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

## Objectives

- Identify the unique vocabulary associated with thermodynamics through the precise definition of basic concepts to form a sound foundation for the development of the principles of thermodynamics.
- Review the metric SI and the English unit systems.
- Explain the basic concepts of thermodynamics such as system, state, state postulate, equilibrium, process, and cycle.
- Review concepts of temperature, temperature scales, pressure, and absolute and gage pressure.
- Introduce an intuitive systematic problem-solving technique.

# THERMODYNAMICS AND ENERGY

- **Thermodynamics**: The science of *energy*.
- **Energy**: The ability to cause changes.
- The name *thermodynamics* stems from the Greek words *therme* (heat) and *dynamis* (power).
- **Conservation of energy principle**: During an interaction, energy can change from one form to another but the total amount of energy remains constant.
- Energy cannot be created or destroyed.
- **The first law of thermodynamics**: An expression of the conservation of energy principle.
- The first law asserts that *energy* is a thermodynamic property.

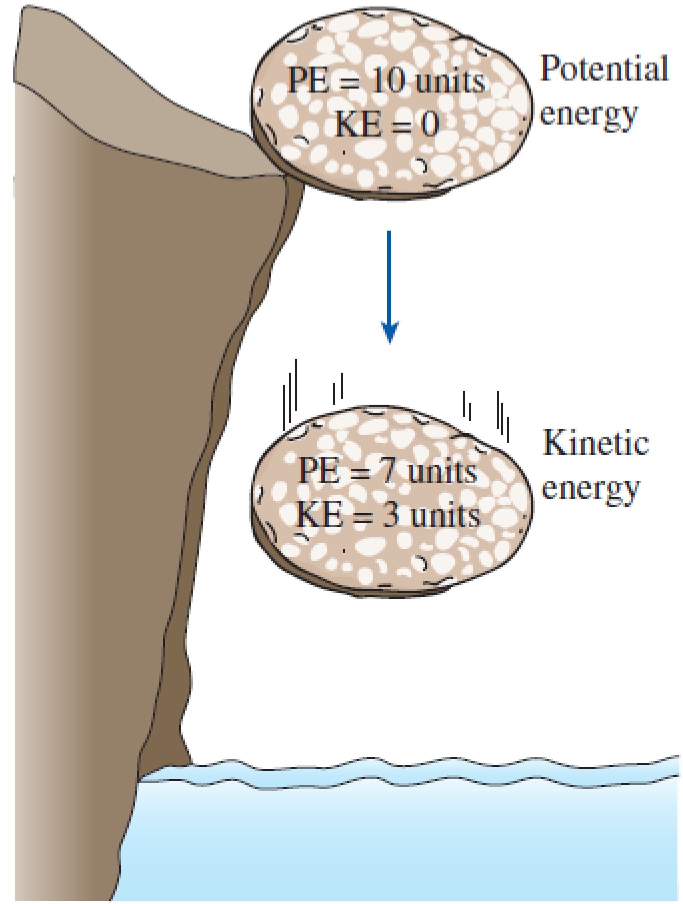


**FIGURE 1–1**
Energy cannot be created or destroyed; it can only change forms (the first law).

- **The second law of thermodynamics:** It asserts that energy has *quality* as well as *quantity*, and actual processes occur in the direction of decreasing quality of energy.
- **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 text.
- **Statistical thermodynamics**: A microscopic approach, based on the average behavior of large groups of individual particles.
- It is used in this text only in the supporting role.

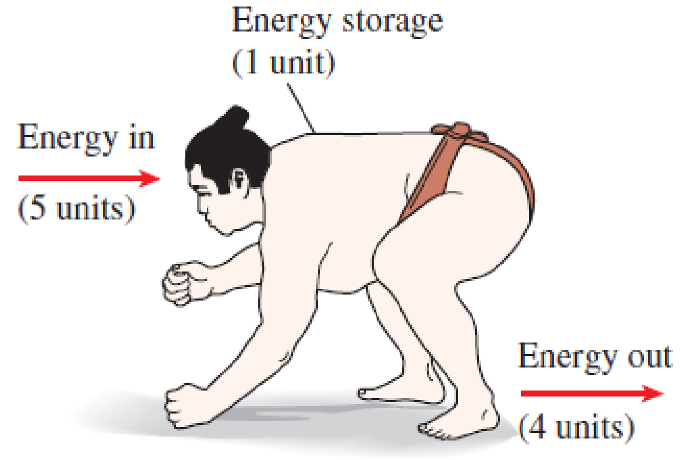


**FIGURE 1–2**
Conservation of energy principle for the human body.

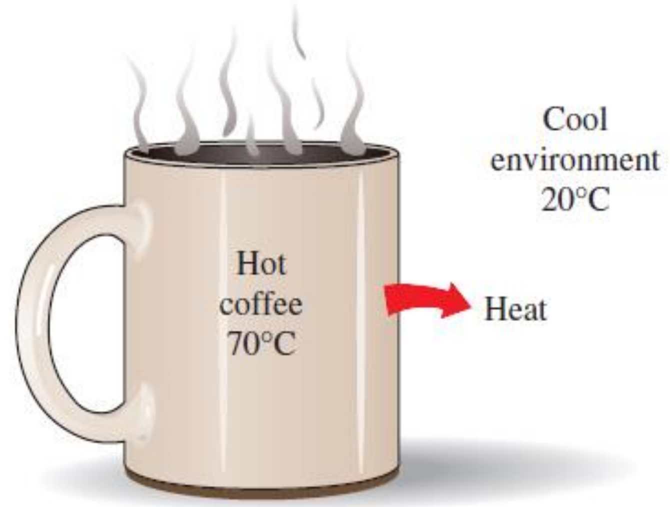


**FIGURE 1–3**
Heat flows in the direction of decreasing temperature.

# Application Areas of Thermodynamics

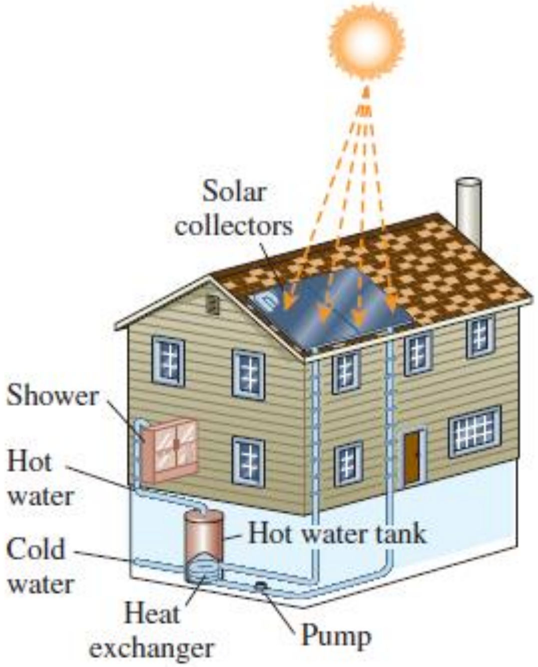


**FIGURE 1–4**
The design of many engineering systems, such as this solar hot water system, involves thermodynamics.

Refrigerator
*© McGraw-Hill Education, Jill Braaten*

Boats
*© Doug Menuez/Getty Images RF*

Aircraft and spacecraft
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Power plants
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All activities in nature involve some interaction between energy and matter; thus, it is hard to imagine an area that does not relate to thermodynamics in some manner.

Human body

*© Ryan McVay/Getty Images RF*

Cars

*© Mark Evans/Getty Images RF*

Wind turbines

*© F. Schussler/PhotoLink/Getty Images RF*

Food processing

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A piping network in an industrial facility.

*Courtesy of UMDE Engineering Contracting and Trading. Used by permission*

# IMPORTANCE OF DIMENSIONS AND UNITS

- Any physical quantity can be characterized by **dimensions**.
- The magnitudes assigned to the dimensions are called **units**.
- Some basic dimensions such as mass *m*, length *L*, time *t*, and temperature *T* are selected as **primary** or **fundamental dimensions**, while others such as velocity *V*, energy *E*, and volume *V* are expressed in terms of the primary dimensions and are called **secondary dimensions**, or **derived dimensions**.
- **Metric SI system**: A simple and logical system based on a decimal relationship between the various units.
- **English system**: It has no apparent systematic numerical base, and various units in this system are related to each other rather arbitrarily.

**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) |

**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, $\mu$ |
| $10^{-9}$ | nano, n |
| $10^{-12}$ | pico, p |
| $10^{-15}$ | femto, f |
| $10^{-18}$ | atto, a |
| $10^{-21}$ | zepto, z |
| $10^{-24}$ | yocto, y |

# Some SI and English Units

$$1 \text{ lbm} = 0.45359 \text{ kg}$$

$$1 \text{ ft} = 0.3048 \text{ m}$$

$$\text{Force} = (\text{Mass})(\text{Acceleration})$$

$$F = ma$$

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

$$1 \text{ lbf} = 32.174 \text{ lbm}\cdot\text{ft/s}^2$$

Work = Force × Distance
1 J = 1 N·m
1 cal = 4.1868 J
1 Btu = 1.0551 kJ

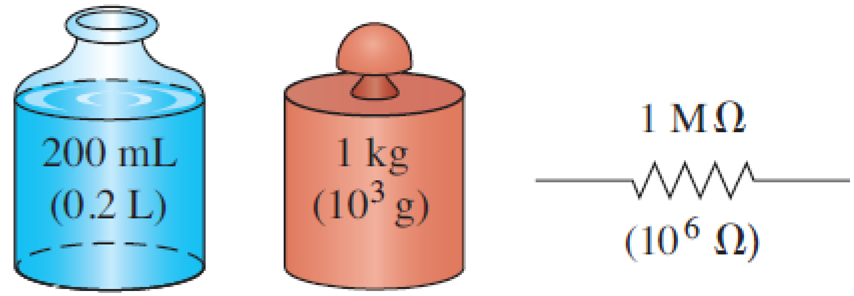



**FIGURE 1–6**
The SI unit prefixes are used in all branches of engineering.

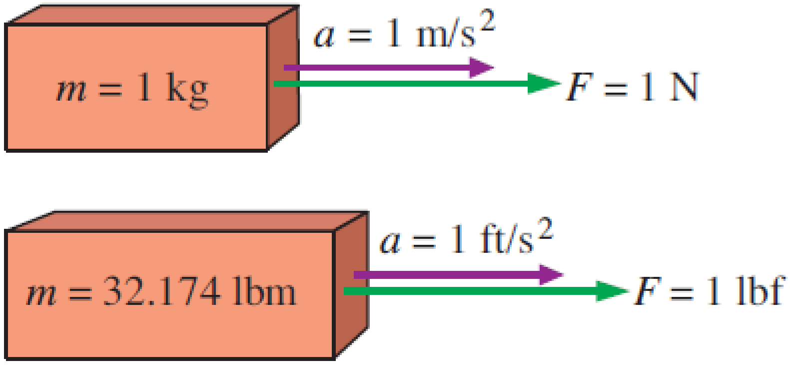



**FIGURE 1–7**
The definition of the force units.

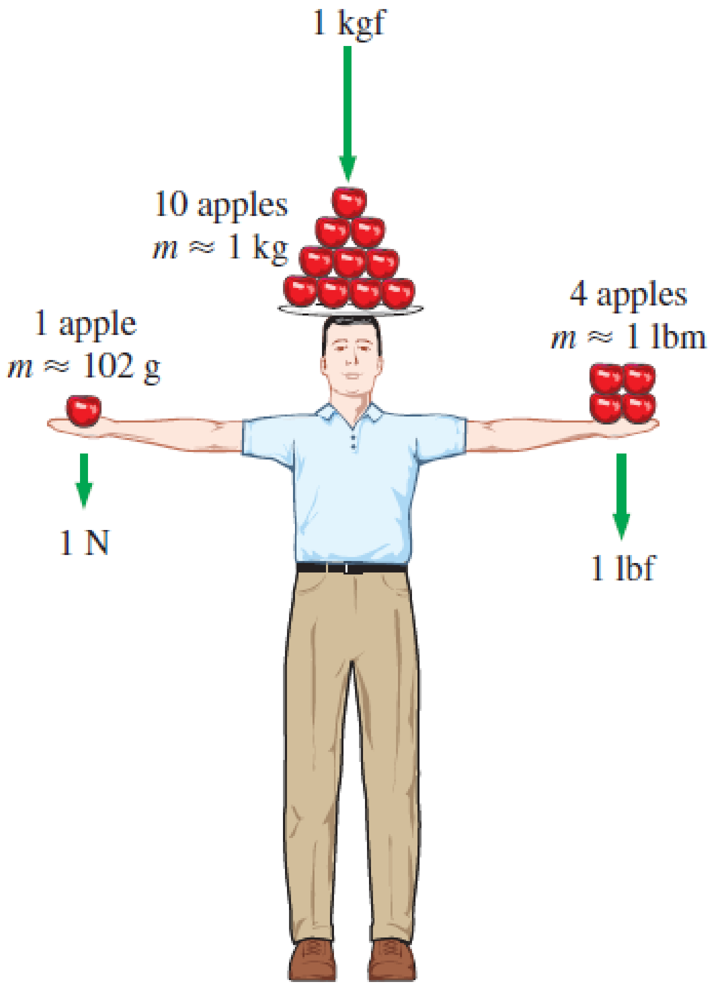



**FIGURE 1–8**
The relative magnitudes of the force units newton (N), kilogram-force (kgf), and pound-force (lbf).

**FIGURE 1–9**
A body weighing 150 lbf on earth will weigh only 25 lbf on the moon.

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

$W$ weight
$m$ mass
$g$ gravitational acceleration

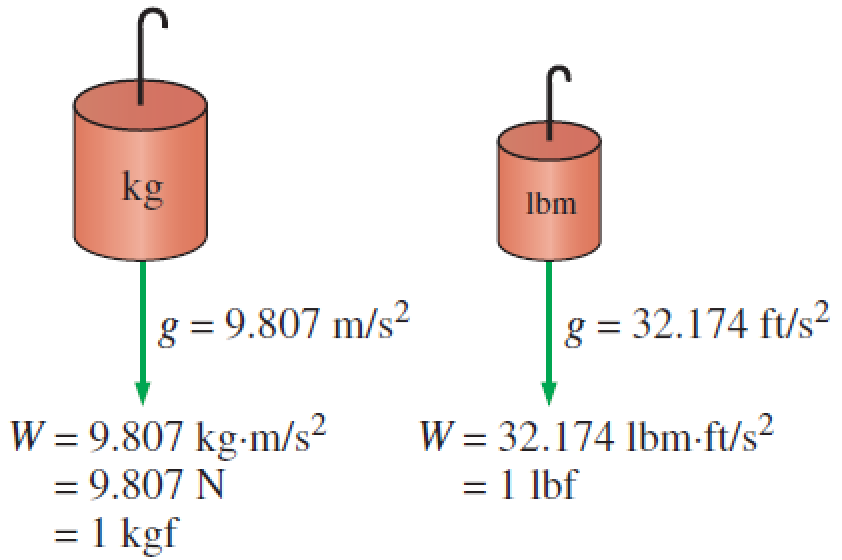



**FIGURE 1–10**
The weight of a unit mass at sea level.

**FIGURE 1–11**
A typical match yields about one Btu (or one kJ) of energy if completely burned.

**Specific weight $\gamma$:** The weight of a unit volume of a substance.

$$\gamma = \rho g$$

# Dimensional homogeneity

All equations must be dimensionally **homogeneous**.

# Unity Conversion Ratios

*All nonprimary units (secondary units) can be formed by combinations of primary units*.
Force units, for example, can be expressed as

$$\mathrm{N} = \mathrm{kg}\,\frac{\mathrm{m}}{\mathrm{s}^2} \quad \text{and} \quad \mathrm{lbf} = 32.174\ \mathrm{lbm}\,\frac{\mathrm{ft}}{\mathrm{s}^2}$$

They can also be expressed more conveniently as **unity conversion ratios** as

$$\frac{\mathrm{N}}{\mathrm{kg}\cdot\mathrm{m/s}^2} = 1 \quad \text{and} \quad \frac{\mathrm{lbf}}{32.174\ \mathrm{lbm}\cdot\mathrm{ft/s}^2} = 1$$

Unity conversion ratios are identically equal to 1 and are unitless, and thus such ratios (or their inverses) can be inserted conveniently into any calculation to properly convert units.

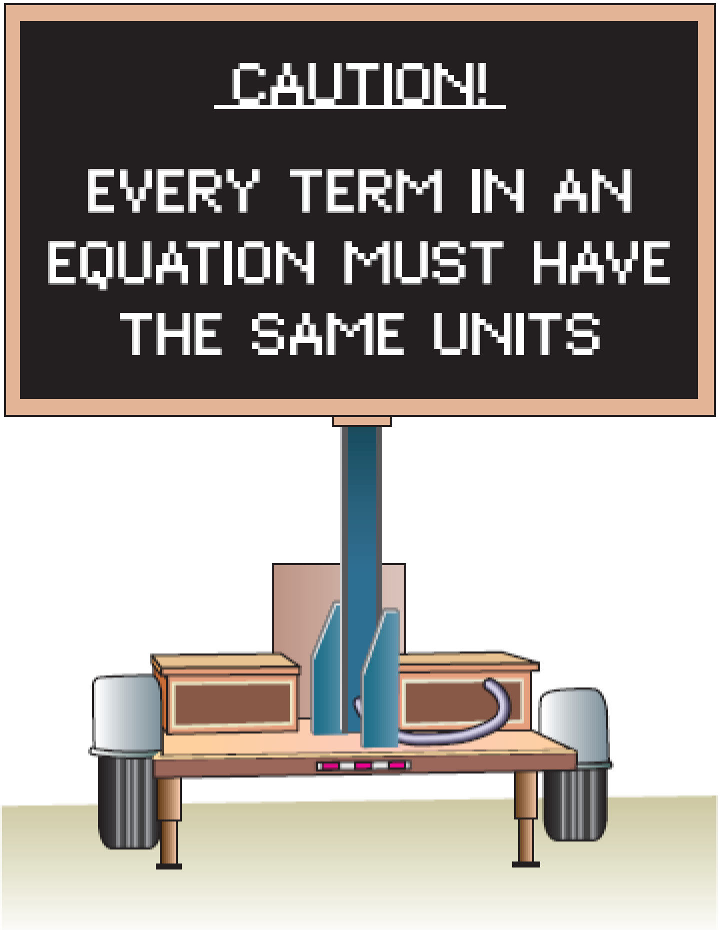



**FIGURE 1–14**
Always check the units in your calculations.

$$\left(\frac{32.174\ \text{lbm}\cdot\text{ft/s}^2}{1\ \text{lbf}}\right)\left(\frac{1\ \text{kg}\cdot\text{m/s}^2}{1\ \text{N}}\right)$$

$$\left(\frac{1\ \text{W}}{1\ \text{J/s}}\right)\left(\frac{1\ \text{kJ}}{1000\ \text{N}\cdot\text{m}}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right)$$

$$\left(\frac{0.3048\ \text{m}}{1\ \text{ft}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right)\left(\frac{1\ \text{lbm}}{0.45359\ \text{kg}}\right)$$

**FIGURE 1–15**
Every unity conversion ratio (as well as its inverse) is exactly equal to one. Shown here are a few commonly used unity conversion ratios.


**FIGURE 1–16**
A mass of 1 lbm weighs 1 lbf on earth.

$$W = mg = (453.6\ \mathrm{g})(9.81\ \mathrm{m/s^2})\left(\frac{1\ \mathrm{N}}{1\ \mathrm{kg{\cdot}m/s^2}}\right)\left(\frac{1\ \mathrm{kg}}{1000\ \mathrm{g}}\right) = 4.49\ \mathrm{N}$$


**FIGURE 1–17**
A quirk in the metric system of units.

# SYSTEMS AND CONTROL VOLUMES

- **System**: A quantity of matter 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.
- The boundary of a system can be *fixed* or *movable.*
- 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

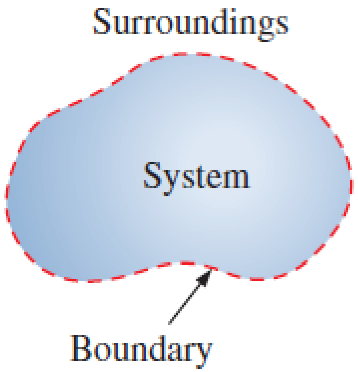



**FIGURE 1–18**
System, surroundings, and boundary.

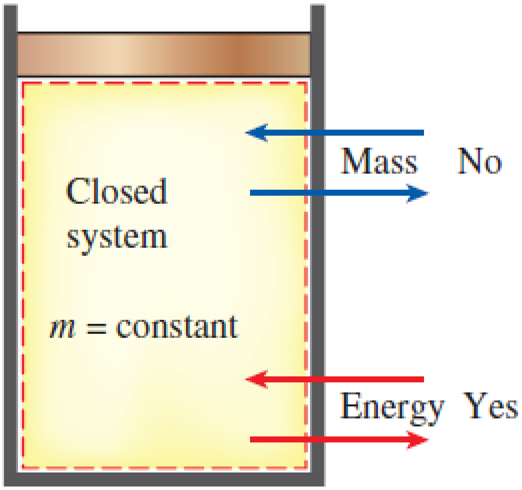



**FIGURE 1–19**
Mass cannot cross the boundaries of a closed system, but energy can.

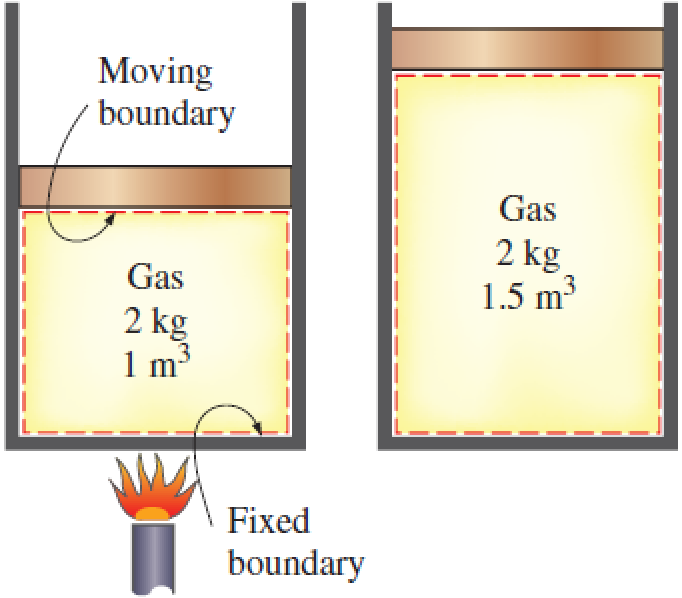
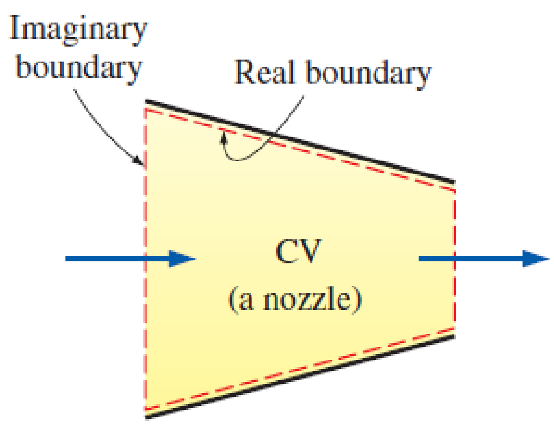



**FIGURE 1–20**
A closed system with a moving boundary.

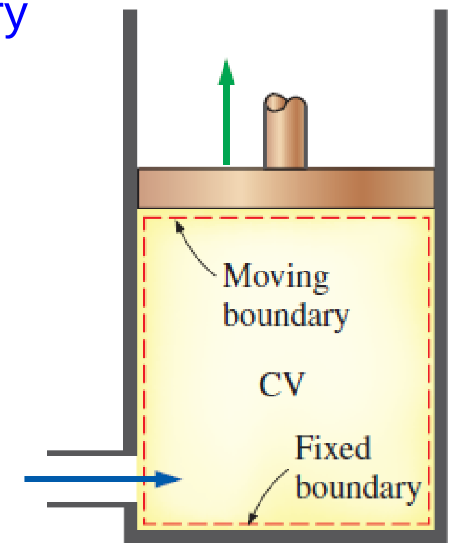
- **Open system (control volume)**: A properly selected region in space.
- It usually encloses a device that involves mass flow such as a compressor, turbine, or nozzle.
- Both mass and energy can cross the boundary of a control volume.
- **Control surface**: The boundaries of a control volume. It can be real or imaginary.

**FIGURE 1–22**
An open system (a control volume) with one inlet and one exit.

A control volume can involve fixed, moving, real, and imaginary boundaries.




(*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

# 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.

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

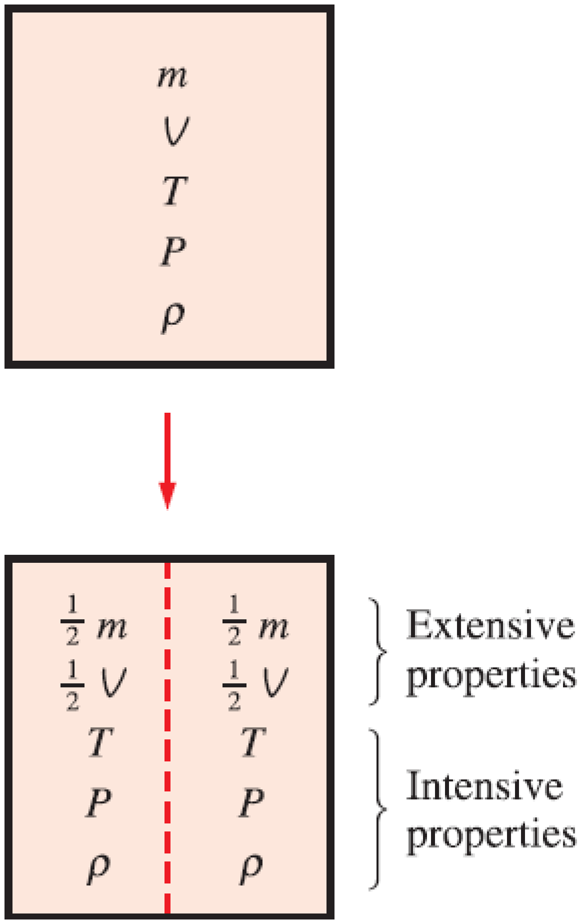



**FIGURE 1–23**
Criterion to differentiate intensive and extensive properties.