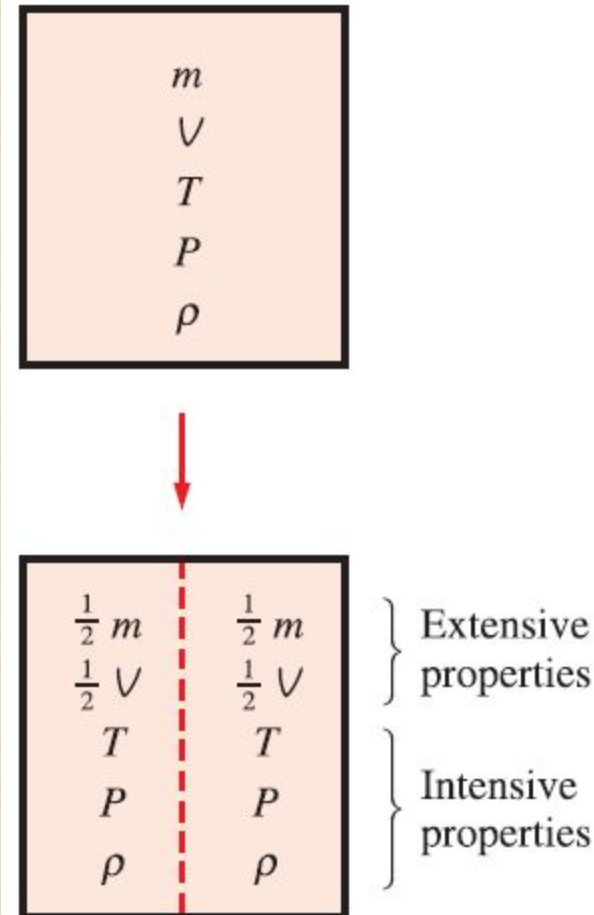


# PROPERTIES OF A SYSTEM

- **Property:** Any characteristic of a system.
- Some familiar properties are pressure  $P$ , temperature  $T$ , volume  $V$ , and mass  $m$ .
- Properties are considered to be either *intensive* or *extensive*.
- **Intensive properties:** Those that are independent of the mass of a system, such as temperature, pressure, and density.
- **Extensive properties:** Those whose values depend on the size—or extent—of the system.
- **Specific properties:** Extensive properties per unit mass.

$$(\nu = V/m)$$

$$(e = E/m).$$

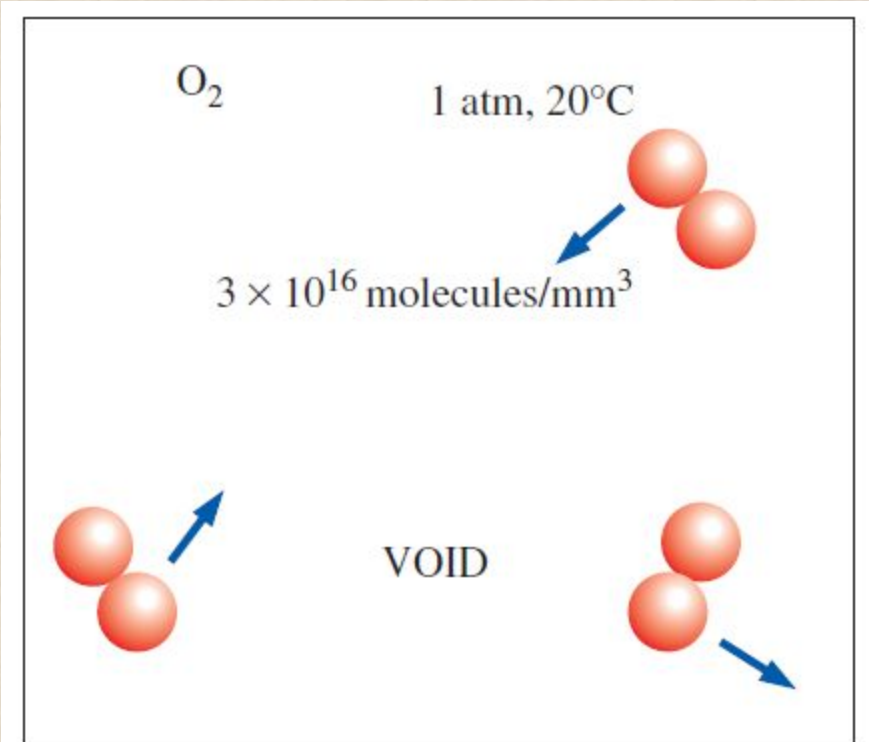


**FIGURE 1–23**

Criterion to differentiate intensive and extensive properties.

# Continuum

- Matter is made up of atoms that are widely spaced in the gas phase. Yet it is very convenient to disregard the atomic nature of a substance and view it as a continuous, homogeneous matter with no holes, that is, a **continuum**.
- The continuum idealization allows us to treat properties as point functions and to assume the properties vary continually in space with no jump discontinuities.
- This idealization is valid as long as the size of the system we deal with is large relative to the space between the molecules.
- This is the case in practically all problems.
- In this text we will limit our consideration to substances that can be modeled as a continuum.



**FIGURE 1–24**

Despite the relatively large gaps between molecules, a gas can usually be treated as a continuum because of the very large number of molecules even in an extremely small volume.

# DENSITY AND SPECIFIC GRAVITY

## Density

$$\rho = \frac{m}{V} \quad (\text{kg/m}^3)$$

## Specific volume

$$\nu = \frac{V}{m} = \frac{1}{\rho}$$

**Specific gravity:** The ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4°C).

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

**Specific weight:** The weight of a unit volume of a substance.

$$\gamma_s = \rho g \quad (\text{N/m}^3)$$

$V = 12 \text{ m}^3$   
 $m = 3 \text{ kg}$

↓

$\rho = 0.25 \text{ kg/m}^3$   
 $\nu = \frac{1}{\rho} = 4 \text{ m}^3/\text{kg}$

Density is mass per unit volume;  
specific volume is volume per unit mass.

TABLE 1-3

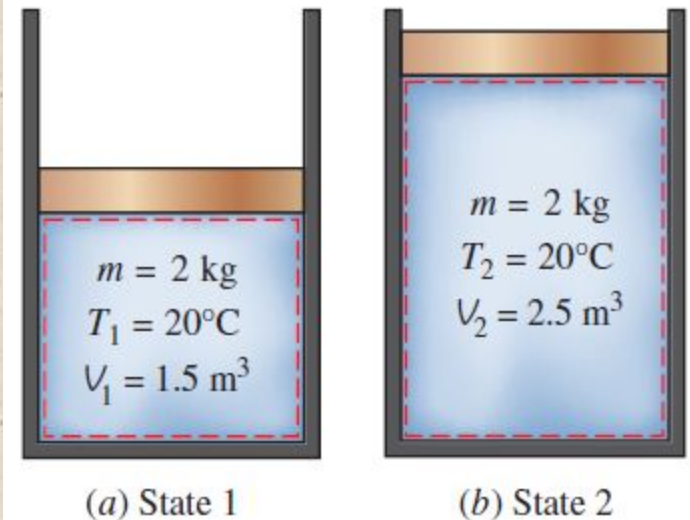
Specific gravities of some substances at 0°C

Substance	SG
Water	1.0
Blood	1.05
Seawater	1.025
Gasoline	0.7
Ethyl alcohol	0.79
Mercury	13.6
Wood	0.3–0.9
Gold	19.2
Bones	1.7–2.0
Ice	0.92
Air (at 1 atm)	0.0013



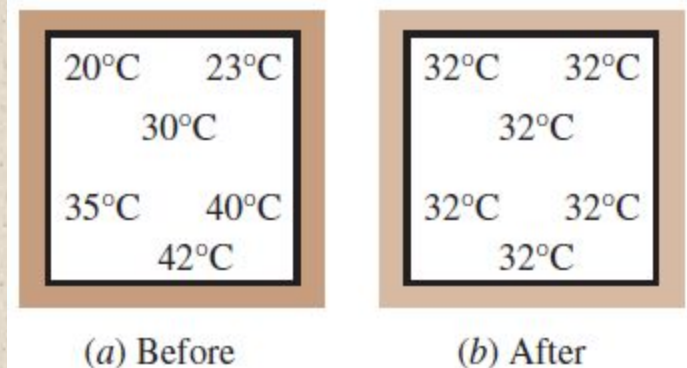
# STATE AND EQUILIBRIUM

- Thermodynamics deals with *equilibrium* states.
- **Equilibrium:** A state of balance.
- In an equilibrium state there are no unbalanced potentials (or driving forces) within the system.
- **Thermal equilibrium:** If the temperature is the same throughout the entire system.
- **Mechanical equilibrium:** If there is no change in pressure at any point of the system with time.
- **Phase equilibrium:** If a system involves two phases and when the mass of each phase reaches an equilibrium level and stays there.
- **Chemical equilibrium:** If the chemical composition of a system does not change with time, that is, no chemical reactions occur.



**FIGURE 1–26**

A system at two different states.



**FIGURE 1–27**

A closed system reaching thermal equilibrium.

# The State Postulate

- The number of properties required to fix the state of a system is given by the **state postulate**:
  - ✓ *The state of a simple compressible system is completely specified by two independent, intensive properties.*
- **Simple compressible system**: If a system involves no electrical, magnetic, gravitational, motion, and surface tension effects.



**FIGURE 1–28**

The state of nitrogen is fixed by two independent, intensive properties.

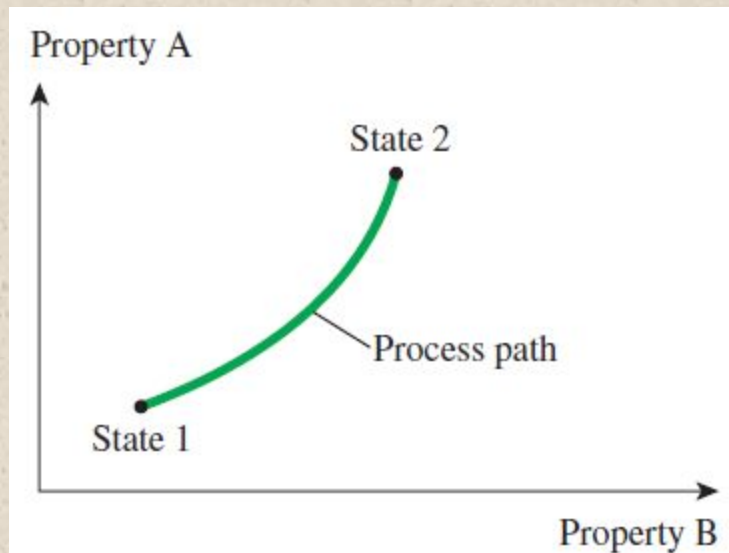
# PROCESSES AND CYCLES

**Process:** Any change that a system undergoes from one equilibrium state to another.

**Path:** The series of states through which a system passes during a process.

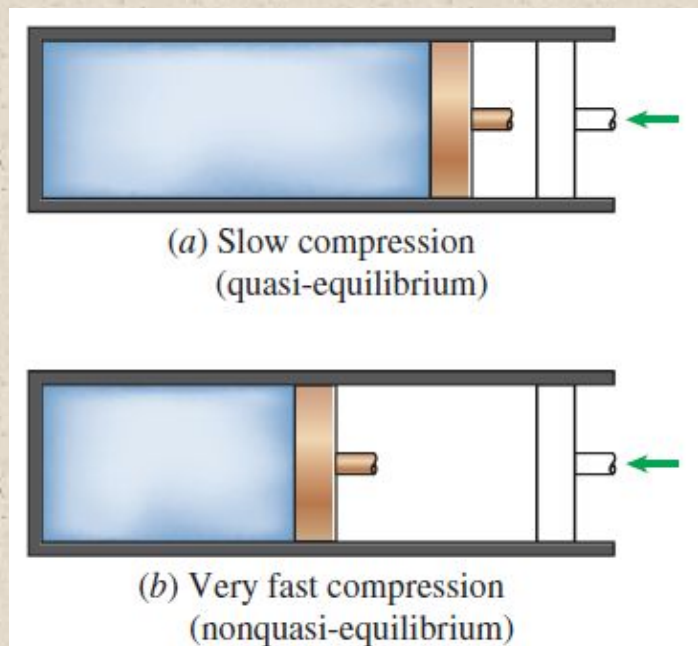
To describe a process completely, one should specify the initial and final states, as well as the path it follows, and the interactions with the surroundings.

**Quasistatic or quasi-equilibrium process:** When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times.



**FIGURE 1-29**

A process between states 1 and 2 and the process path.

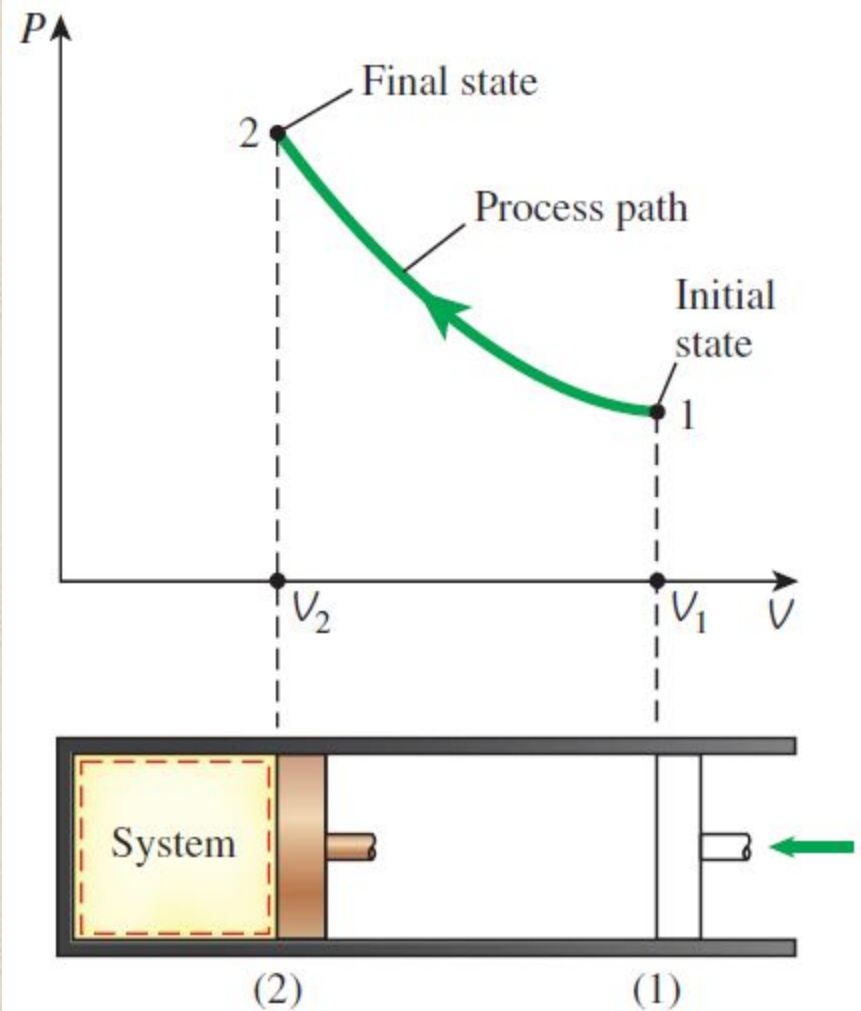


**FIGURE 1-30**

Quasi-equilibrium and nonquasi-equilibrium compression processes.



- Process diagrams plotted by employing thermodynamic properties as coordinates are very useful in visualizing the processes.
- Some common properties that are used as coordinates are temperature  $T$ , pressure  $P$ , and volume  $V$  (or specific volume  $v$ ).
- The prefix *iso-* is often used to designate a process for which a particular property remains constant.
- **Isothermal process:** A process during which the temperature  $T$  remains constant.
- **Isobaric process:** A process during which the pressure  $P$  remains constant.
- **Isochoric (or isometric) process:** A process during which the specific volume  $v$  remains constant.
- **Cycle:** A process during which the initial and final states are identical.

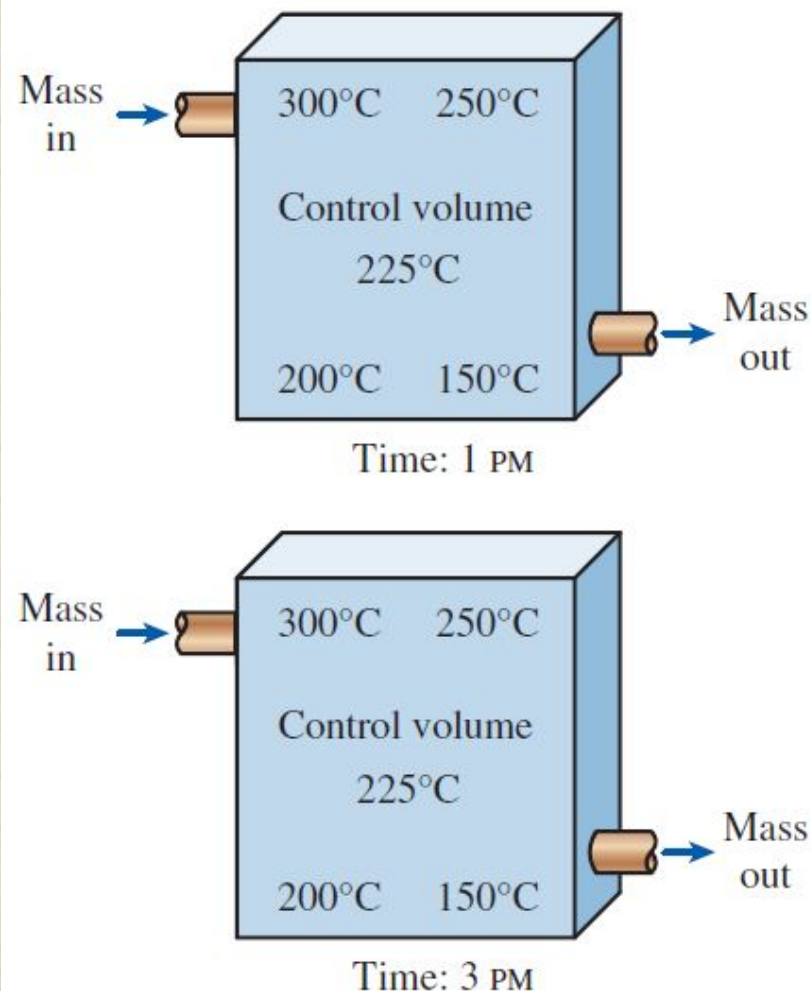


**FIGURE 1–31**

The  $P$ - $V$  diagram of a compression process.

# The Steady-Flow Process

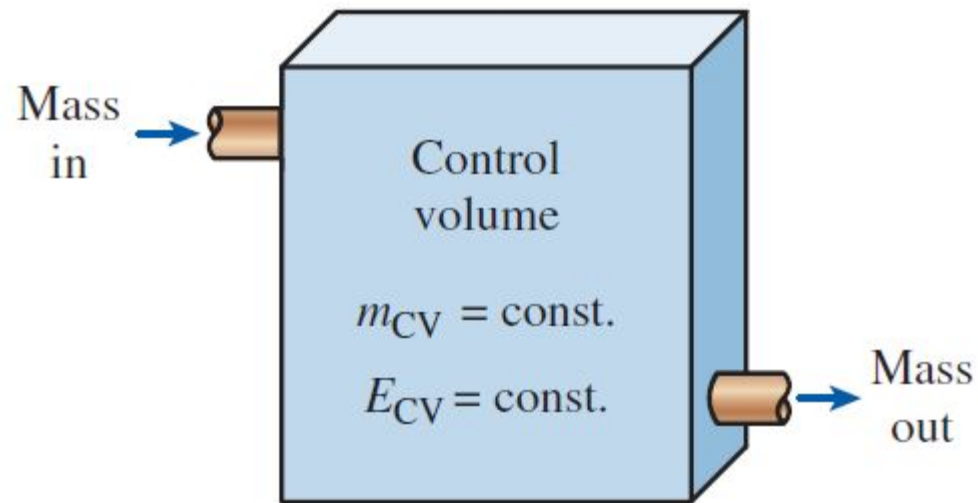
- The term *steady* implies *no change with time*. The opposite of steady is *unsteady*, or *transient*.
- A large number of engineering devices operate for long periods of time under the same conditions, and they are classified as *steady-flow devices*.
- **Steady-flow process:** A process during which a fluid flows through a control volume steadily.
- Steady-flow conditions can be closely approximated by devices that are intended for continuous operation such as **turbines, pumps, boilers, condensers, and heat exchangers or power plants or refrigeration systems.**



**FIGURE 1–32**

During a steady-flow process, fluid properties within the control volume may change with position but not with time.



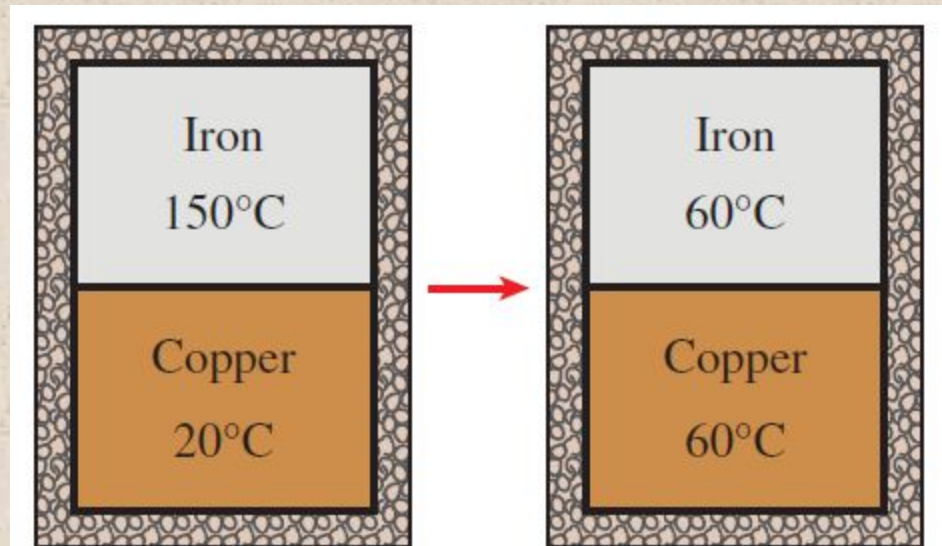


**FIGURE 1–33**

Under steady-flow conditions, the mass and energy contents of a control volume remain constant.

# TEMPERATURE AND THE ZEROth LAW OF THERMODYNAMICS

- **The zeroth law of thermodynamics:** If two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other.
- 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.*



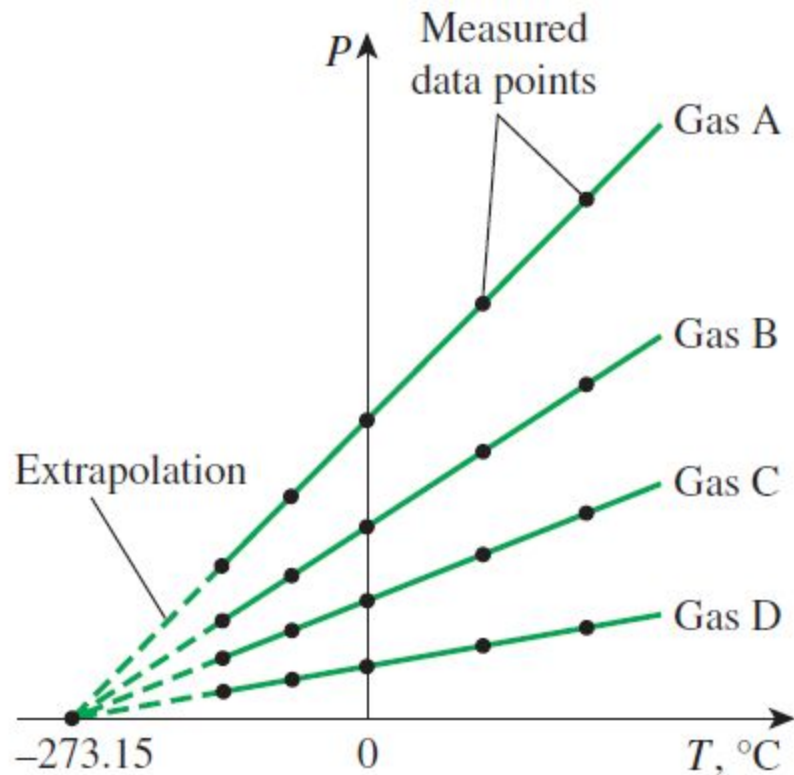
**FIGURE 1–34**

Two bodies reaching thermal equilibrium after being brought into contact in an isolated enclosure.

# Temperature Scales

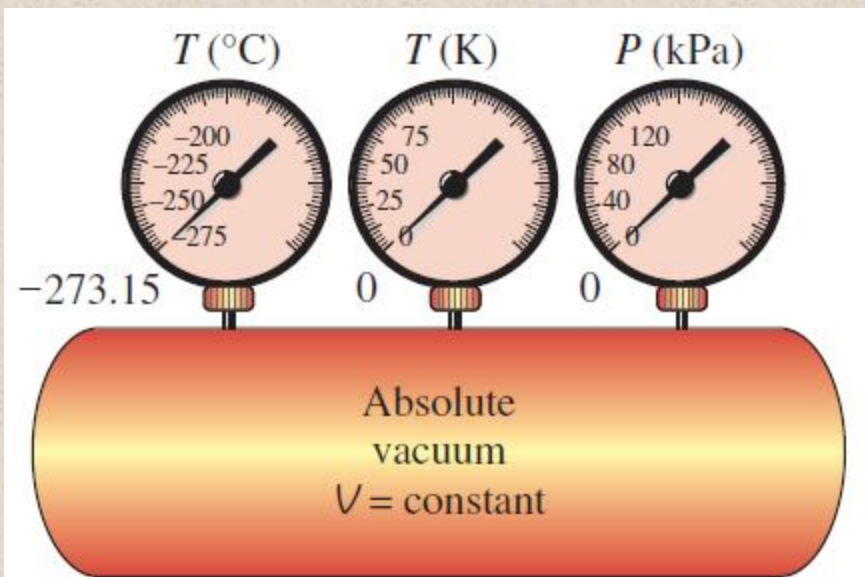
- All temperature scales are based on some easily reproducible states such as the freezing and boiling points of water: the *ice point* and the *steam point*.
- **Ice point:** A mixture of ice and water that is in equilibrium with air saturated with vapor at 1 atm pressure (0°C or 32°F).
- **Steam point:** A mixture of liquid water and water vapor (with no air) in equilibrium at 1 atm pressure (100°C or 212°F).
- **Celsius scale:** in SI unit system
- **Fahrenheit scale:** in English unit system
- **Thermodynamic temperature scale:** A temperature scale that is independent of the properties of any substance.
- **Kelvin scale** (SI) **Rankine scale** (E)
- A temperature scale nearly identical to the Kelvin scale is the **ideal-gas temperature scale**. The temperatures on this scale are measured using a **constant-volume gas thermometer**.





**FIGURE 1-35**

$P$  versus  $T$  plots of the experimental data obtained from a constant-volume gas thermometer using four different gases at different (but low) pressures.



**FIGURE 1-36**

A constant-volume gas thermometer would read  $-273.15^\circ\text{C}$  at absolute zero pressure.

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

$$T(\text{R}) = T(^{\circ}\text{F}) + 459.67$$

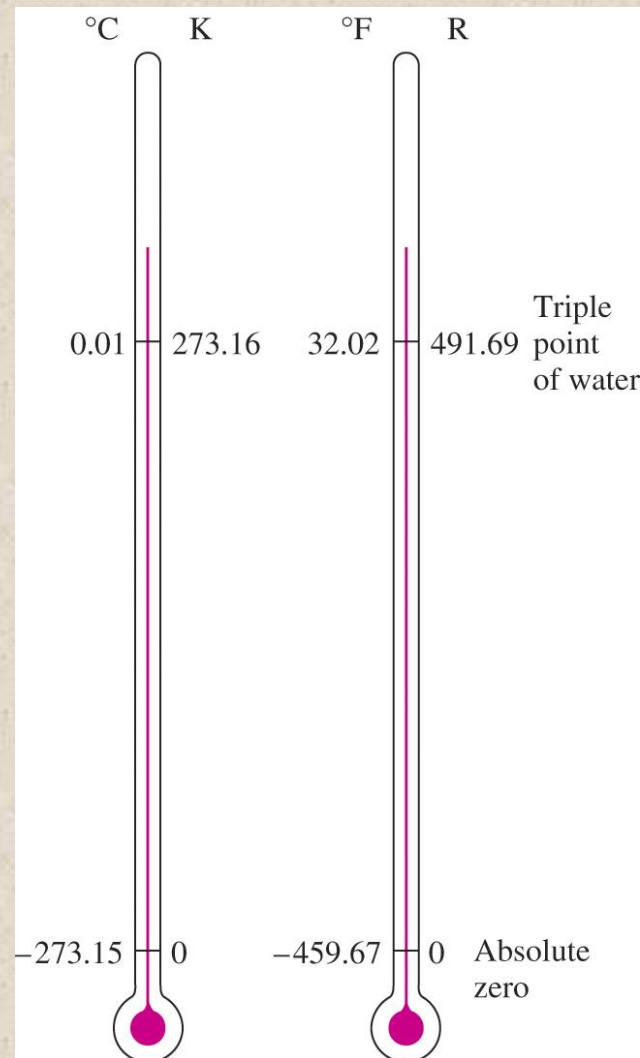
$$T(\text{R}) = 1.8T(\text{K})$$

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

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

$$\Delta T(\text{R}) = \Delta T(^{\circ}\text{F})$$

Comparison of  
temperature  
scales.



Comparison of  
magnitudes of  
various  
temperature  
units.

- The reference temperature in the original Kelvin scale was the **ice point**, 273.15 K, which is the temperature at which water freezes (or ice melts).
- The reference point was changed to a much more precisely reproducible point, the **triple point** of water (the state at which all three phases of water coexist in equilibrium), which is assigned the value 273.16 K.

# The International Temperature Scale of 1990 (ITS-90)

The *International Temperature Scale of 1990* supersedes the International Practical Temperature Scale of 1968 (**IPTS-68**), 1948 (**IPTS-48**), and 1927 (**ITS-27**).

The ITS-90 is similar to its predecessors except that it is more refined with updated values of fixed temperatures, has an extended range, and conforms more closely to the thermodynamic temperature scale.

On this scale, the unit of thermodynamic temperature  $T$  is again the kelvin (K), defined as the fraction  $1/273.16$  of the thermodynamic temperature of the triple point of water, which is sole defining fixed point of both the ITS-90 and the Kelvin scale and is the most important thermometric fixed point used in the calibration of thermometers to ITS-90. The unit of Celsius temperature is the degree Celsius ( $^{\circ}\text{C}$ ).

The ice point remains the same at  $0^{\circ}\text{C}$  (273.15 K) in both ITS-90 and IPTS-68, but the steam point is  $99.975^{\circ}\text{C}$  in ITS-90 whereas it was  $100.000^{\circ}\text{C}$  in IPTS-68.

The change is due to precise measurements made by gas thermometry by paying particular attention to the effect of sorption (the impurities in a gas absorbed by the walls of the bulb at the reference temperature being desorbed at higher temperatures, causing the measured gas pressure to increase).



# PRESSURE

**Pressure:** A normal force exerted by a fluid per unit area

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

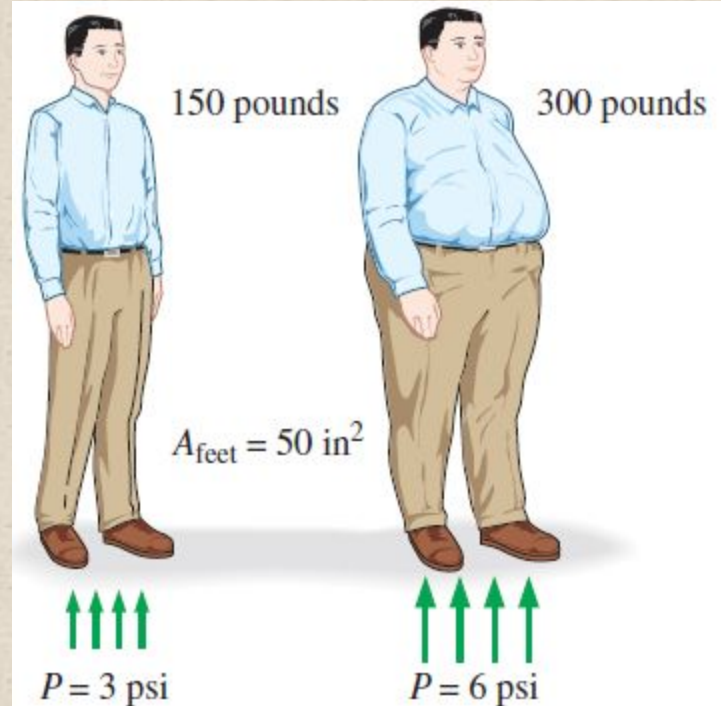
$$1 \text{ bar} = 10^5 \text{ Pa} = 0.1 \text{ MPa} = 100 \text{ kPa}$$

$$1 \text{ atm} = 101,325 \text{ Pa} = 101.325 \text{ kPa} = 1.01325 \text{ bars}$$

$$\begin{aligned} 1 \text{ kgf/cm}^2 &= 9.807 \text{ N/cm}^2 = 9.807 \times 10^4 \text{ N/m}^2 = 9.807 \times 10^4 \text{ Pa} \\ &= 0.9807 \text{ bar} \\ &= 0.9679 \text{ atm} \end{aligned}$$



Some basic pressure gages.



$$P = \sigma_n = \frac{W}{A_{\text{feet}}} = \frac{150 \text{ lbf}}{50 \text{ in}^2} = 3 \text{ psi}$$

**FIGURE 1–39**

The normal stress (or “pressure”) on the feet of a chubby person is much greater than on the feet of a slim person.

- **Absolute pressure:** The actual pressure at a given position. It is measured relative to absolute vacuum (i.e., absolute zero pressure).
- **Gage pressure:** The difference between the absolute pressure and the local atmospheric pressure. Most pressure-measuring devices are calibrated to read zero in the atmosphere, and so they indicate gage pressure.
- **Vacuum pressures:** Pressures below atmospheric pressure.

Throughout this text, the pressure ***P*** will denote **absolute pressure** unless specified otherwise.

