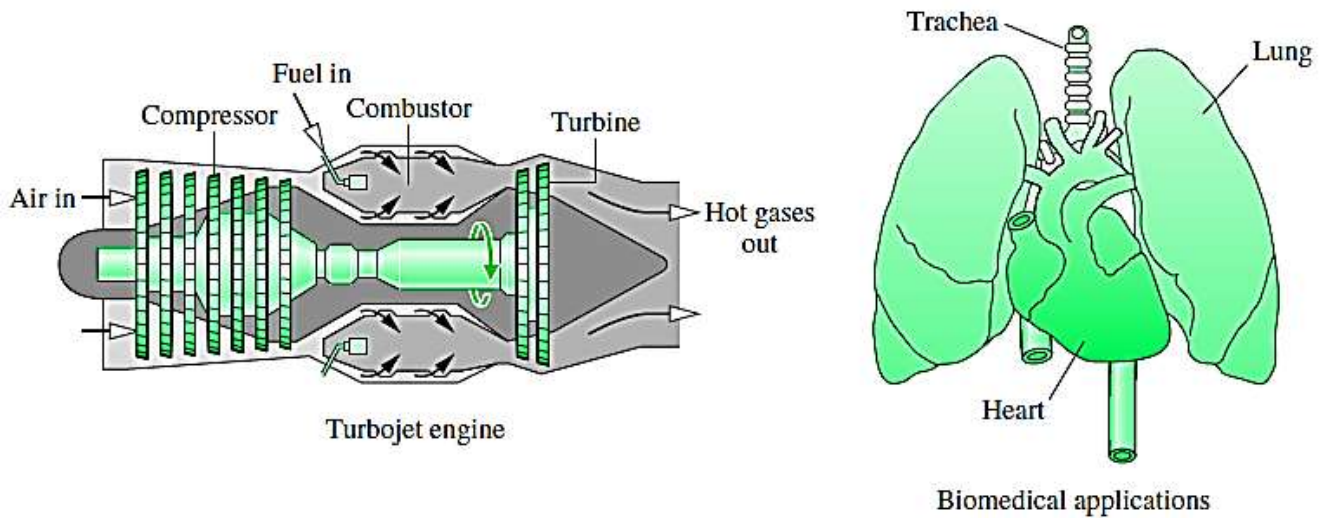
Alternative energy systems

- 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

Physics seven basic quantities (Fundamental Quantities) and their drives and SI units

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

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*.

International System of Units 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 and related quantities* are listed in Table 1.2 and discussed in the following paragraphs.

**TABLE 1.2** Fundamental Quantities and SI Units

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

Length is the most extended dimension of an object. 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.

Mass is a measure of a body's inertia. 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.

Time is defined as the duration in which all things happen, or a precise instant that something happens. 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.

Force is, “The agency **واسطة** او **مؤثر** that tends to change the momentum of a massive body". The SI unit of force, called the newton, is a secondary or derived unit, defined in terms of the base units for mass, length, and time.

Temperature is a degree of hotness or coldness measured on a definite scale. The SI base unit for temperature is the kelvin, K. Temperature is included for thermodynamics.

The electric current is the time rate of flow of electric charge and 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. Table 1.3 shows the SI and British units for derived quantities pertinent **لها صلة** to thermodynamics.

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>	Lbf=slug.ft/sec <sup>2</sup>
g	Local acceleration of	تسجيل 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

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

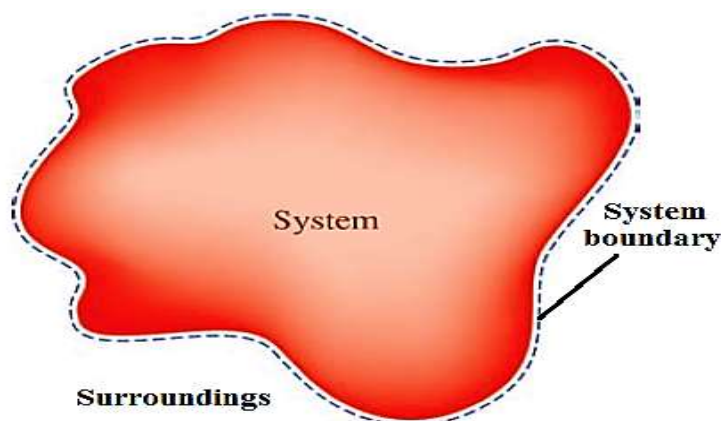


**Table 1.4 SI Units Prefixes**

Prefix	Symbol	Multiplier	Exponential	Normalized	E Notation
yotta	Y	1,000,000,000,000,000,000,000,000	$10^{24}$	$1.0 \times 10^{24}$	1.0E24
zetta	Z	1,000,000,000,000,000,000,000	$10^{21}$	$1.0 \times 10^{21}$	1.0E21
exa	E	1,000,000,000,000,000,000	$10^{18}$	$1.0 \times 10^{18}$	1.0E18
peta	P	1,000,000,000,000,000	$10^{15}$	$1.0 \times 10^{15}$	1.0E15
tera	T	1,000,000,000,000	$10^{12}$	$1.0 \times 10^{12}$	1.0E12
giga	G	1,000,000,000	$10^9$	$1.0 \times 10^9$	1.0E9
mega	M	1,000,000	$10^6$	$1.0 \times 10^6$	1.0E6
kilo	k	1,000	$10^3$	$1.0 \times 10^3$	1.0E3
hecto	h	100	$10^2$	$1.0 \times 10^2$	1.0E2
deca	da	10	$10^1$	$1.0 \times 10^1$	1.0E1
		1	$10^0$	$1.0 \times 10^0$	1.0E0
deci	d	0.1	$10^{-1}$	$1.0 \times 10^{-1}$	1.0E-1
centi	c	0.01	$10^{-2}$	$1.0 \times 10^{-2}$	1.0E-2
milli	m	0.001	$10^{-3}$	$1.0 \times 10^{-3}$	1.0E-3
micro	$\mu$	0.000001	$10^{-6}$	$1.0 \times 10^{-6}$	1.0E-6
nano	n	0.000000001	$10^{-9}$	$1.0 \times 10^{-9}$	1.0E-9
pico	p	0.0000000000001	$10^{-12}$	$1.0 \times 10^{-12}$	1.0E-12
femto	f	0.00000000000000001	$10^{-15}$	$1.0 \times 10^{-15}$	1.0E-15
atto	a	0.000000000000000000001	$10^{-18}$	$1.0 \times 10^{-18}$	1.0E-18
zepto	z	0.0000000000000000000000001	$10^{-21}$	$1.0 \times 10^{-21}$	1.0E-21
yocto	y	0.000000000000000000000000001	$10^{-24}$	$1.0 \times 10^{-24}$	1.0E-24

### The Thermodynamics Systems

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.

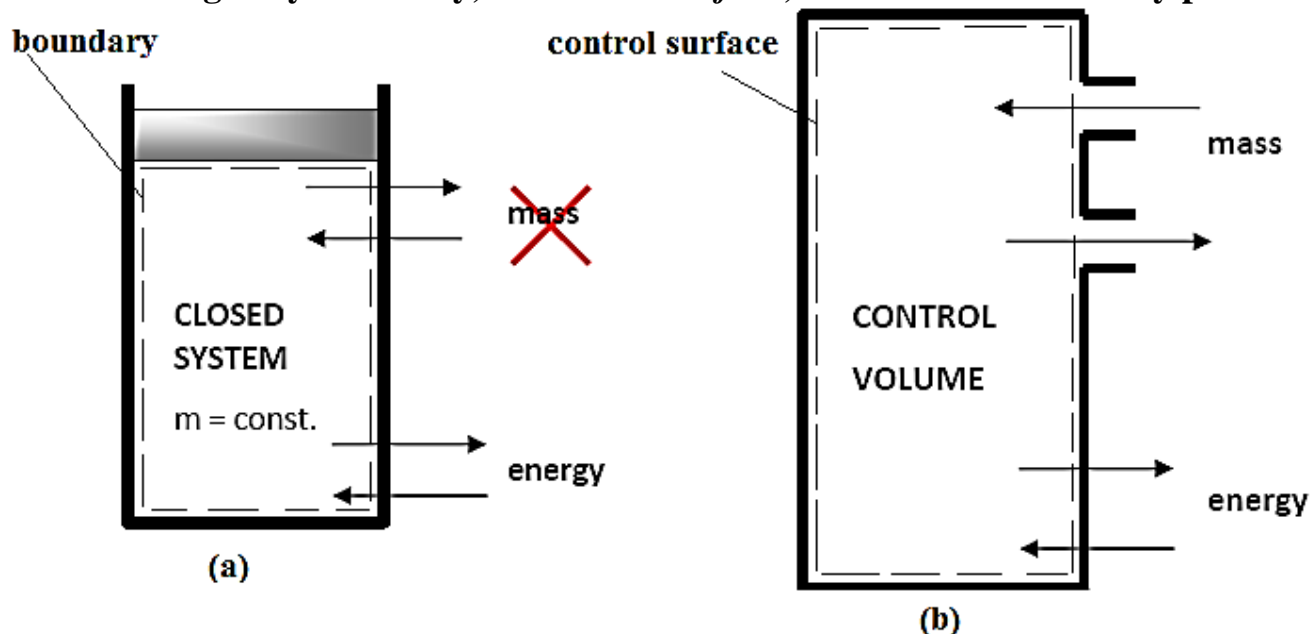


Figure 1.4 (a) Closed system, mass cannot cross the boundaries, but energy can, and the boundary may be fixed or moving, and real or imaginary (b) Control volume, both mass and energy can cross the boundaries.

## MACROSCOPIC AND MICROSCOPIC VIEWS OF THERMODYNAMICS

Thermodynamic system can be studied from a macroscopic or a microscopic point of view. The macroscopic approach 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.

### **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.

### **Properties of a system**

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.

### **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.

An easy way to determine whether a property is intensive or extensive is to divide the system into two equal parts with an imaginary partition, as shown in Fig. 1.6.

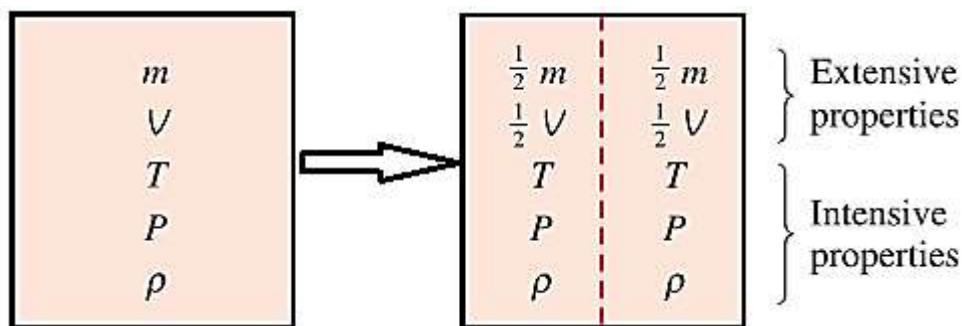


Fig. 1.6 Criterion to differentiate intensive and extensive properties.

### State and equilibrium

The word *state* refers to the condition of a system as completely described by its properties, without undergoing any change. At this point, all the properties can be measured or calculated throughout the entire system. At a given state, all the properties of a system have fixed values. If the value of even one property changes, the state will change to a different one. In Fig. 1.7 a system is shown at two different states.

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

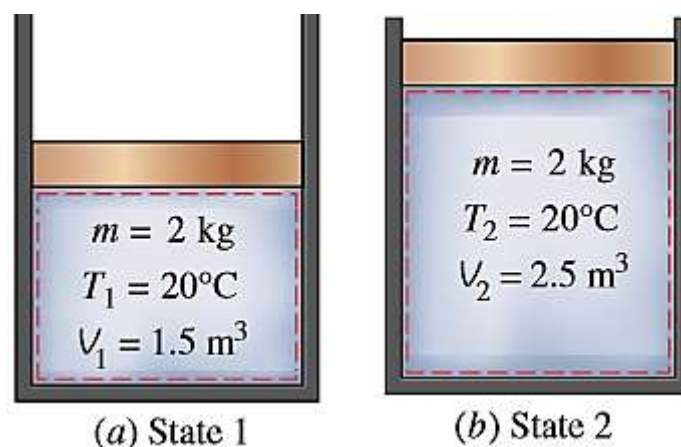


Figure 1.7 A system at two different states.

Thermodynamics deals with equilibrium states. The word equilibrium implies a state of balance. In an equilibrium state, there are no unbalanced potentials (or driving forces) within the system. A system in equilibrium experiences no changes when it is isolated from its surroundings. There are many types of equilibrium, and a system is not in thermodynamic equilibrium unless the conditions of all the relevant types of equilibrium are satisfied. For example, a system is in thermal equilibrium if the temperature is the same throughout the entire system, as shown in Fig. 1.8. That is, the system involves no temperature differential, which is the driving force for heat flow. Mechanical equilibrium is related to pressure, and a system is in mechanical equilibrium if there is no change in pressure at any point of the system with time. However, the pressure may vary within the system with elevation because of gravitational effects.

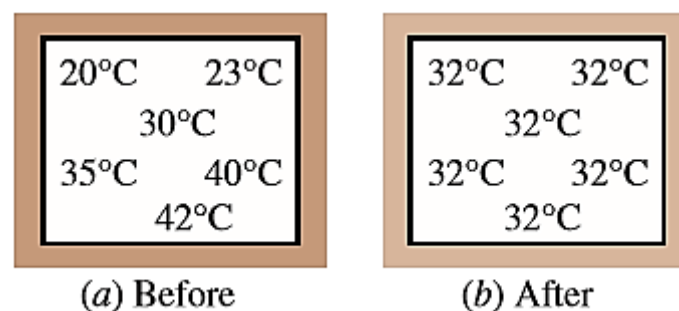


Figure 1.8 A closed system reaching thermal equilibrium.

For example, the higher pressure at a bottom layer is balanced by the extra weight it must carry, and, therefore, there is no imbalance of forces. The variation of pressure because of gravity in most thermodynamic systems is relatively small and usually disregarded. If a system involves two phases, it is in phase equilibrium when the mass of each phase reaches an equilibrium level and stays there. Finally, a system is in chemical equilibrium if its chemical composition does not change with time, that is, no chemical reactions occur. A system will not be in equilibrium unless all the relevant equilibrium criteria are satisfied.

### The State Postulate

To describe the system state, we do not need to specify all the properties, it is enough to specify a sufficient number of properties and the rest of the properties assume certain values automatically. The number of properties required to fix the state of a system is given by the state postulate

### Processes and cycles

Any change that a system undergoes from one equilibrium state to another is called a process, and the series of states through which a system passes during a process is called the path of the process (Fig. 1.9). To describe a process completely, one should specify the initial and final states of the process, as well as the path it follows, and the

interactions with the surroundings. (A process is a transformation from one state to another).

When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times, it is called a quasi-static, or quasi-equilibrium, process. A quasi-equilibrium process can be viewed as a sufficiently slow process that allows the system to adjust itself internally so that properties in one part of the system do not change any faster than those at other parts. See Fig. 1.10.

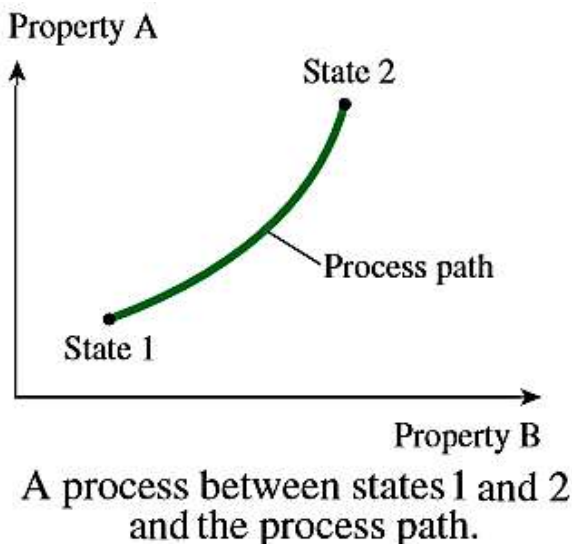
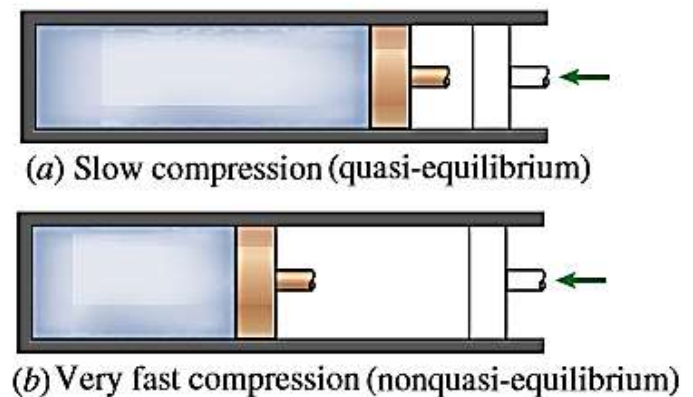


Figure 1.9



Quasi-equilibrium and nonquasi-equilibrium compression processes.

Figure 1.10

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..

### 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.

### Some Important Quantities

#### 1. Force

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.

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

*for example..* 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  $9.80665 m/s^2$ . 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 using a *unit conversion factor* as:

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

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.

## 2. 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.

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

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  $\text{kg/kmol}$ . 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

$$\bar{v} = Mv$$

Sometimes the density of a substance is given relative to the density of a well-known substance. Then it is called relative density or specific gravity SG (dimensionless quantity), 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,

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

### 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.

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

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,  $p_{\text{atm}}$ .

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

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

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

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



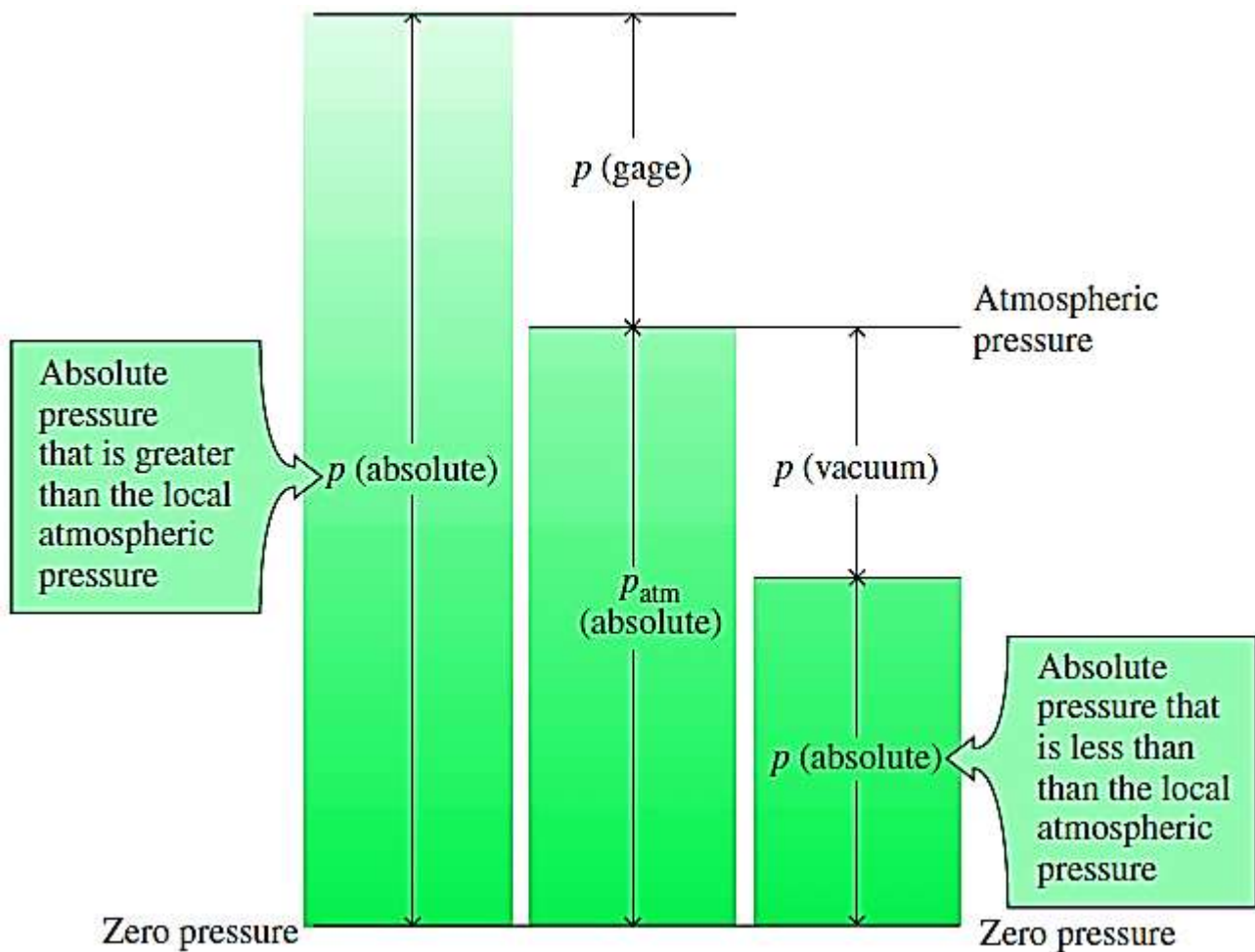


Figure 1.7 Relationships among the absolute, atmospheric, gage, and vacuum pressures.

## 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

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

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

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

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

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.

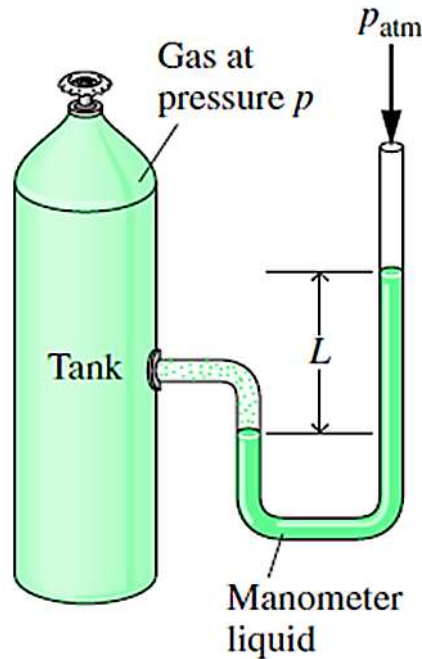
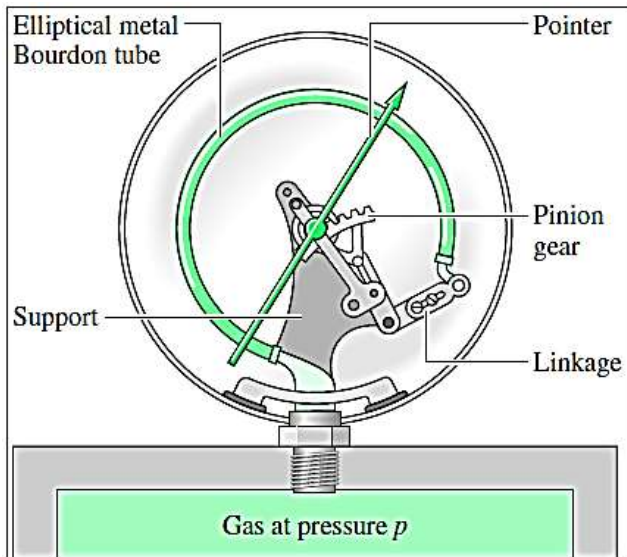


Figure 1.8 Pressure measurement by a manometer.

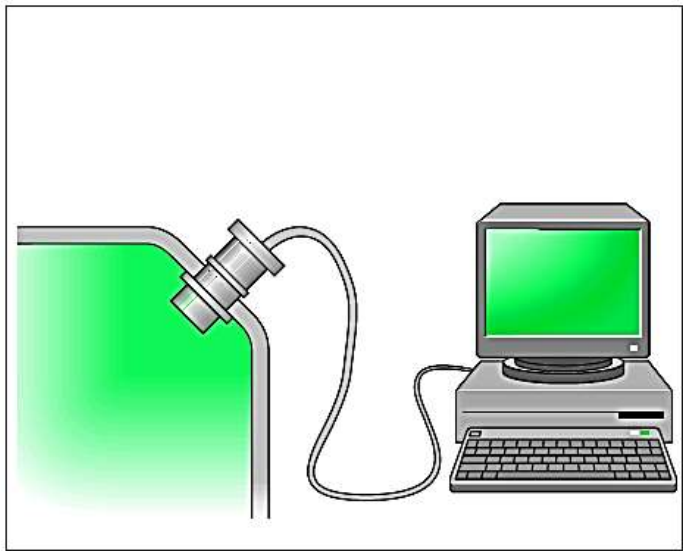
A Bourdon tube gage is shown in Fig. 1.9. The figure shows a curved tube having an elliptical cross section with one end attached to the pressure to be measured and the other end connected to a pointer by a mechanism. When fluid under pressure fills the tube, the elliptical section tends to become circular, 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.

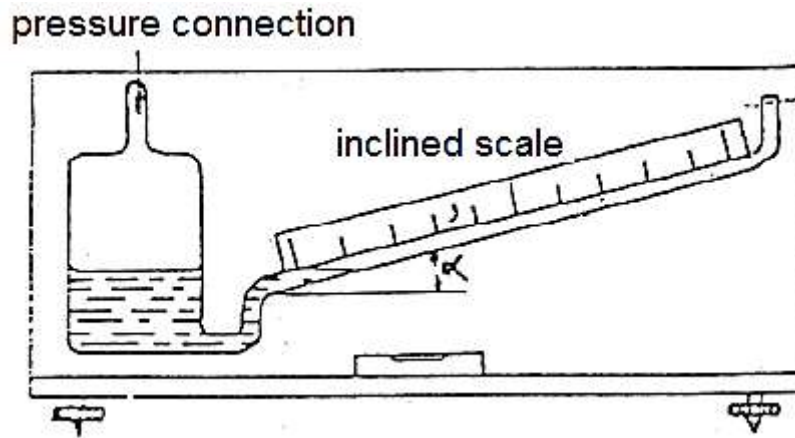


Figure 1.11b The inclined manometer

### Temperature and the zeroth law of thermodynamics

Simply, temperature is a measure of “hotness” or “coldness,” but it is not easy to give an exact definition for it. Based on our physiological sensations, we express the level of temperature qualitatively with words like freezing cold, cold, warm, hot, and red-hot, without assign numerical values to temperatures. Also our senses may be misleading. Fortunately, several properties of materials change with temperature in a repeatable and predictable way, and this forms the basis for accurate temperature measurement. When a body is brought into contact with another body that is at a different temperature, heat is transferred from the body at higher temperature to the one at lower temperature until both bodies attain the same temperature (Fig. 1–12). At that point, the heat transfer stops, and the two bodies are said to have reached thermal equilibrium. The equality of temperature is the only requirement for thermal equilibrium.

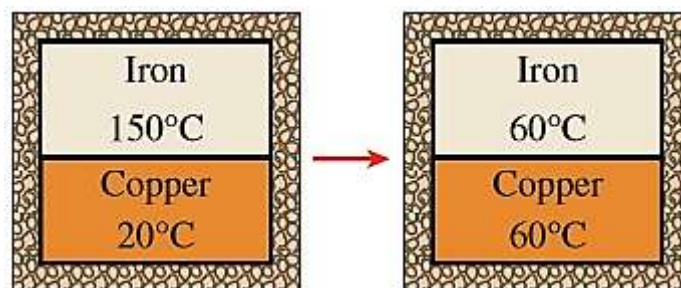


Figure 1–12 Two bodies reaching thermal equilibrium after being brought into contact in an isolated enclosure.

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 see Fig. (1.13). It is one of the basic laws of thermodynamics. and it serves as a basis for the validity of temperature measurement. By replacing the third body with a thermometer, the zeroth law can be restated as 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, after more than half a century of the

first and the second laws of thermodynamics. It was named the zeroth law since its value is the fundamental physical principle was recognized

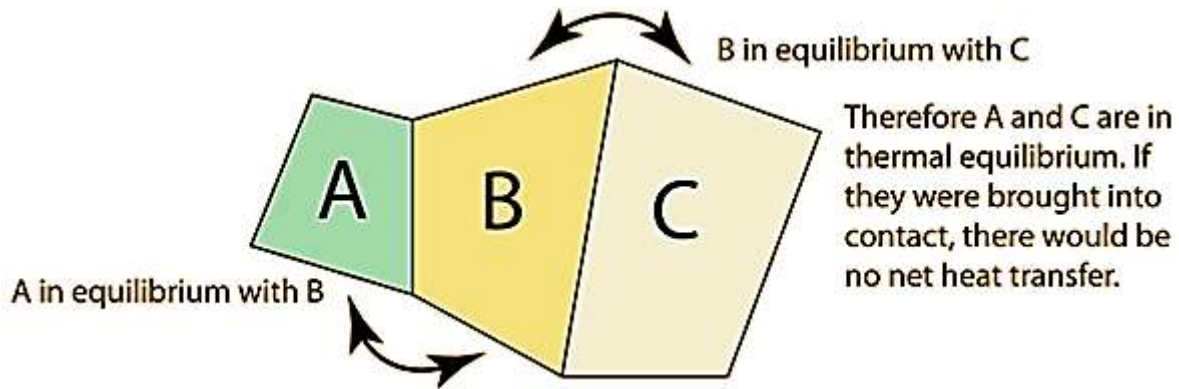


Fig. 1.13 Zeroth Law of Thermodynamics

## Measuring Temperature

### 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. 1.14a, 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 high temperature measured.

### 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. 1.14(b)

Semiconductor types are called thermistors. A variety of instruments measure temperature by sensing radiation, such as the ear thermometer shown in Fig. 1.14(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. 1.15 has a very accurate measuring method and adopted internationally as the standard instrument for calibrating the 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.

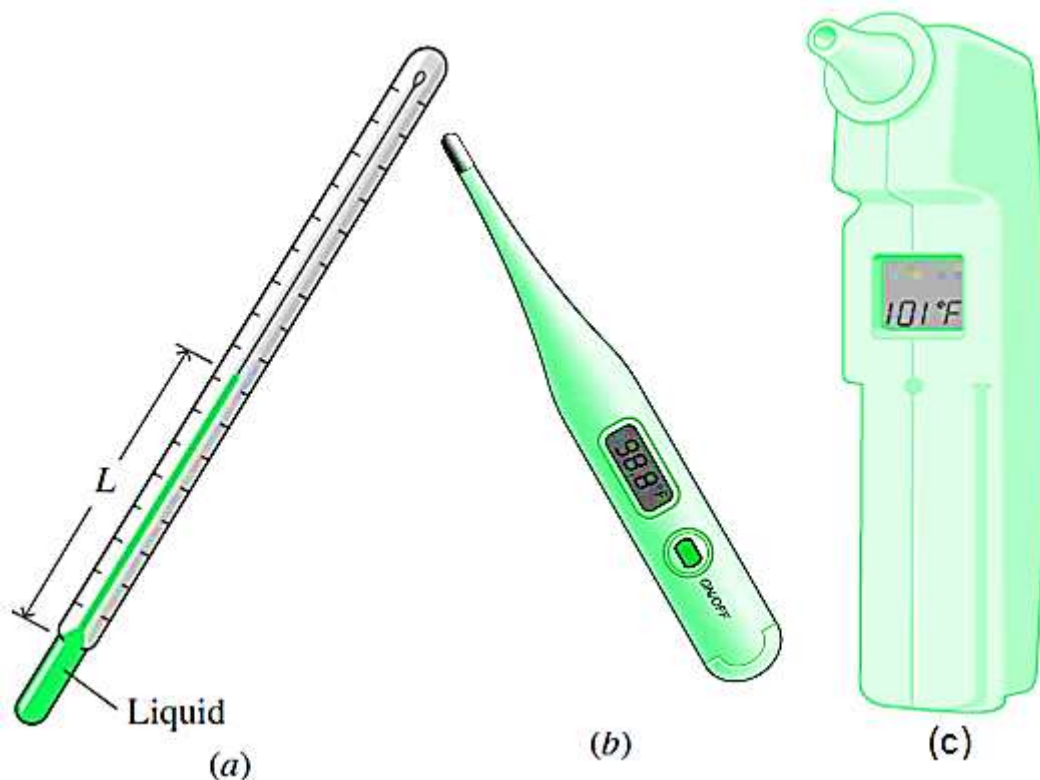
Then the gas is kept at constant volume by raising or lowering the reservoir. The temperature of a gas is proportional to its pressure at constant volume. That is, the temperature of a gas of fixed volume varies linearly with pressure at sufficiently low pressures.

## Kelvin Scale

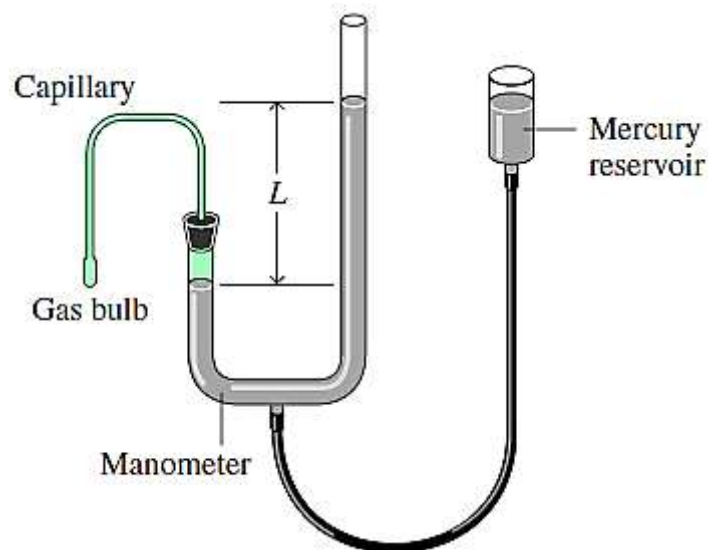
*Absolute temperature* is the temperature measured from a point where the molecules of a substance have so called 'zero energy'.

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



**Figure 1.15 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. 1.16

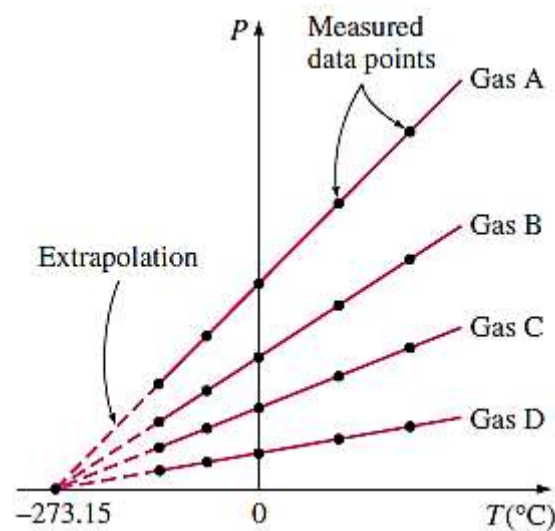


Figure 1.16 p T diagram of different gases

### 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. 1.17. 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.

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

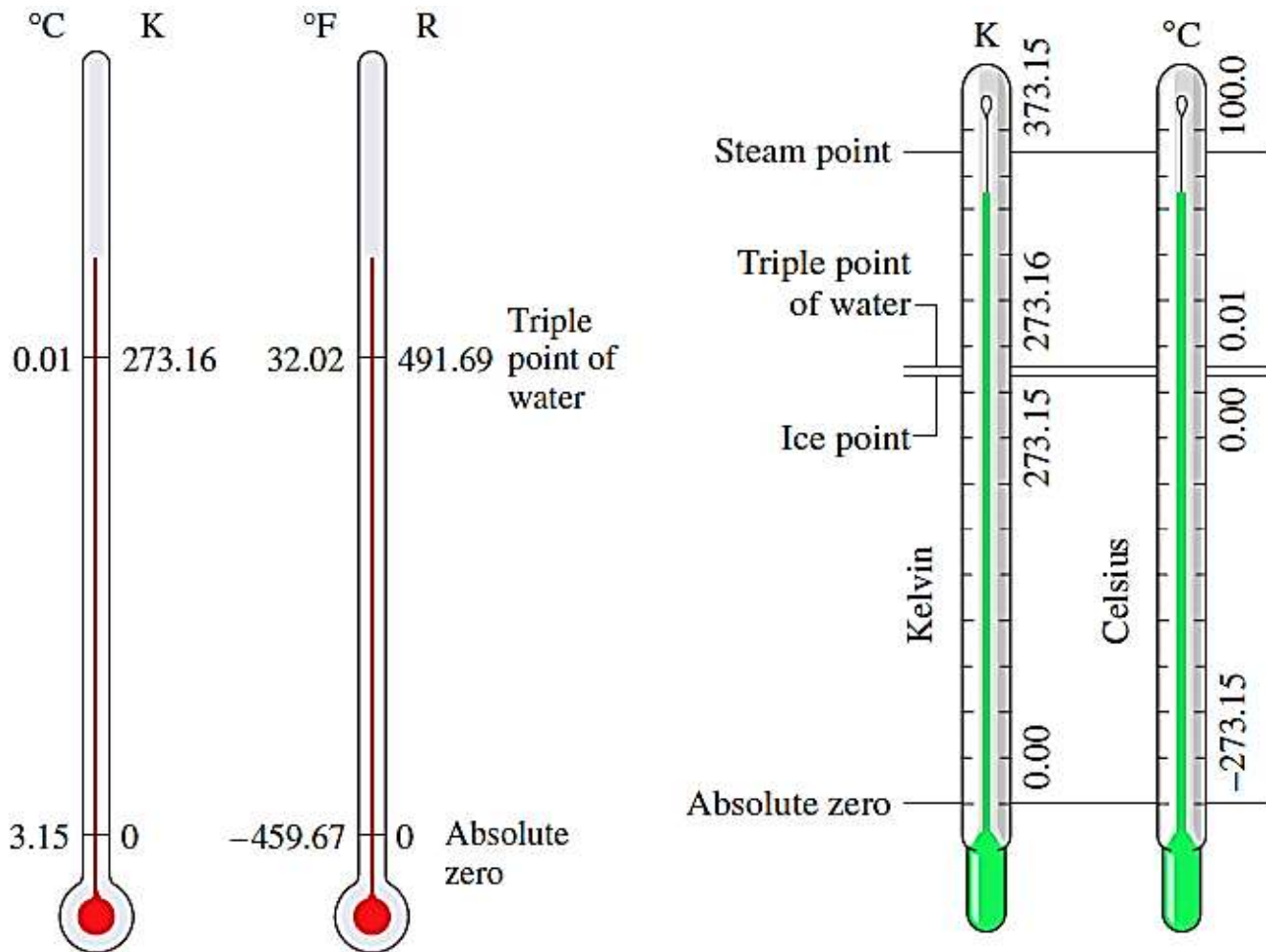


Figure 1.17 Comparison of temperature scales.

### 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