Thermodynamics: An Engineering Approach
8th Edition
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CHAPTER 1
INTRODUCTION AND BASIC CONCEPTS

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Objectives

- Introduction to thermodynamics
- Review of dimensions and units
- Understand the basic concepts and definitions of:
  - ✓ system
  - ✓ state
  - ✓ state postulate
  - ✓ equilibrium
  - ✓ process
  - ✓ cycle
- Define properties of a system
  - ✓ intensive
  - ✓ extensive
- Review concepts of temperature, temperature scales
- Review concepts of pressure: absolute and gage pressure

THERMODYNAMICS AND ENERGY

- The name ***thermodynamics*** stems from the Greek words *therme* (heat) and *dynamis* (power) → heat to power
- **Thermodynamics:** the science of *energy transformation*
- **Energy:** the ability to cause changes

- Examples of energy transformations: one form to another
  - ✓ Conversion of electrical energy into mechanical energy (electric mixer)
  - ✓ Conversion of electrical energy into thermal energy (electric heater)

THERMODYNAMICS vs. HEAT TRANSFER

- Thermodynamics provides answer to question of *"how much"* but not *"how fast"* an energy transformation will take place
- For example: if we know the temperature drop of an iron rod between two time instances, we can find out the amount of heat loss from the rod the from thermodynamics principles

- However, to find out the amount of heat loss in a given time duration we use principles of heat transfer

FUNDAMENTAL LAWS OF NATURE

- **The first law of thermodynamics:** Energy cannot be created or destroyed; it can only change forms
- **The second law of thermodynamics:** Processes occur in a certain direction

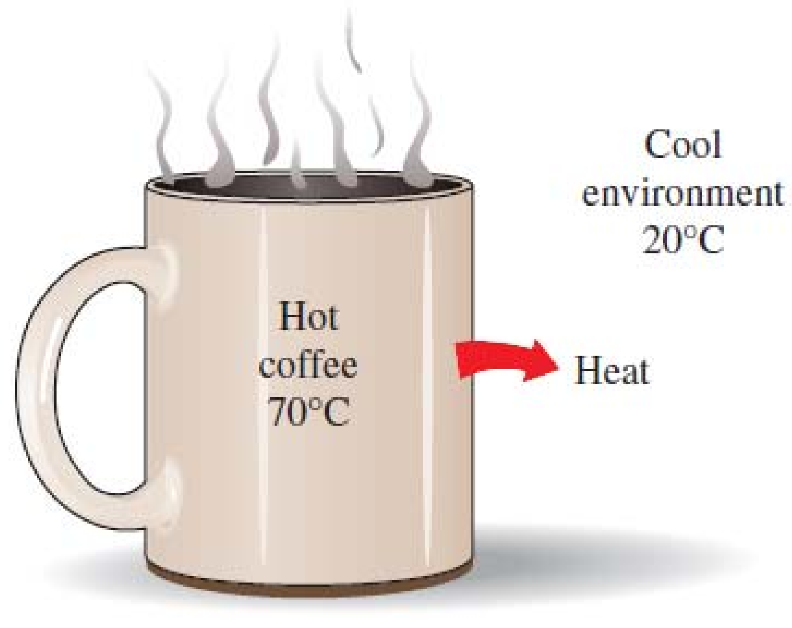


FIGURE 1–3
Heat flows in the direction of decreasing temperature. **(the second law)**

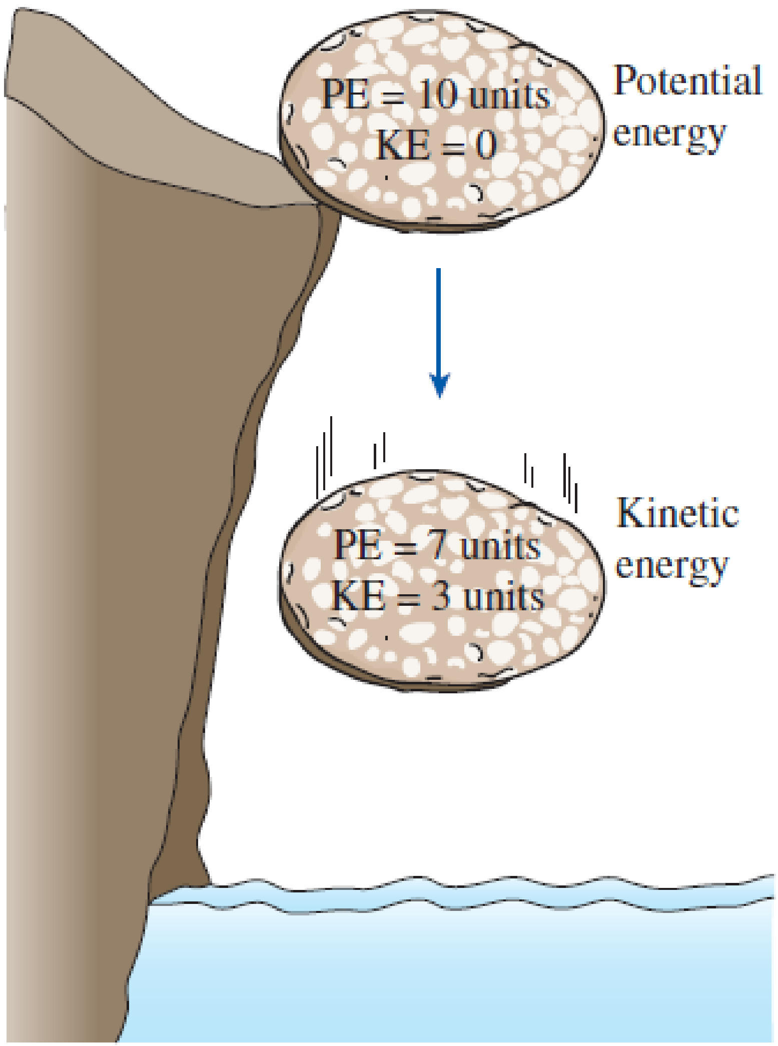


FIGURE 1–1
Energy cannot be created or destroyed; it can only change forms (the first law).

Macroscopic vs. Microscopic Approach

- **Classical thermodynamics**: A macroscopic approach to the study of thermodynamics that does not require a knowledge of the behavior of individual particles
- It provides a direct and easy way to the solution of engineering problems and **it is used in this course**
- **Statistical thermodynamics**: A microscopic approach, based on the average behavior of large groups of individual particles
- It is used in this course only in the supporting role

Application Areas of Thermodynamics

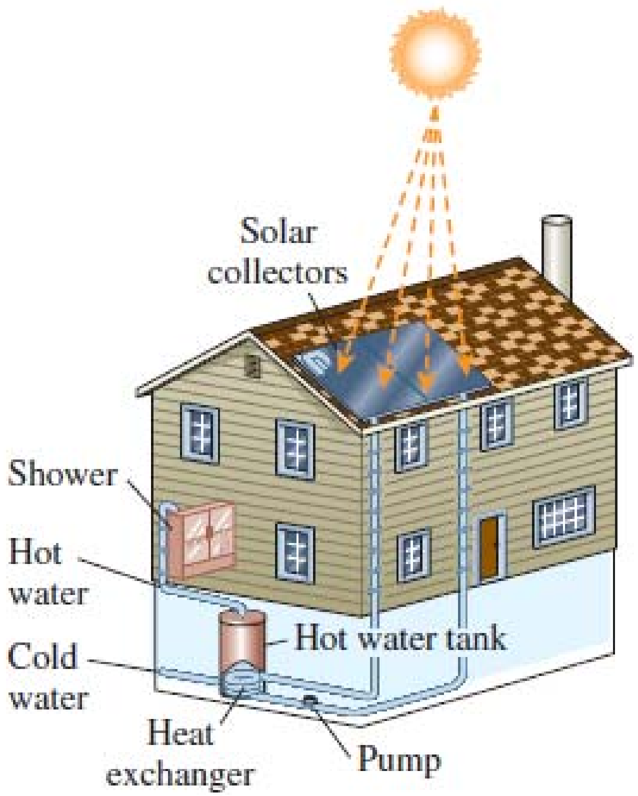
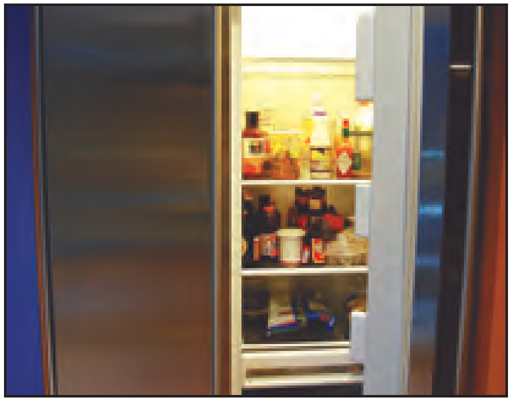


FIGURE 1–4
The design of many engineering systems, such as this solar hot water system, involves thermodynamics.



Refrigerator
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Boats
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Aircraft and spacecraft
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Power plants
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- In all the examples above energy is changing its form
- In aircraft / power plants heat is converted to work
- In refrigerator work input it required to transfer heat from low (refrigerated space) to high (room) temperature

Application Areas of Thermodynamics

Human body

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Cars

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Wind turbines

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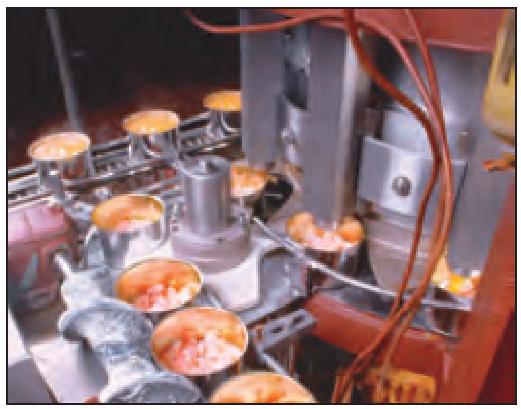

Food processing

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A piping network in an industrial facility.

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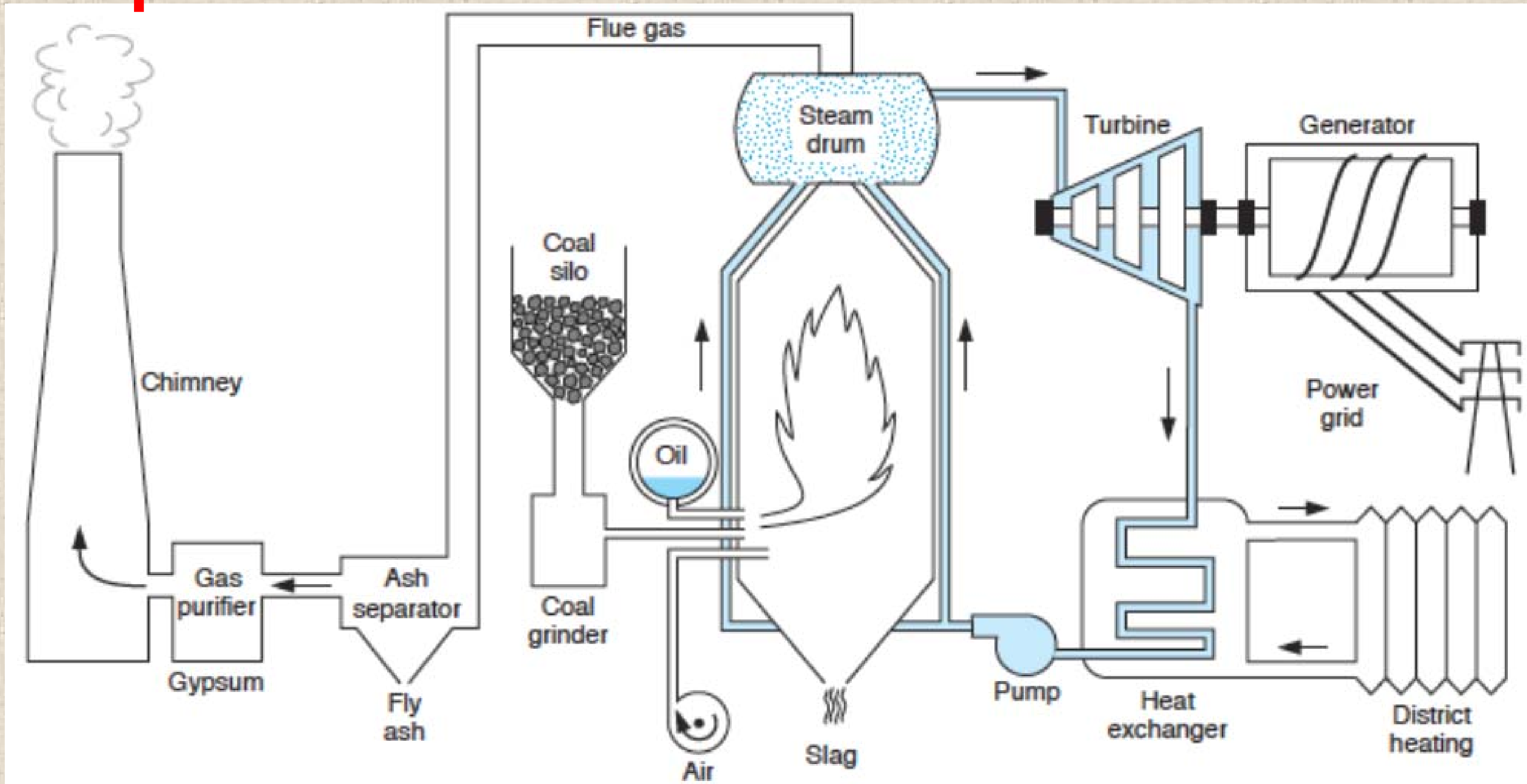
- It is hard to imagine an area that does not relate to thermodynamics in some manner

Example: Steam Power Plant



- Some questions to which the answer lie in thermodynamics:
  - ✓ What is the rate of coal consumption (kg/s) for generating 1 kW of electricity
  - ✓ What will be the temperature of gases inside the furnace?
  - ✓ How does the state of steam change after turning the turbine?
  - ✓ How much heat is available for “District heating” as the steam cools in the heat exchanger

DIMENSIONS AND UNITS

- Any physical quantity can be characterized by **dimensions**
- **Primary** or **fundamental dimensions:** mass *m*, length *L*, time *t*, temperature *T etc…*
- **Secondary dimensions**, or **derived dimensions:** volume *V*, energy *E,* velocity *V etc…* are expressed in terms of the primary dimensions
- The magnitudes assigned to the dimensions are called **units**
- **Metric SI system**: A simple and logical system based on a decimal relationship between the various units (e.g. 1 cm = 10 mm), **we will use SI units**
- **English system**: It has no apparent systematic numerical base, and various units in this system are related to each other rather arbitrarily (e.g. 1 feet = 12 inches), we will not use English units in this course

Primary Units

TABLE 1–1

The seven fundamental (or primary) dimensions and their units in SI

Dimension	Unit
Length	meter (m)
Mass	kilogram (kg)
Time	second (s)
Temperature	kelvin (K)
Electric current	ampere (A)
Amount of light	candela (cd)
Amount of matter	mole (mol)

SI unit prefixes

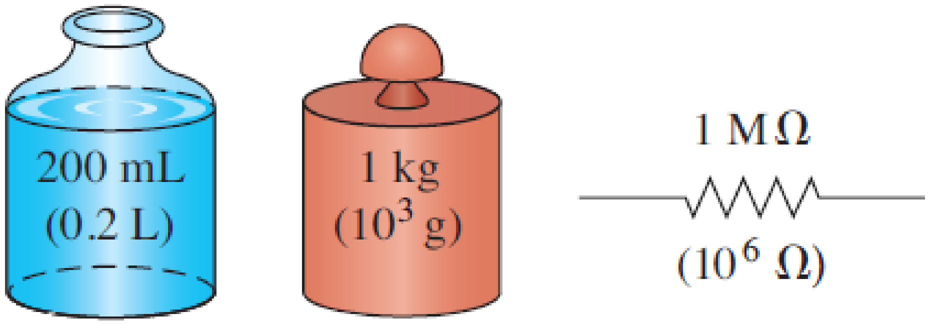


FIGURE 1–6
The SI unit prefixes are used in all branches of engineering.

TABLE 1–2
Standard prefixes in SI units

Multiple	Prefix
10^{24}	yotta, Y
10^{21}	zetta, Z
10^{18}	exa, E
10^{15}	peta, P
10^{12}	tera, T
10^{9}	giga, G
10^{6}	mega, M
10^{3}	kilo, k
10^{2}	hecto, h
10^{1}	deka, da
10^{-1}	deci, d
10^{-2}	centi, c
10^{-3}	milli, m
10^{-6}	micro, μ
10^{-9}	nano, n
10^{-12}	pico, p
10^{-15}	femto, f
10^{-18}	atto, a
10^{-21}	zepto, z
10^{-24}	yocto, y

Weight

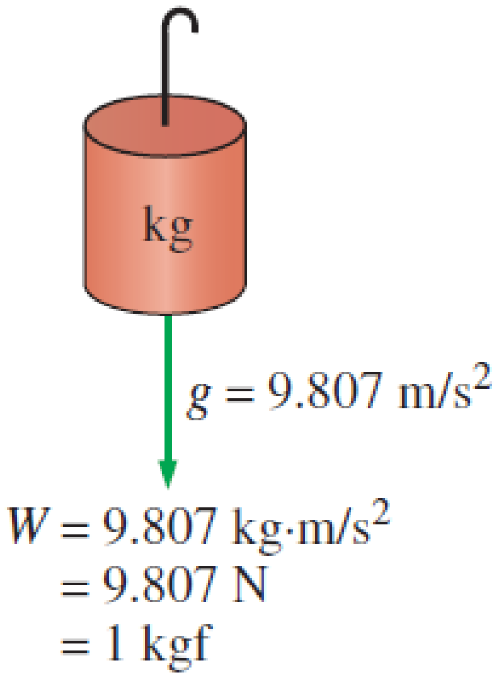


FIGURE 1–10

The weight of a unit mass at sea level.

$$W = mg \qquad \text{(N)}$$

W weight
m mass
g gravitational acceleration

FIGURE 1–9

A body weighing 68 kgf on earth will weigh only 11.3 kgf the moon.

- Another *force* unit in common use is *kilogram-force (kgf)*, which is the *weight* of 1 kg mass as sea level (1kgf = 9.807 N)
- Unlike mass *weight is a force*

- This kind of weighing scale measures the force and not mass, hence on moon it will show lower reading (of force)

Secondary Units

- Just as all secondary dimensions can be formed by suitable combinations of primary dimensions, all secondary units can be formed by combinations of primary units

Force = Mass × Acceleration

$1\ N = kg \cdot m/s^2$

unit of force is: newton (N) (and not Newton)

Work = Force × Distance

$1\ J = 1\ N \cdot m$

$1\ J = 1\ kg \cdot m^2/s^2$

unit of work is: joule (J) (and not Joule)

Power = Work / Time

$1\ W = 1\ J/s$

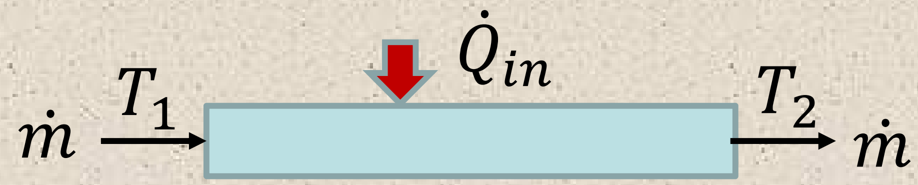
$1\ W = 1\ N \cdot m/s$

$1\ W = 1\ kg \cdot m^2/s^3$

unit of power is: watt (W) (and not Watt)

Dimensional homogeneity

- All equations must be dimensionally **homogeneous**
- That is every term in the equation must have the same unit
- Checking dimensions can serve as a valuable tool to spot errors



$$\underbrace{\dot m}_{\text{mass flow rate}} \underbrace{c_p}_{\text{specific heat}} \underbrace{(T_2 - T_1)}_{\text{temperature difference}} = \underbrace{\dot Q_{in}}_{\text{heat rate}}$$

$$\left(\frac{\cancel{kg}}{s}\right)\left(\frac{J}{\cancel{kg}-\cancel{K}}\right)(\cancel{K}) = (W)$$

$$\left(\frac{J}{s}\right) = \left(\frac{J}{s}\right)$$

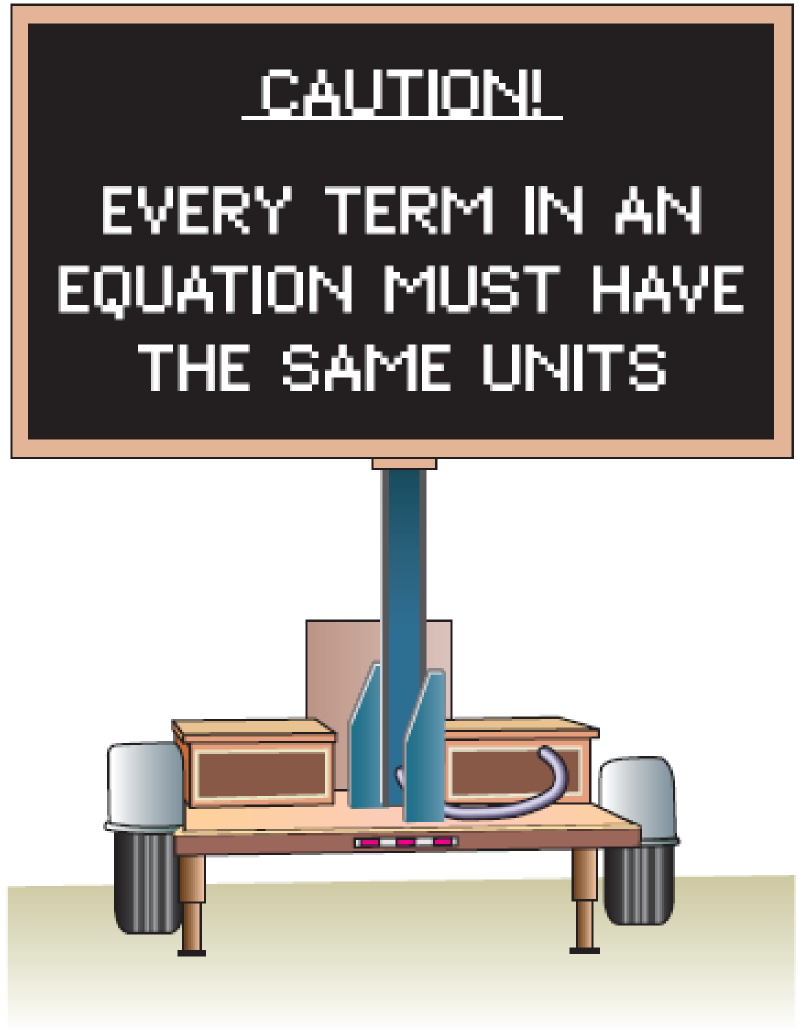


FIGURE 1–14
Always check the units in your calculations.

SYSTEMS AND CONTROL VOLUMES

- **System**: A *fixed amount of mass* or a *region in space* chosen for study
- **Surroundings**: The mass or region outside the system
- **Boundary**: The *real* or *imaginary* surface that separates the system from its surroundings, and it has *zero thickness* (i.e., zero mass or volume)

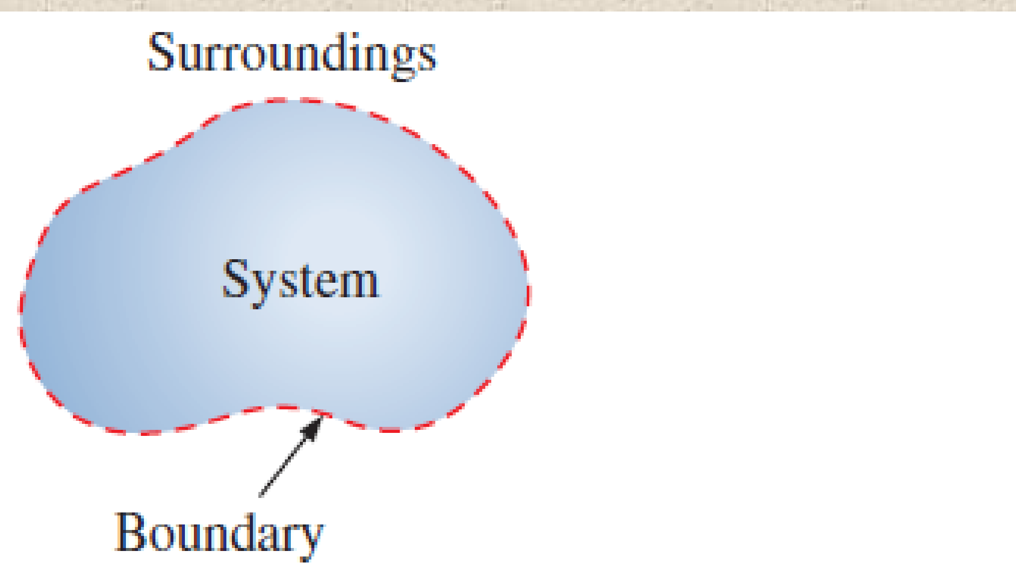


FIGURE 1–18
System, surroundings, and boundary.

- The boundary of a system can be *fixed* or *movable*
- *We will apply the laws of thermodynamics on a system and carefully choosing the system can considerably simplify the solution*

Closed System

- Systems may be considered to be *closed* or *open*.
- **Closed system (Control mass):**
  - ✓ A *fixed amount of mass*, and no mass can cross its boundary
  - ✓ Energy (heat and work) can cross its boundary
  - ✓ Volume may change (if boundary is not fixed)
- **Isolated system:**
  - ✓ Special case of closed system
  - ✓ Neither mass nor energy can cross its boundary

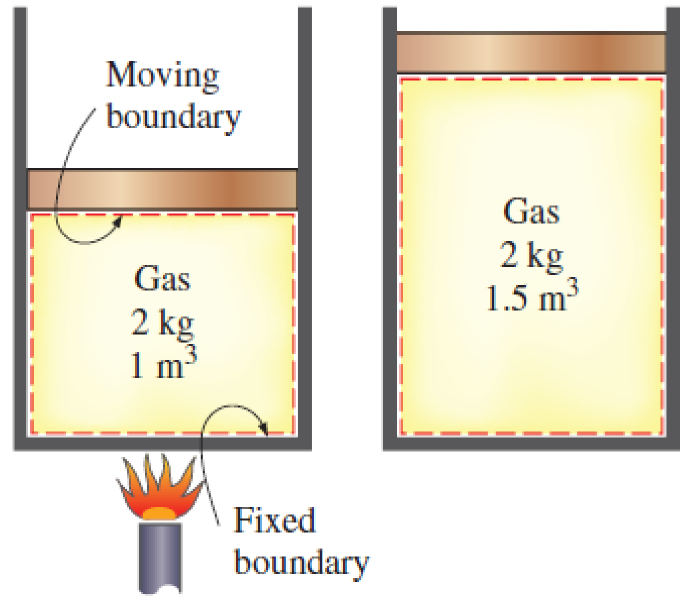


FIGURE 1–20
A closed system with a moving boundary.

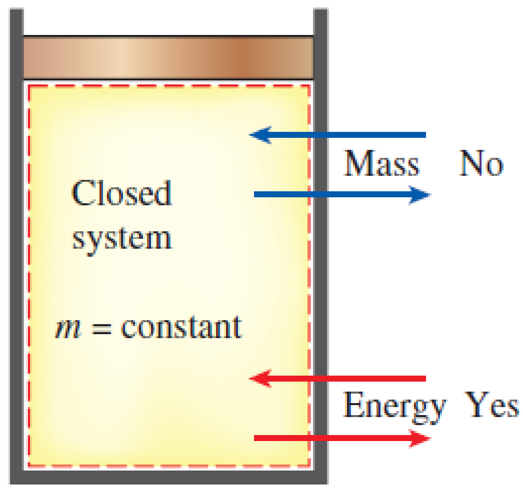
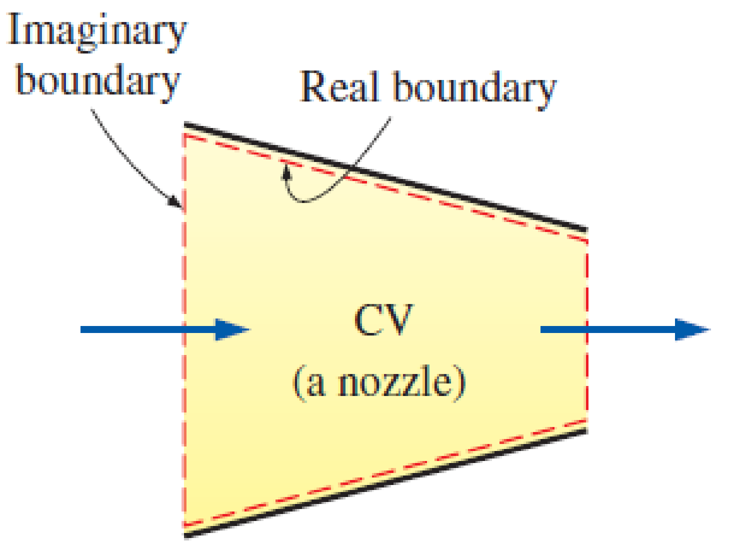
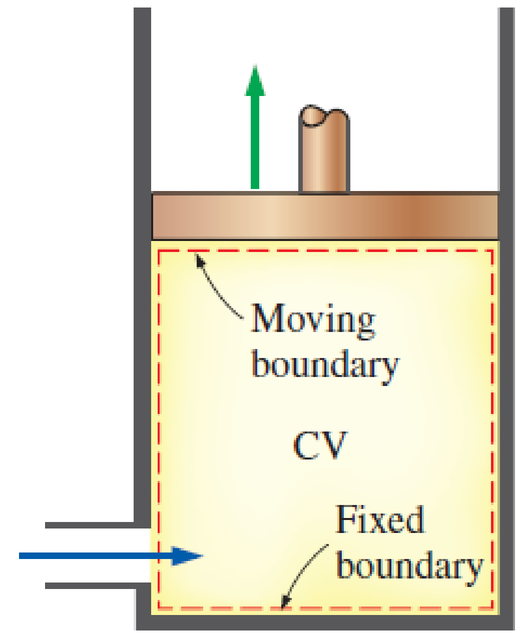


FIGURE 1–19
Mass cannot cross the boundaries of a closed system, but energy can.

- **Open system (control volume):**
  - ✓ A properly selected *region* in space
  - ✓ It usually encloses a device that involves *mass flow* such as a compressor, turbine, or nozzle
  - ✓ Both mass and energy can cross the boundary of a control volume
- **Control surface:**
  - ✓ The boundary of a control volume
  - ✓ It can be real or imaginary
  - ✓ It can be fixed (more common) or moving
- Any arbitrary region can be selected as control volume, though *proper choice makes the analysis easier*



(*a*) A control volume (CV) with real and imaginary boundaries

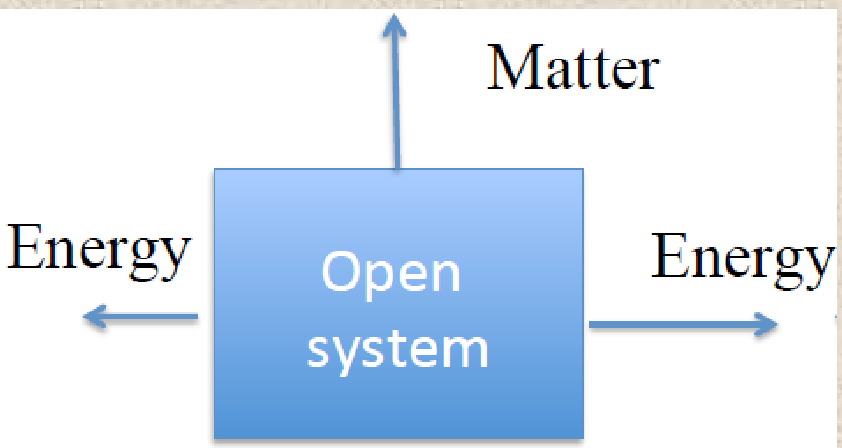


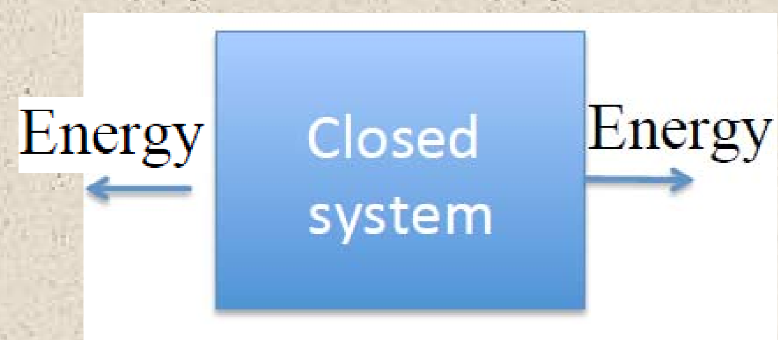
(*b*) A control volume (CV) with fixed and moving boundaries as well as real and imaginary boundaries

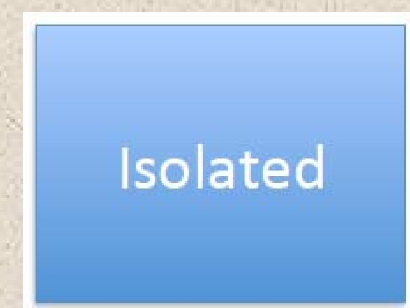
Open

Closed

Isolated







PROPERTIES OF A SYSTEM

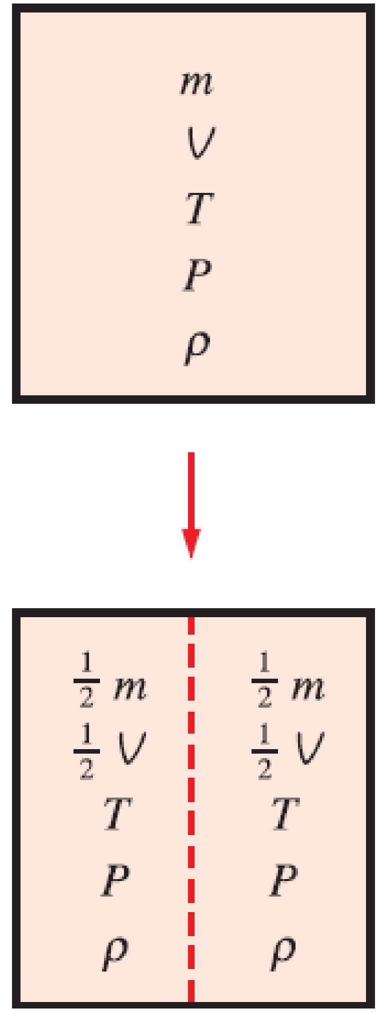
- **Property:** Any characteristic of a system
- Some familiar properties are:
  - ✓ pressure P
  - ✓ temperature T
  - ✓ volume V
  - ✓ mass m
- The list can be extended:
  - ✓ velocity
  - ✓ momentum
  - ✓ elevation
  - ✓ density
  - ✓ viscosity
  - ✓ energy
- Essential features of a property are:
  - ✓ A property should have a definite value when the system is in a particular state
  - ✓ The value of the property should be determinable irrespective of how the system is brought to that particular state

INTENSIVE EXTENSIVE AND SPECIFIC PROPERTIES

- Properties are considered to be either *intensive* or *extensive*
- **Intensive properties:** Those that are independent of the mass of a system, e.g. temperature, pressure, and density
- **Extensive properties:** Those whose values depend on the size—or extent—of the system, e.g. total mass, total volume, total momentum, total energy
- **Specific properties:** Extensive properties per unit mass

$(v = V/m)$ specific volume

$(e = E/m)$ specific energy



Divide the system into two equal parts, each part will have same value of intensive properties as the original system, but half the value of the extensive property

Extensive properties

Intensive properties

FIGURE 1–23

Criterion to differentiate intensive and extensive properties.

Continuum

- Matter is made up of atoms/molecules that are widely spaced: view it as a continuous, homogeneous matter with no voids, 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*

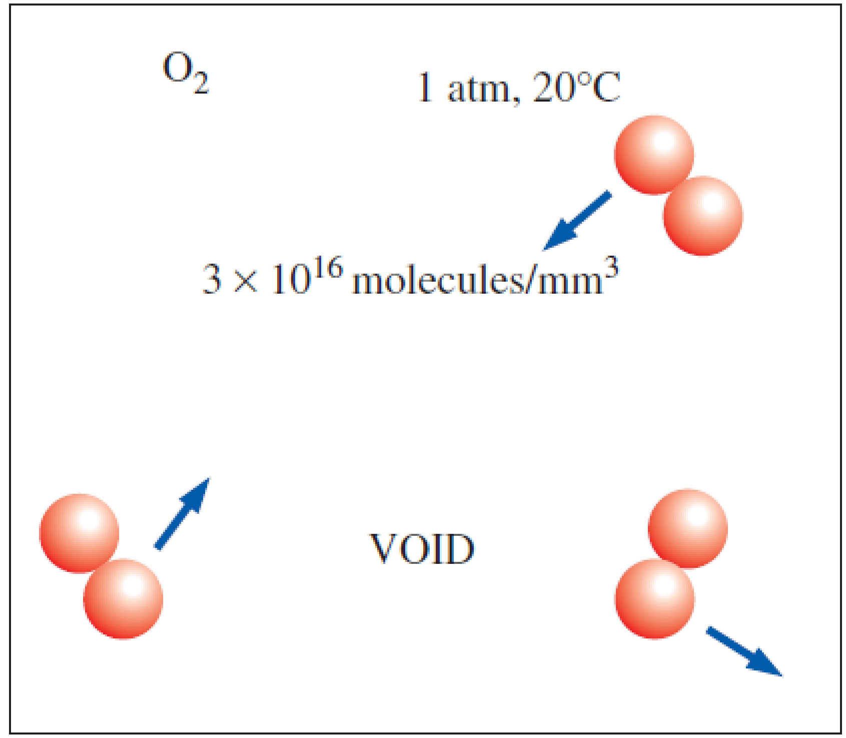


FIGURE 1–24
Despite the relatively large gaps between molecules, a gas can usually be treated as a continuum because of the very large number of molecules even in an extremely small volume.

DENSITY AND SPECIFIC VOLUME

Density

$$\rho = \frac{m}{V} \qquad (\mathrm{kg/m^3})$$

Density is mass per unit volume

Specific volume

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

Specific volume is volume per unit mass

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

$\downarrow$

$\rho = 0.25\ \mathrm{kg/m^3}$
$v = \frac{1}{\rho} = 4\ \mathrm{m^3/kg}$

- Specific volume is an *intensive property* of the corresponding extensive property: volume

SPECIFIC GRAVITY

Specific gravity:
or Relative density: $$SG = \frac{\rho}{\rho_{H_2O}}$$

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

- Specific gravity is not a "specific" property as defined

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 OF A SYSTEM

- Consider a (closed) system at a particular instant of time. At this time, all the properties can be measured or calculated throughout the entire system, which gives us a set of properties (at every location) that completely describes the condition, or the ***state***, of the system
- At a given state, all the properties (at every location) of the system have fixed values
- If the value of even one property (at any location) changes, the state will change to a different one

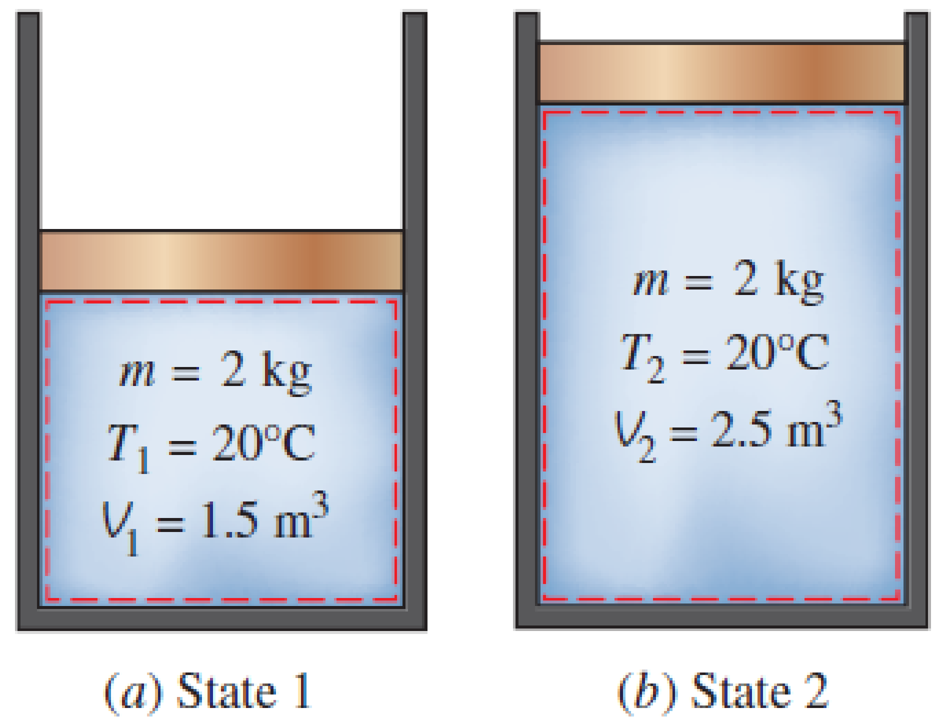
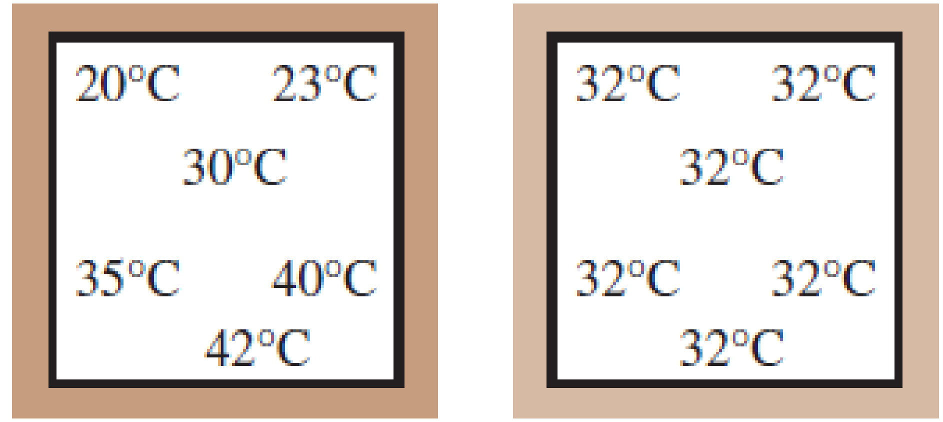


FIGURE 1–26
A system at two different states.

EQUILIBRIUM STATE

- **Equilibrium:** A state of balance, in an equilibrium state there are no unbalanced potentials (or driving forces) within the system
- If you leave a system for infinitely long time it will eventually reach the equilibrium state
- **Thermodynamics deals with *equilibrium* states**
- Henceforth, unless otherwise specified, “state” means “equilibrium state”

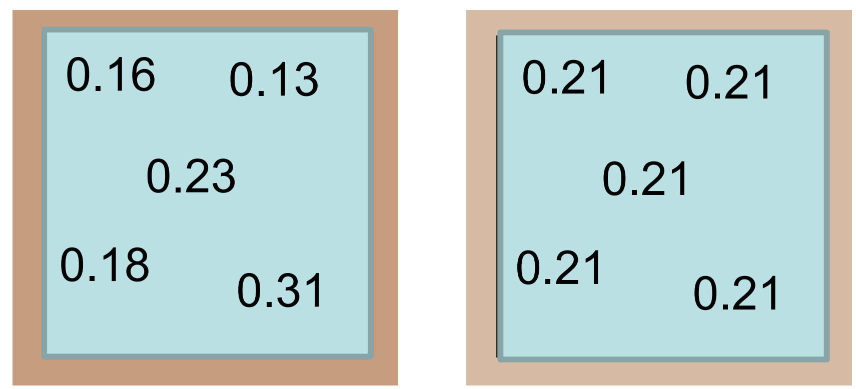


(*a*) Before (*b*) After

uniform temperature

FIGURE 1–27

A closed system reaching thermal equilibrium.



(*a*) Before (*b*) After

uniform concentration

O_2 mole fraction in mixture of (O_2+N_2)

THERMODYNAMIC EQUILIBRIUM

- **Thermal equilibrium:** temperature is the same throughout the entire system (*uniform temperature*; no temperature gradients; no driving force for heat flow)
- **Mechanical equilibrium:** no change in pressure at any point in the system with time (pressure can change within the system with elevation due to gravity) (in absence of external force fields we will have *uniform pressure*; no pressure gradients; no driving force for fluid flow)
- **Phase equilibrium:** in a multiphase system, when the total mass of each phase in the system does not change with time
- **Chemical equilibrium:** if the chemical composition of a system does not change with time, i.e., *no chemical reactions* occur. Also the chemical composition is homogeneous (*uniform species concentration;* i.e. no driving force for diffusion)
- **Thermodynamic equilibrium:** thermal & mechanical & phase & chemical equilibrium

The State Postulate

- We do not need to specify all the properties in order to fix a (equilibrium) state, once a sufficient number of properties are specified, the rest of the properties assume certain values automatically
- The number of properties required to fix the (equilibrium) 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*

FIGURE 1–28
The state of nitrogen is fixed by two independent, intensive properties.

Simple Compressible System

- **Simple compressible system:** If a system involves no electrical, magnetic, gravitational, motion, and surface tension effects. These effects are due to *external force fields* and are negligible for most engineering problems
- Otherwise, an *additional property* needs to be specified for each effect that is significant, e.g. if gravitational effects are to be considered, the elevation “z” needs to be specified in addition
- In this course we will mostly deal with “simple compressible system”

Independent Properties

- **Independent Properties:** Two properties specified are independent if one property can be varied while the other one is held constant
- Temperature and pressure are independent properties of single-phase systems, but are dependent for multiphase system (at $P = 1$ atm water boils at 100 °C but at $P = 2$ atm it boils at 120 °C)
- Temperature and specific volume are always independent properties

PROCESS AND PATH

- **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 (*not useful for non-equilibrium 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

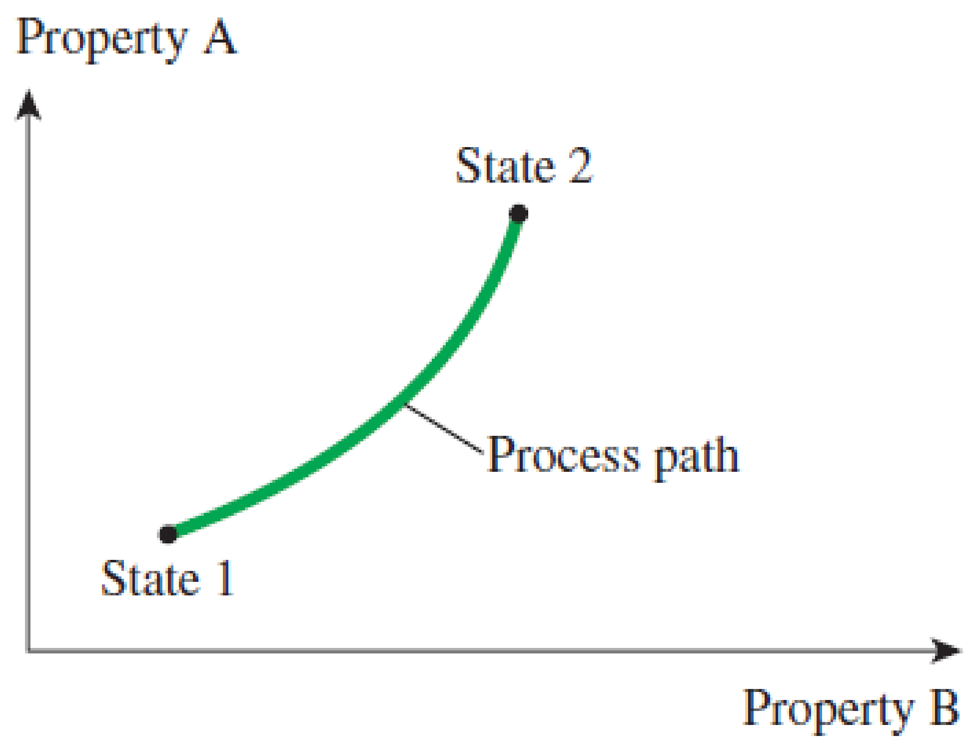


FIGURE 1–29

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

QUASI-EQUILIBRIUM PROCESS

- **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
- It 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
- It is an idealized process and easy to analyze, and many actual processes closely approximate it

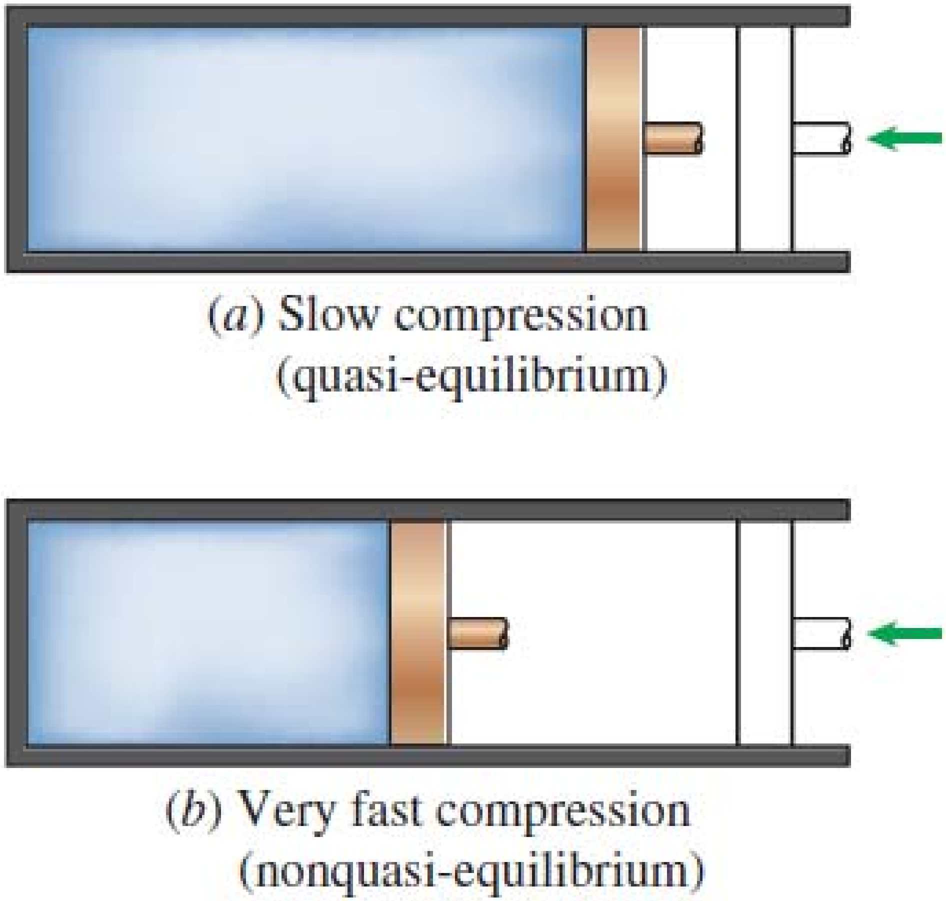


FIGURE 1–30
Quasi-equilibrium and nonquasi-equilibrium compression processes.

PROCESS DIAGRAMS

- 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*)
- Note that as two properties are required to fix the state of a system, hence, each point on the process diagram corresponds to a particular state of the system

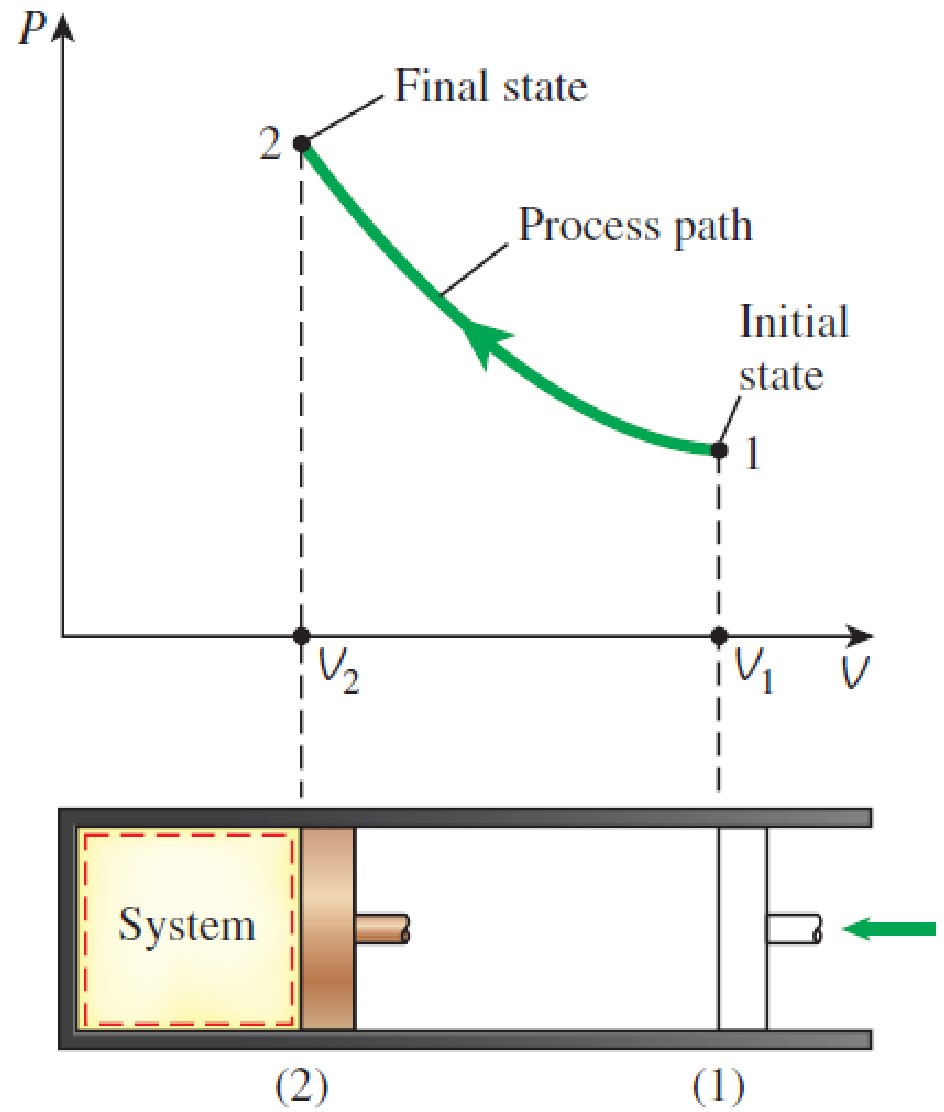
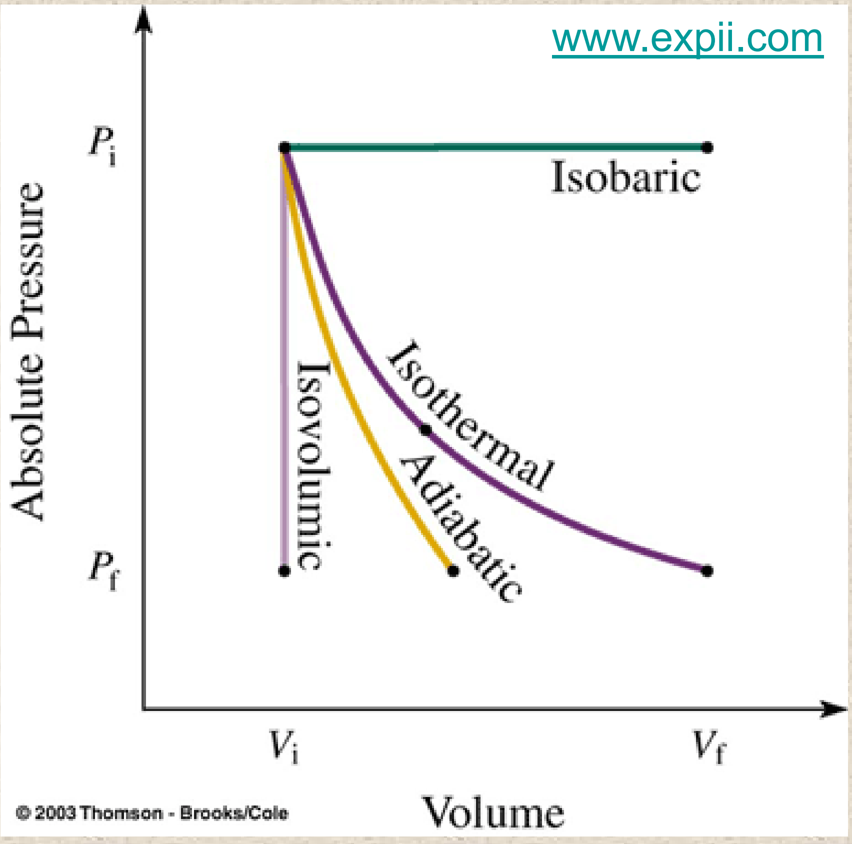
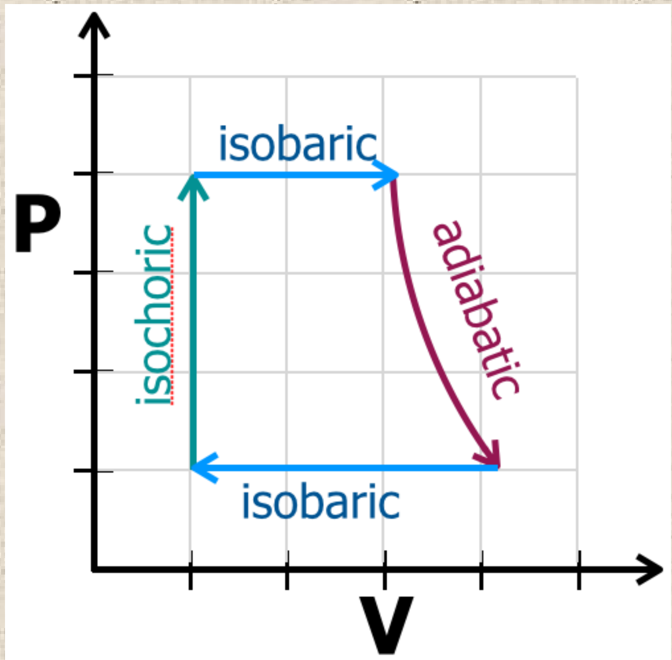


FIGURE 1–31
The *P*-*V* diagram of a compression process.

TYPES OF PROCESSES

- 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





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The Steady-Flow Process

- The term *steady* implies *no change with time*
- The term *uniform* implies no change with location over a specified region
- **Steady-flow process**: A process during which a fluid flows through a control volume steadily
- During a steady-flow process, fluid properties within the control volume *may change with location but not with time* (at a particular location)

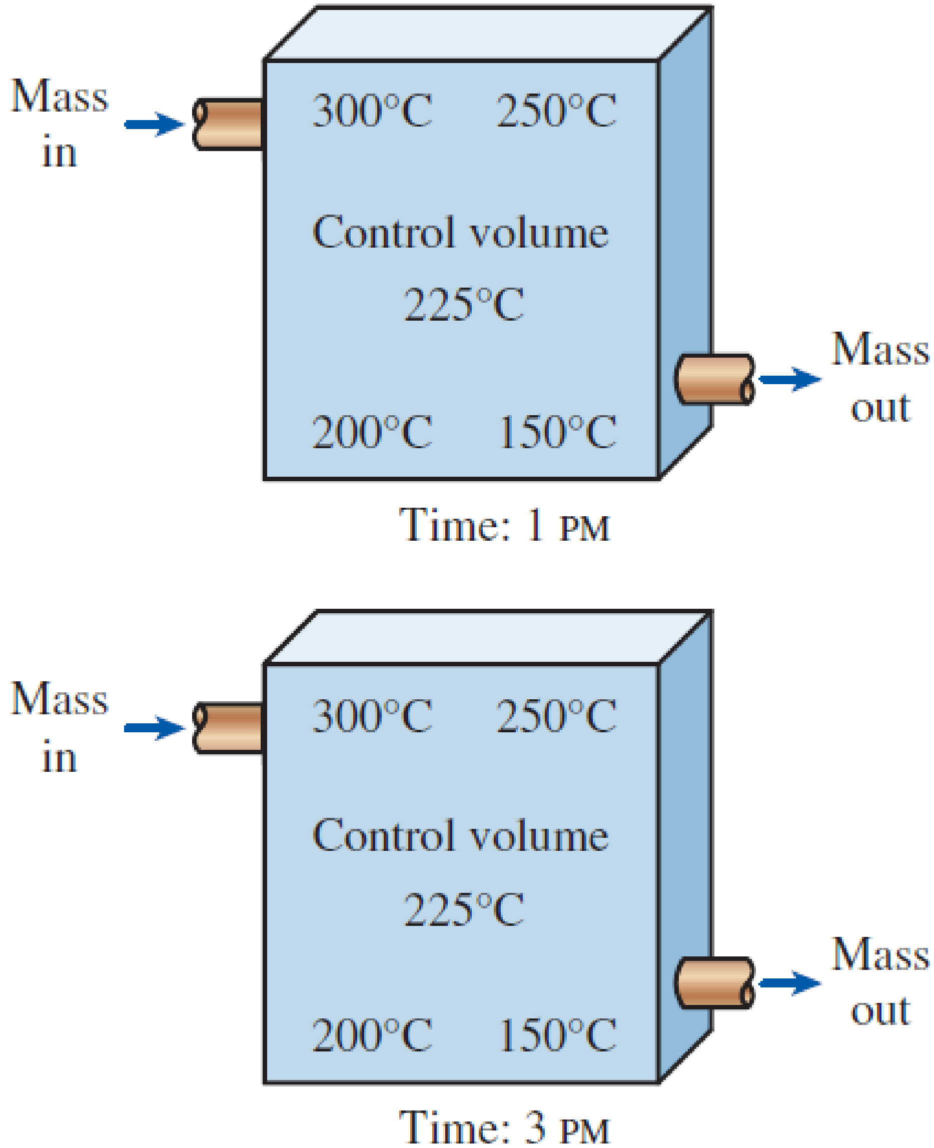


FIGURE 1–32

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

The Steady-Flow Devices

- 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*

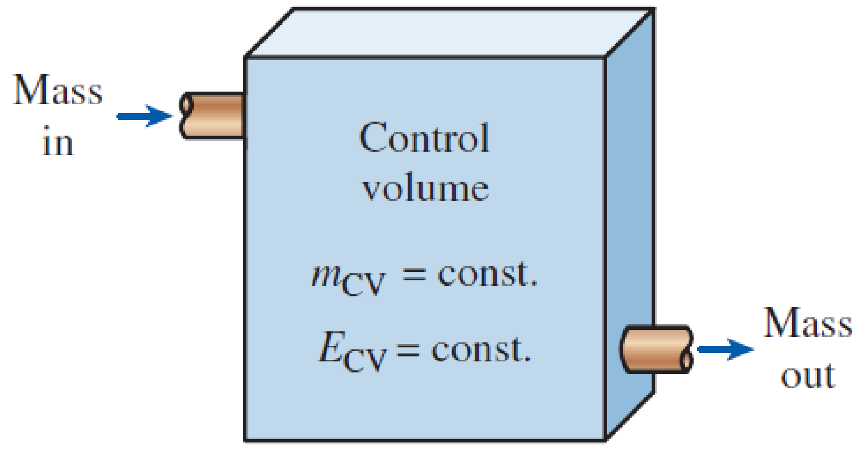
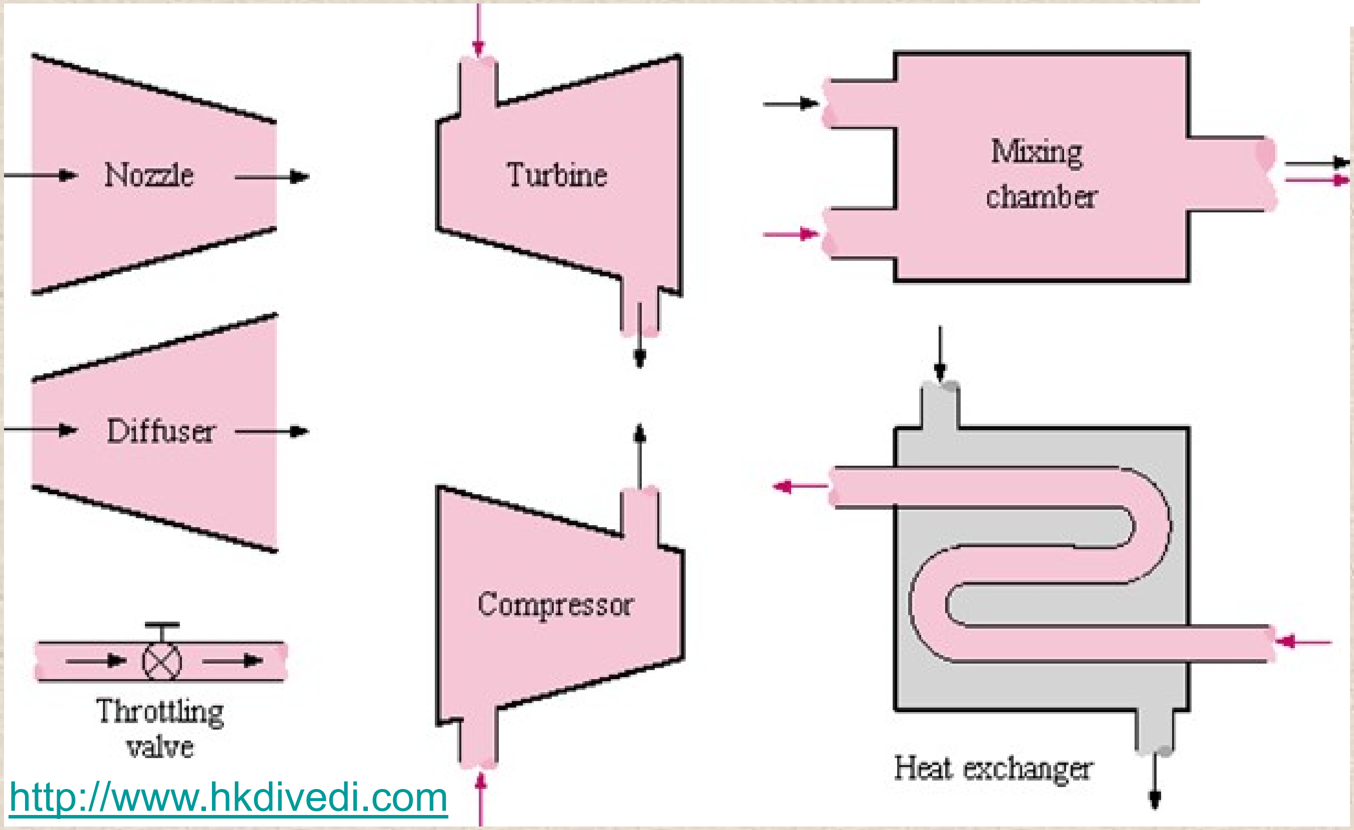


FIGURE 1–33
Under steady-flow conditions, the mass and energy contents of a control volume remain constant.



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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*
- It serves as a basis for the validity of temperature measurement

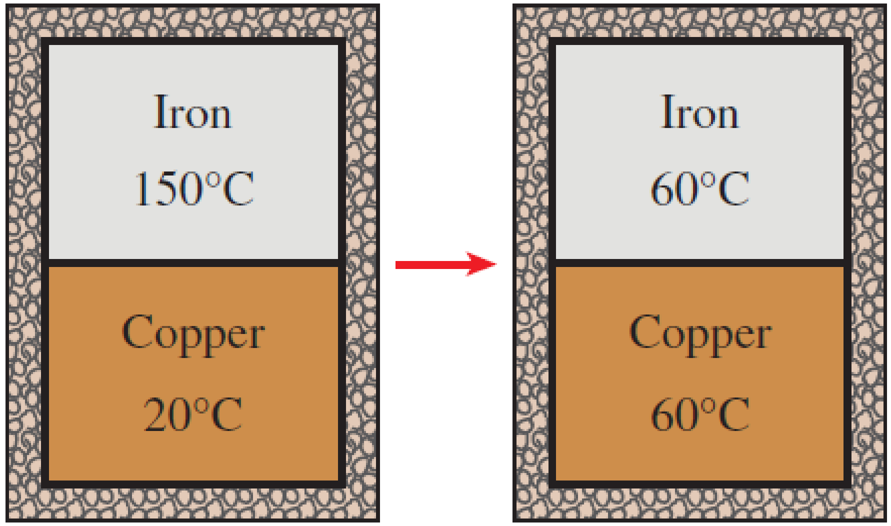


FIGURE 1–34
Two bodies reaching thermal equilibrium after being brought into contact in an isolated enclosure.

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).
- **Steam point**: A mixture of liquid water and water vapor (with no air) in equilibrium at 1 atm pressure (100 °C)
- **Celsius scale**: Two point scale in SI unit system (°C)
- **Thermodynamic temperature scale**: A temperature scale that is independent of the properties of any substance.
- **Kelvin scale:** SI unit system (K and not °K). The lowest temperature on the Kelvin scale is absolute zero, or 0 K, so it needs only one nonzero reference point

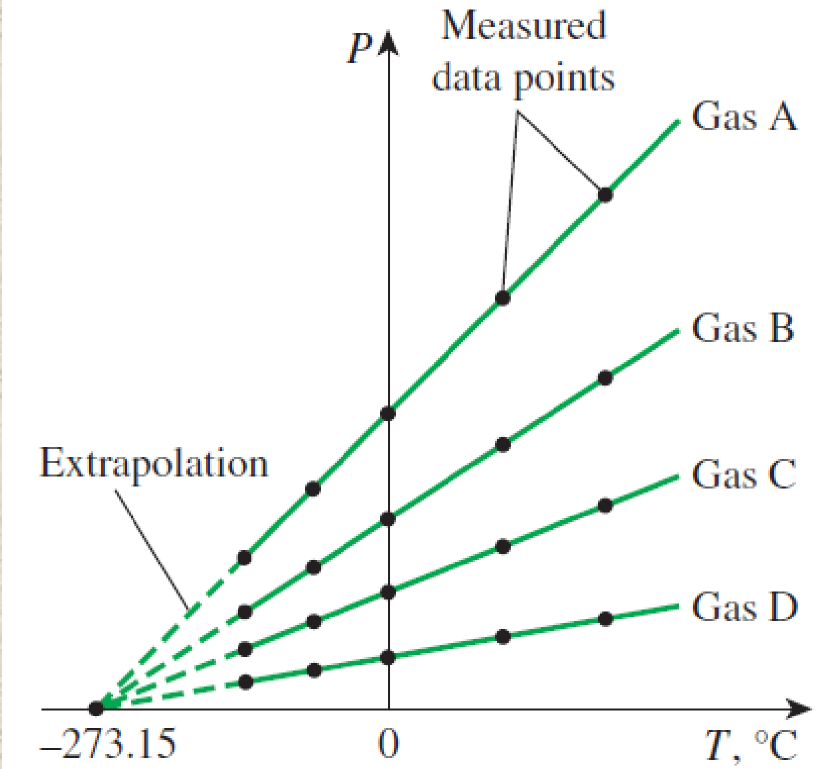


FIGURE 1–35

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

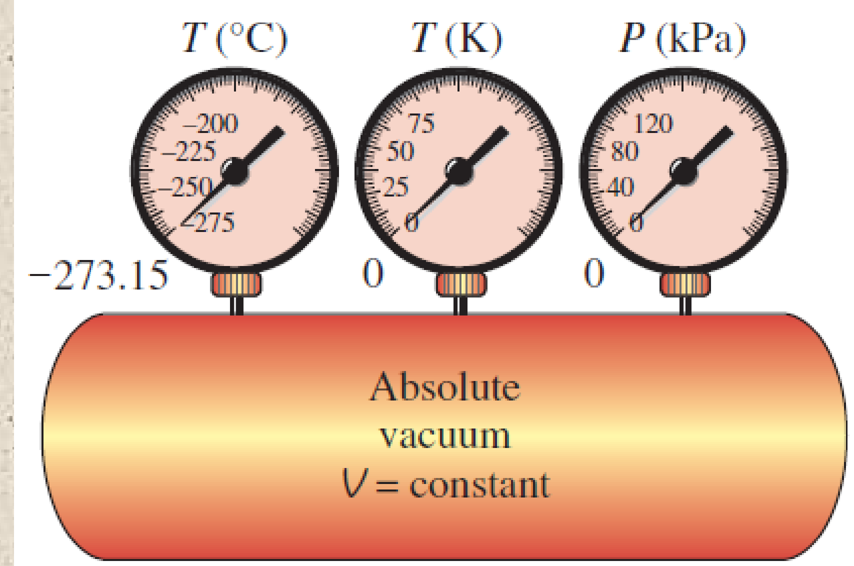


FIGURE 1–36

A constant-volume gas thermometer would read −273.15°C at absolute zero pressure.

$T = a + bP$

$$\left.\begin{array}{l}\text{Celsius scale: } a = -273.15\ ^\circ\text{C} \\ \text{Kelvin scale: } a = 0\ \text{K}\end{array}\right\}\ \text{both have same b}$$

- If the ice and steam points are assigned values 0 °C and 100 °C, respectively, then the gas temperature scale will be identical to the Celsius scale
- In Kelvin scale temperature would read 0 K at absolute zero pressure $T(\text{K}) = T(^\circ\text{C}) + 273.15$ $\quad \Delta T(\text{K}) = \Delta T(^\circ\text{C})$

PRESSURE

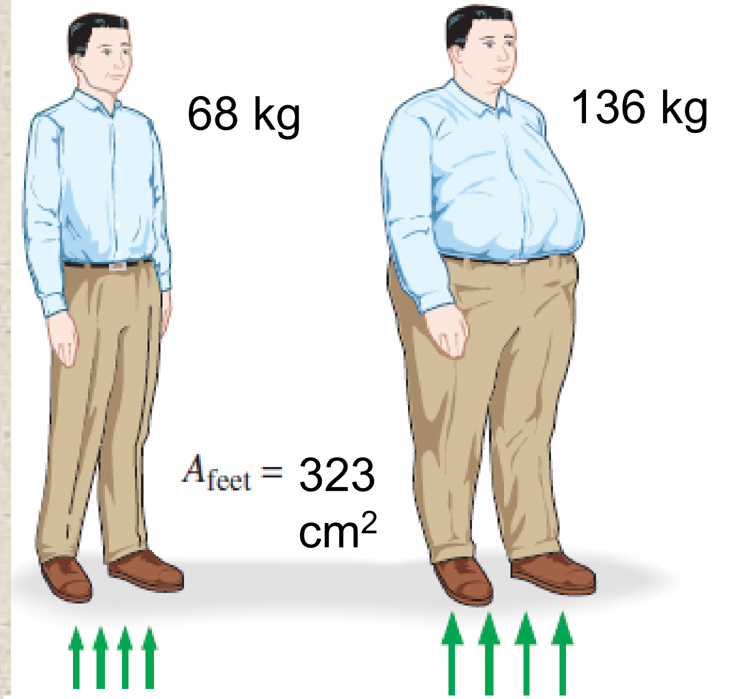
- **Pressure**: A normal force exerted by a fluid per unit area
- We speak of pressure only when we deal with a gas or a liquid
- The counterpart of pressure in solids is *normal stress*

unit: pascal (Pa)

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

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

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



$2.07\ N/cm^2$ $\quad$ $4.14\ N/cm^2$

$$P = \sigma_n = \frac{W}{A_{\text{feet}}} = \frac{68\times 9.81}{323} = 2.07\,\frac{N}{cm^2}$$

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.

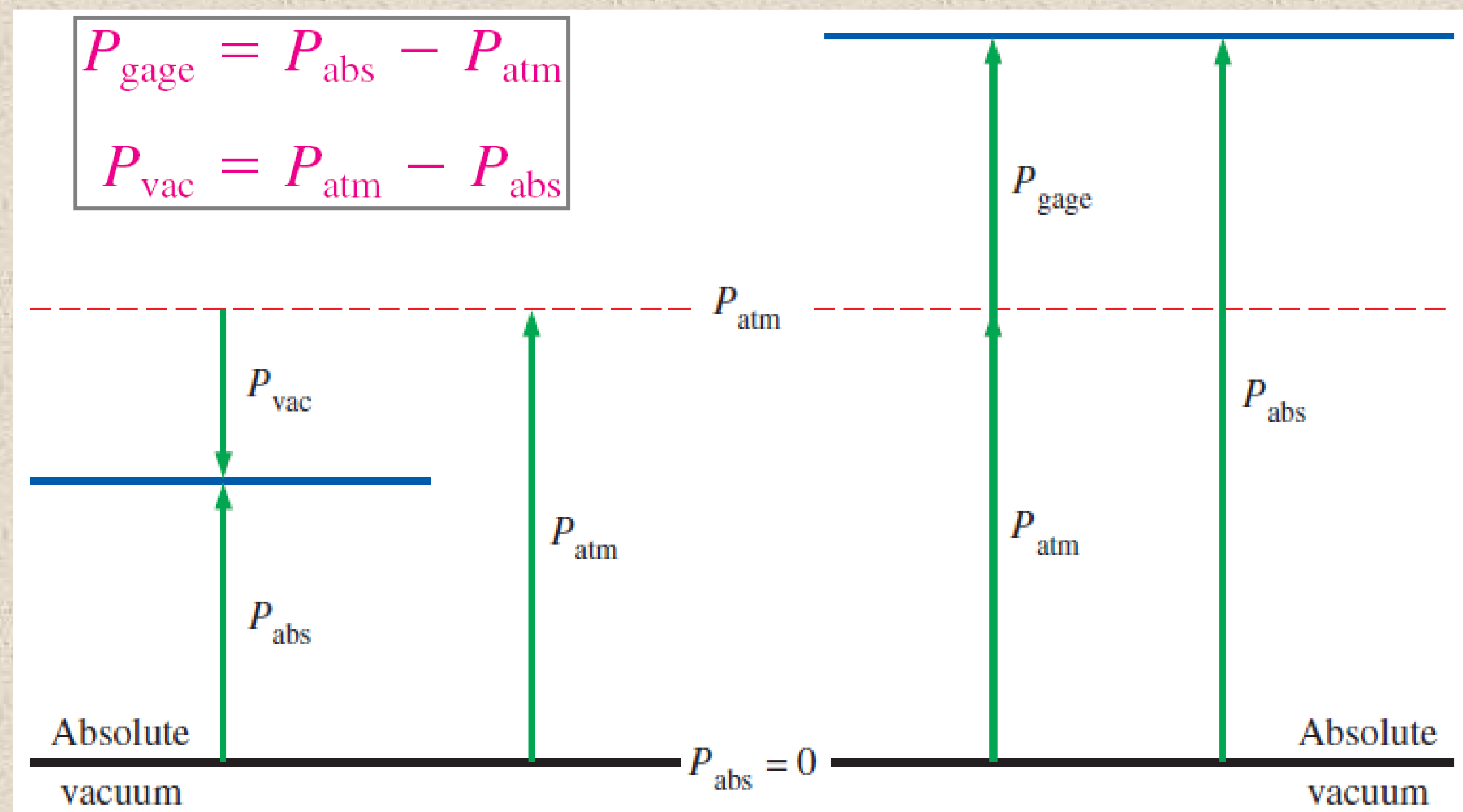
- The pressure unit pascal is too small for pressures encountered in practice, therefore multiples kilopascal (1 kPa = 10^3 Pa) and megapascal (1 Mpa = 10^6 Pa), or bar and standard atmosphere (atm) are commonly used

- **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.

$$P_{gage} = P_{abs} - P_{atm}$$

$$P_{vac} = P_{atm} - P_{abs}$$



Variation of Pressure with Depth

Force balance in the z direction:

$$P_1\,\Delta x\,\Delta y - P_2\,\Delta x\,\Delta y - \rho g\,\Delta x\,\Delta y\,\Delta z = 0$$

$$P_2 - P_1 = -\rho g\,\Delta z$$

when the variation of density with elevation is known

$$\frac{dP}{dz} = -\rho g$$

$$P_2 - P_1 = -\int_1^2 \rho g\,dz$$

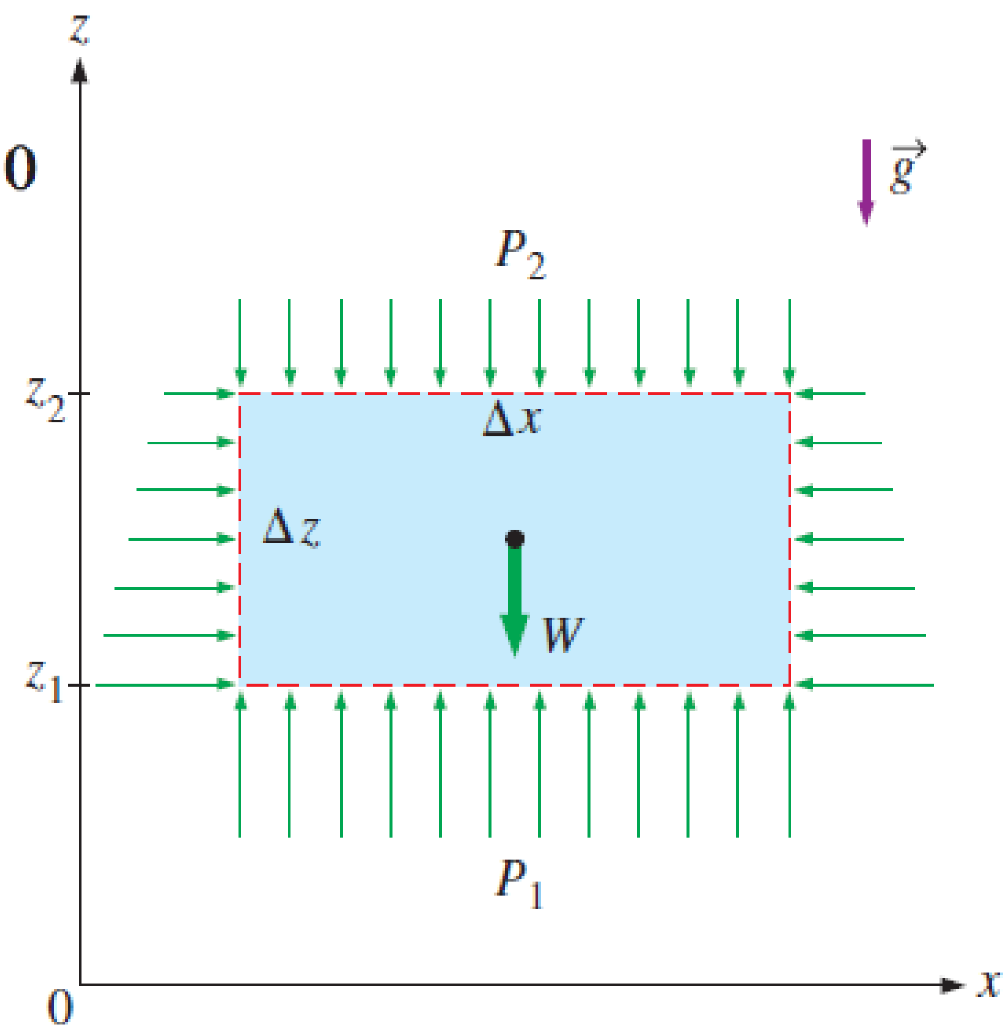


FIGURE 1–43

Free-body diagram of a rectangular fluid element in equilibrium.

Variation of Pressure with Depth

$$P = P_{\text{atm}} + \rho g h$$

$$P_{\text{gage}} = \rho g h$$

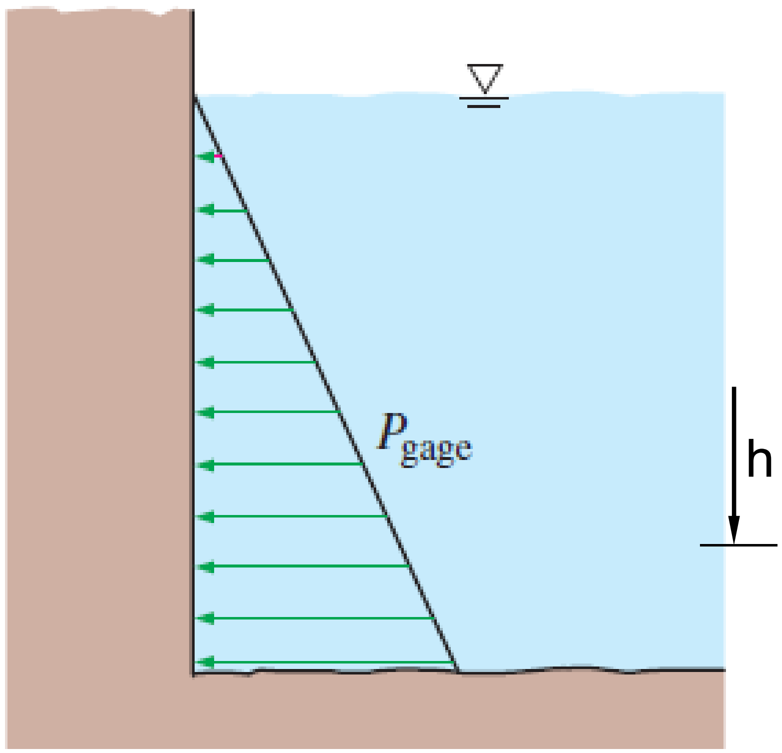


FIGURE 1–42
The pressure of a fluid at rest increases with depth (as a result of added weight).

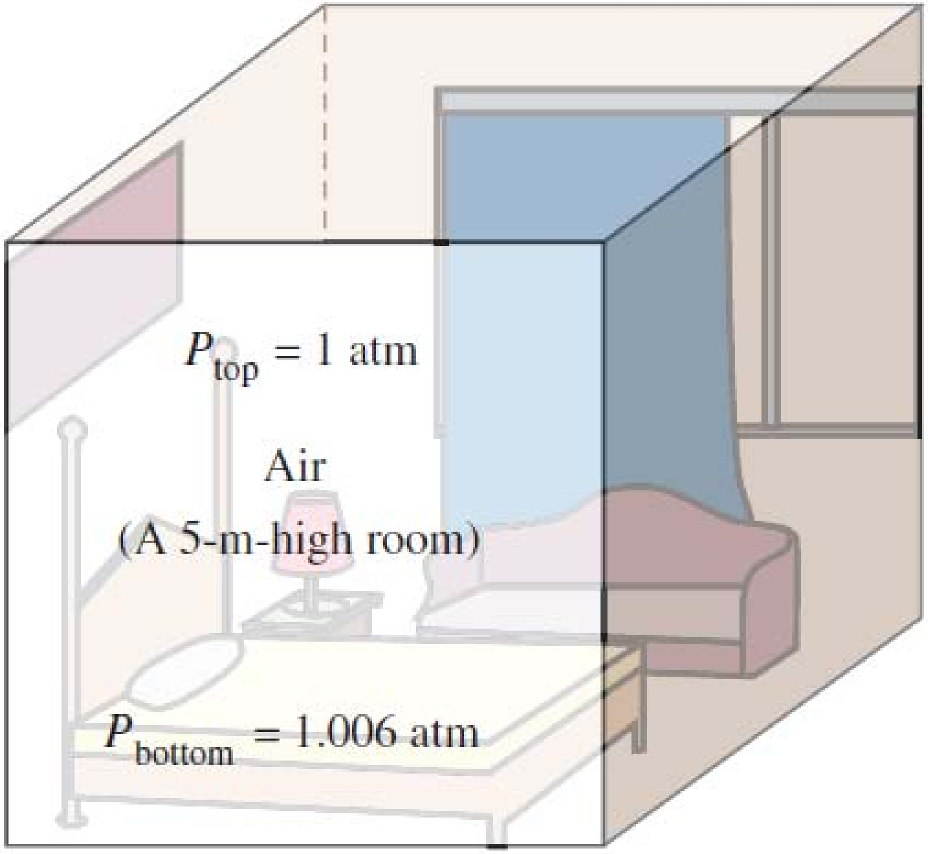


FIGURE 1–44
In a room filled with a gas, the variation of pressure with height is negligible.

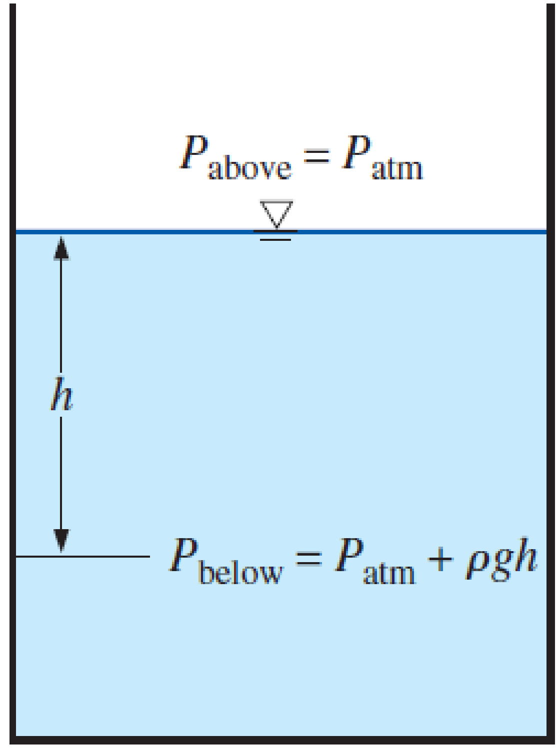


FIGURE 1–45
Pressure in a liquid at rest increases linearly with distance from the free surface.

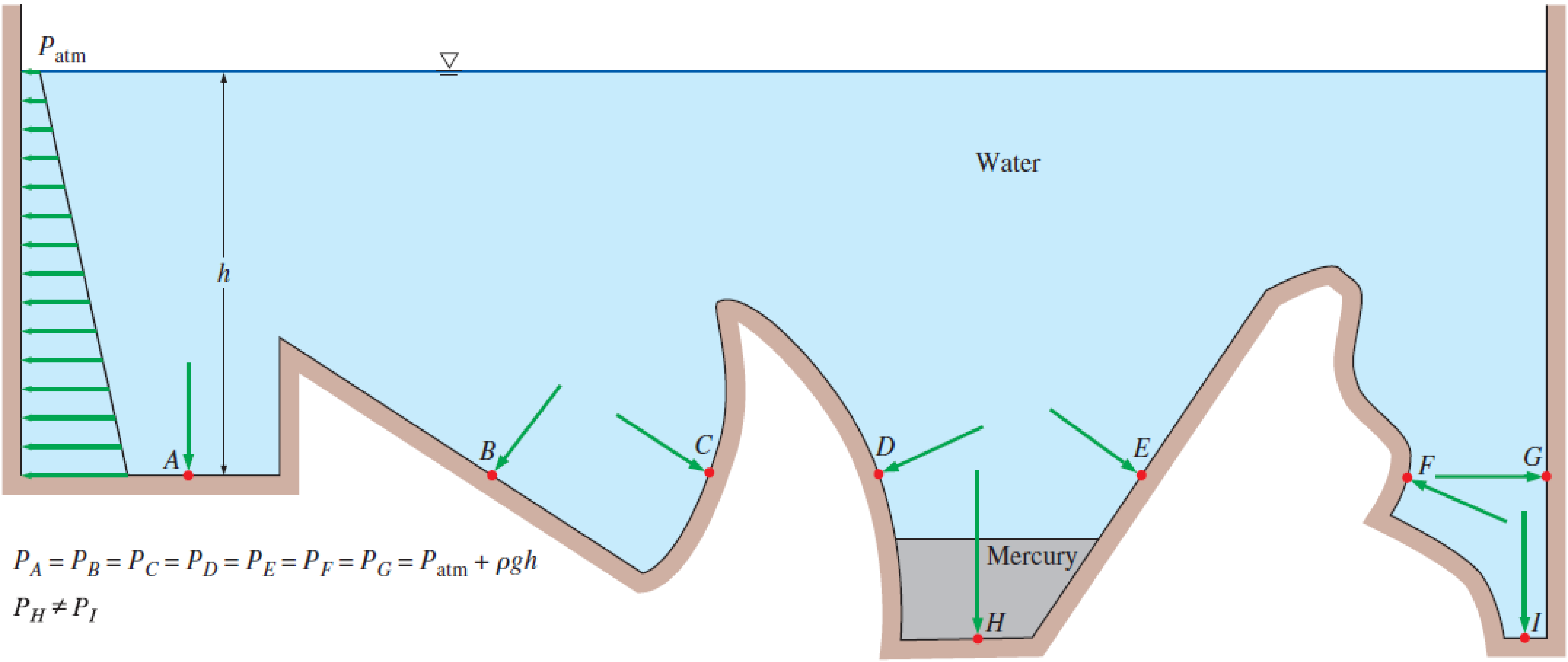


FIGURE 1–46

Under hydrostatic conditions, the pressure is the same at all points on a horizontal plane in a given fluid regardless of geometry, provided that the points are interconnected by the same fluid.

Pascal's law: The pressure applied to a confined fluid increases the pressure throughout by the same amount.

$$P_1 = P_2 \quad \rightarrow \quad \frac{F_1}{A_1} = \frac{F_2}{A_2} \quad \rightarrow \quad \frac{F_2}{F_1} = \frac{A_2}{A_1}$$

The area ratio A_2/A_1 is called the *ideal mechanical advantage* of the hydraulic lift.

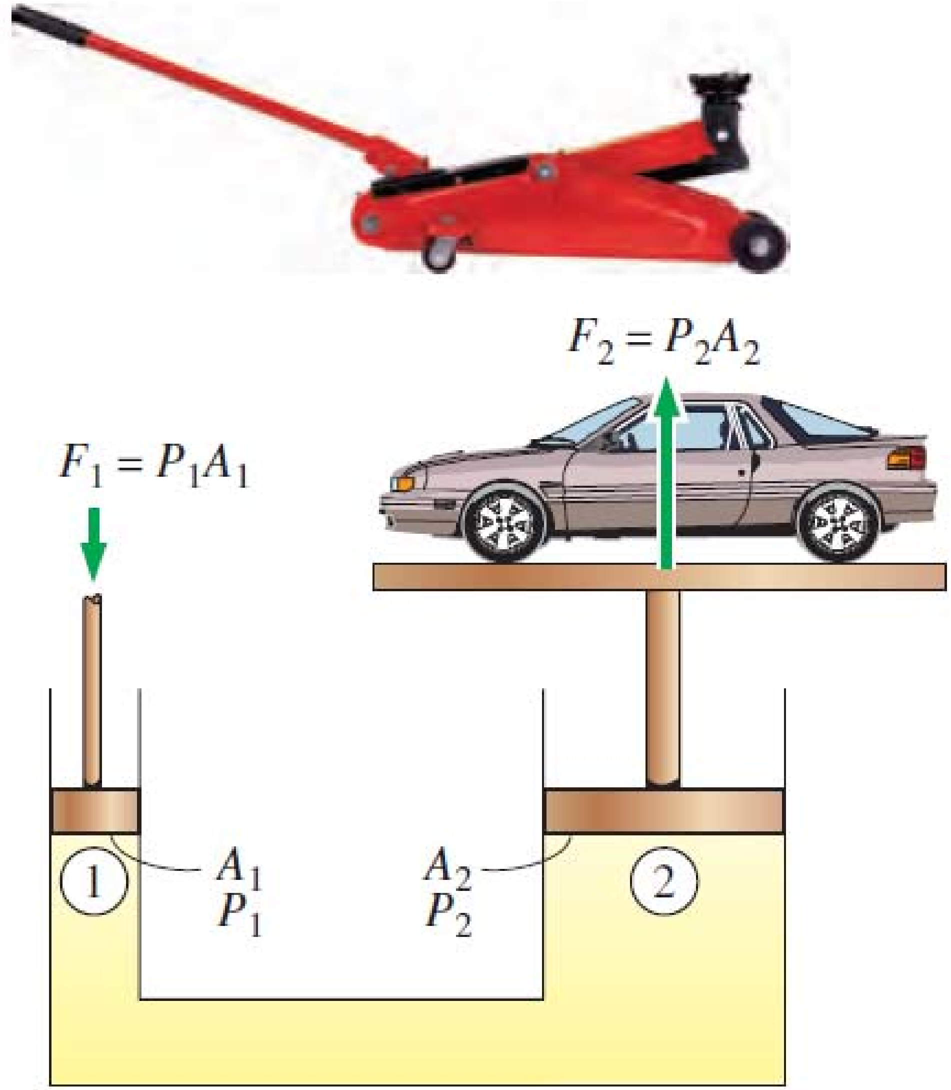


FIGURE 1–47
Lifting of a large weight by a small force by the application of Pascal's law. A common example is a hydraulic jack.

PRESSURE MEASUREMENT DEVICES

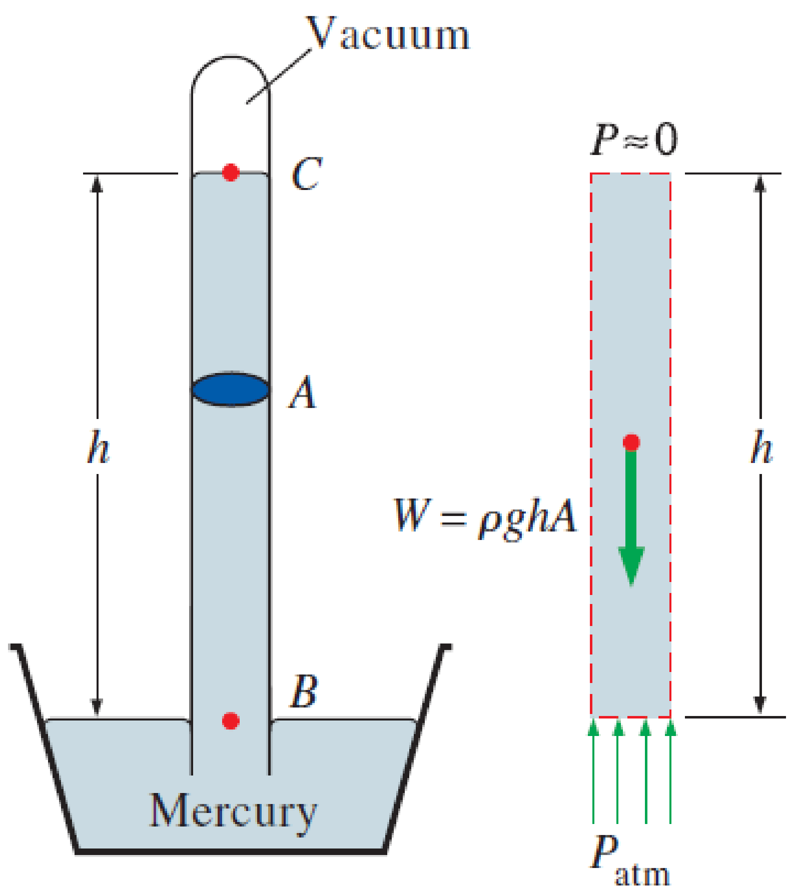


FIGURE 1–48
The basic barometer.

$$P_{atm} = \rho g h$$

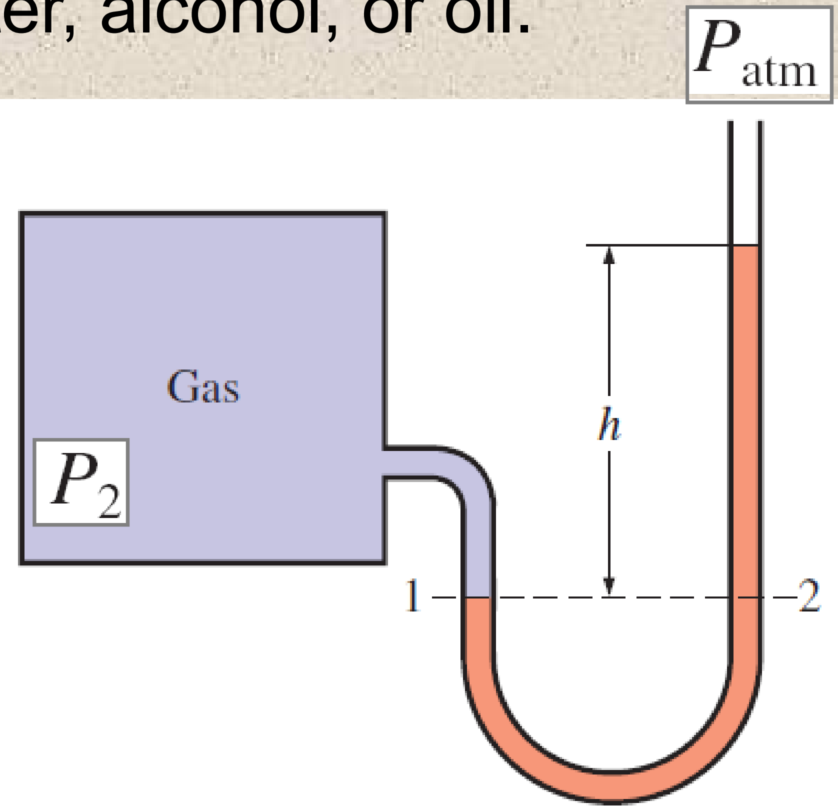
The Barometer

- Atmospheric pressure is measured by a device called a **barometer**; thus, the atmospheric pressure is often referred to as the ***barometric pressure***.
- A frequently used pressure unit is the *standard atmosphere*, which is defined as the pressure produced by a column of mercury 760 mm in height at 0 °C (ρ_{Hg} = 13,595 kg/m^3) under standard gravitational acceleration (g = 9.807 m/s^2).

FIGURE 1–54
A simple U-tube manometer, with high pressure applied to the right side.

The Manometer

- It is commonly used to measure small and moderate pressure differences. A manometer contains one or more fluids such as mercury, water, alcohol, or oil.



$$P_2 = P_{atm} + \rho g h$$

FIGURE 1–55
The basic manometer.

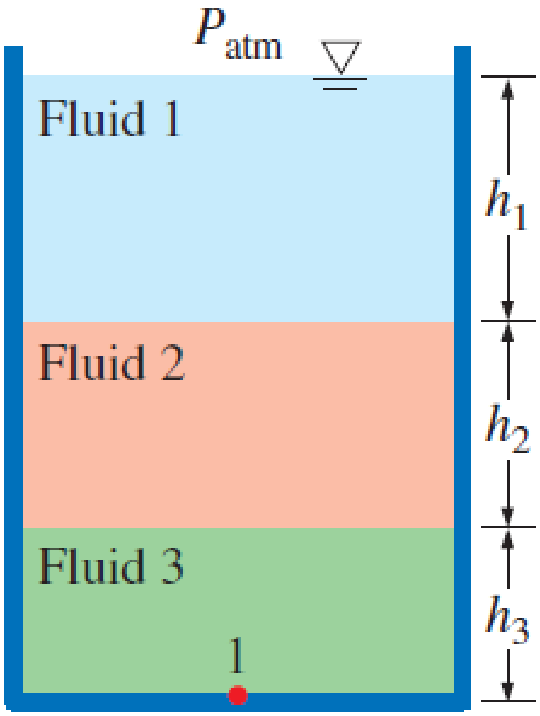


FIGURE 1–57
In stacked-up fluid layers at rest, the pressure change across each fluid layer of density ρ and height h is ρgh.

$$P_{atm} + \rho_1 g h_1 + \rho_2 g h_2 + \rho_3 g h_3 = P_1$$

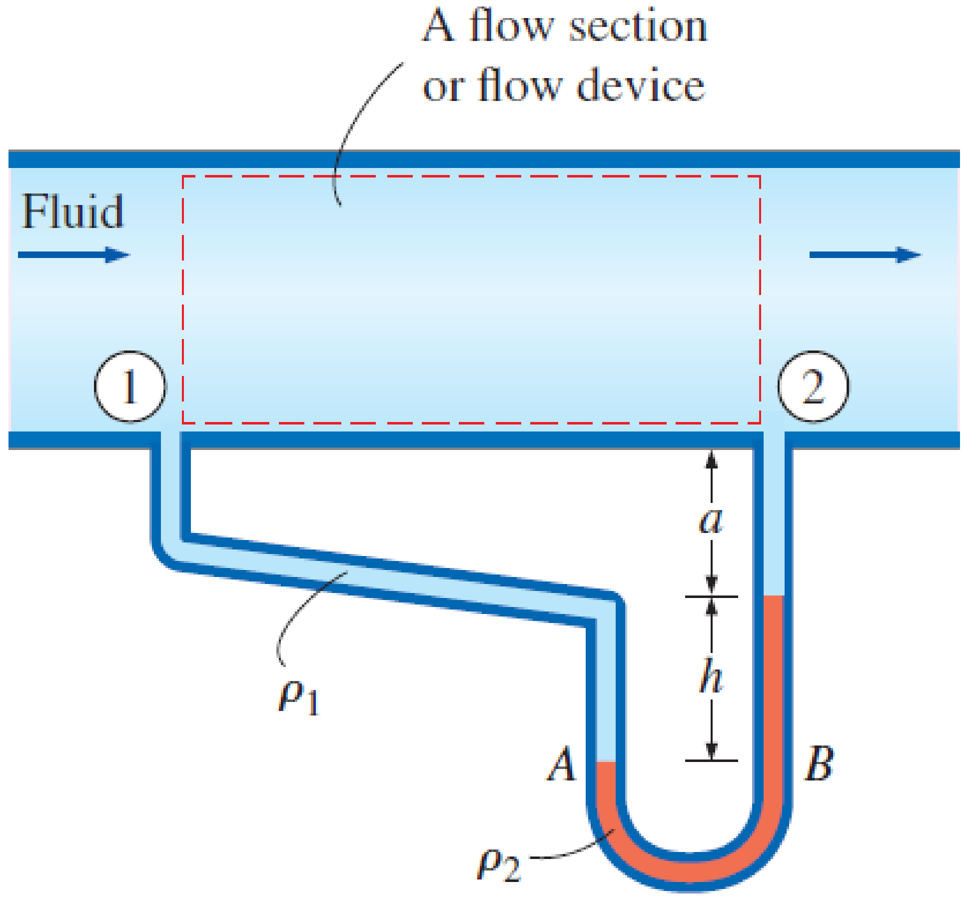


FIGURE 1–58
Measuring the pressure drop across a flow section or a flow device by a differential manometer.

$$P_1 + \rho_1 g(a + h) - \rho_2 g h - \rho_1 g a = P_2$$

$$P_1 - P_2 = (\rho_2 - \rho_1) g h$$

PROBLEM-SOLVING TECHNIQUE

- Step 1: Problem Statement
- Step 2: Schematic
- Step 3: Assumptions and Approximations
- Step 4: Physical Laws
- Step 5: Properties
- Step 6: Calculations
- Step 7: Reasoning, Verification, and Discussion

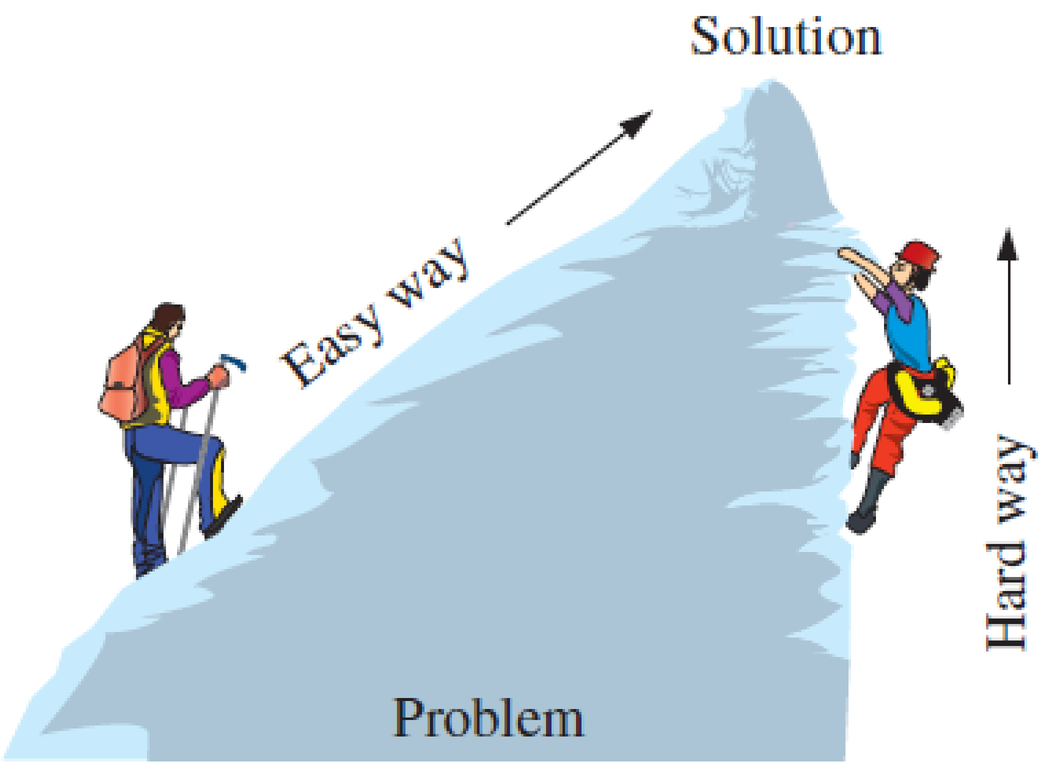


FIGURE 1–62

A step-by-step approach can greatly simplify problem solving.

Assumptions

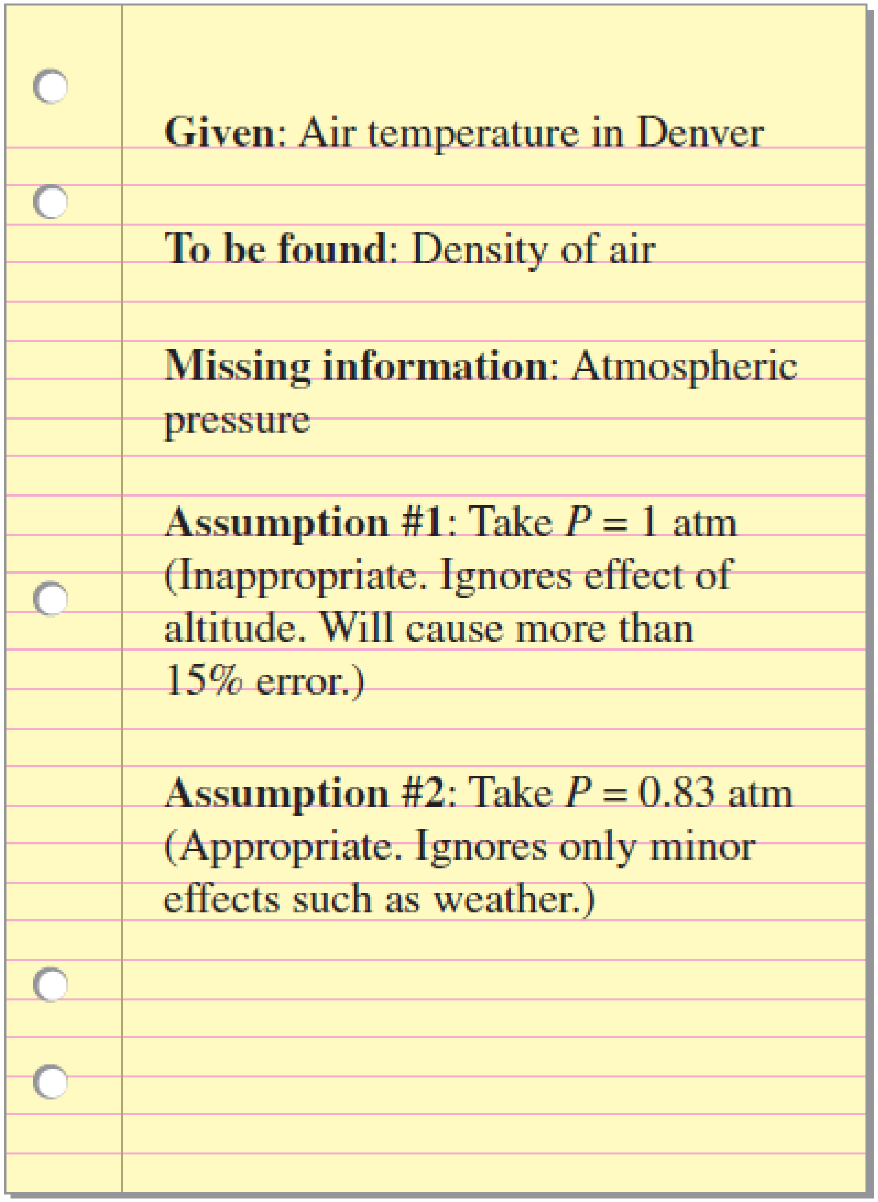


FIGURE 1–63
The assumptions made while solving an engineering problem must be reasonable and justifiable.

A Remark on Significant Digits

- In engineering calculations, the information given is not known to more than a certain number of significant digits, usually three digits
- Consequently, the results obtained cannot possibly be accurate to more significant digits.
- Reporting results in more significant digits implies greater accuracy than exists, and it should be avoided.

Given: Volume: $V = 3.75$ L

Density: $\rho = 0.845$ kg/L

(3 significant digits)

Also, $3.75 \times 0.845 = 3.16875$

Find: Mass: $m = \rho V = 3.16875$ kg

Rounding to 3 significant digits:

$m = 3.17$ kg

FIGURE 1–69

A result with more significant digits than that of given data falsely implies more precision.

Summary

- Thermodynamics and energy
  - ✓ Application areas of thermodynamics
- Importance of dimensions and units
  - ✓ Some SI units, Dimensional homogeneity
- Systems and control volumes
- Properties of a system
  - ✓ Continuum
- Density and specific gravity
- State and equilibrium
  - ✓ The state postulate
- Processes and cycles
  - ✓ The steady-flow process
- Temperature and the zeroth law of thermodynamics
  - ✓ Temperature scales
- Pressure
  - ✓ Variation of pressure with depth
- The manometer
  - ✓ Other pressure measurement devices
- The barometer and atmospheric pressure
- Problem solving technique