CHAPTER ONE

Introduction and Basic Concepts

1.1 THERMODYNAMICS AND ENERGY

Thermodynamics can be defined as the science of ***energy***.

Although everybody has a feeling of what energy is, it is difficult to give a precise definition for it.

Energy can be viewed as the ability to cause changes.

The name ***thermodynamics*** stems from the Greek words ***therme*** **(heat)** and ***dynamis*** **(power),** which is most descriptive of the early efforts to convert heat into power. Today the same name is broadly interpreted to include all aspects of energy and energy transformations including power generation, refrigeration, and relationships among the properties of matter.

One of the most fundamental laws of nature is the **conservation of energy principle**. It simply states that during an interaction, energy can change from one form to another but the total amount of energy remains constant.

That is, **energy cannot be created or destroyed.** A rock falling off a cliff, for example, picks up speed as a result of its potential energy being converted to kinetic energy (Fig. 1–1).

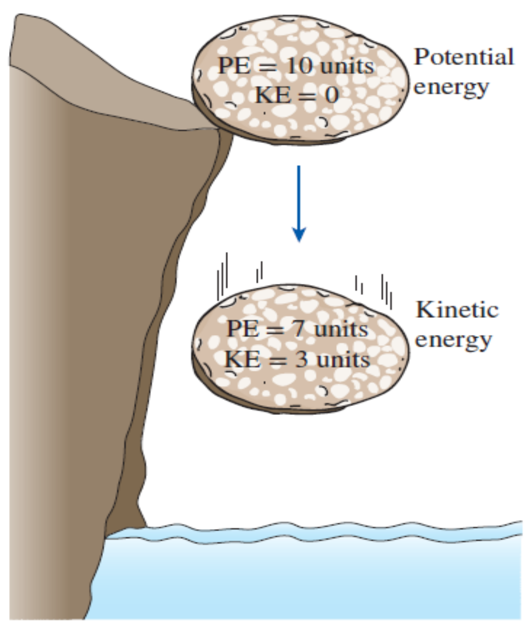


FIGURE 1–1 Energy cannot be created or destroyed; it can only change forms (the first law).

The conservation of energy principle also forms the backbone of the diet industry: A person who has a greater energy input (food) than energy output (exercise) will gain weight (store energy in the form of fat), and a person who has a smaller energy input than output will lose weight (Fig. 1–2). The change in the energy content of a body or any other system is equal to the difference between the energy input and the energy output, and the energy balance is expressed as:

$$(E_{in} - E_{out} = \Delta E).$$

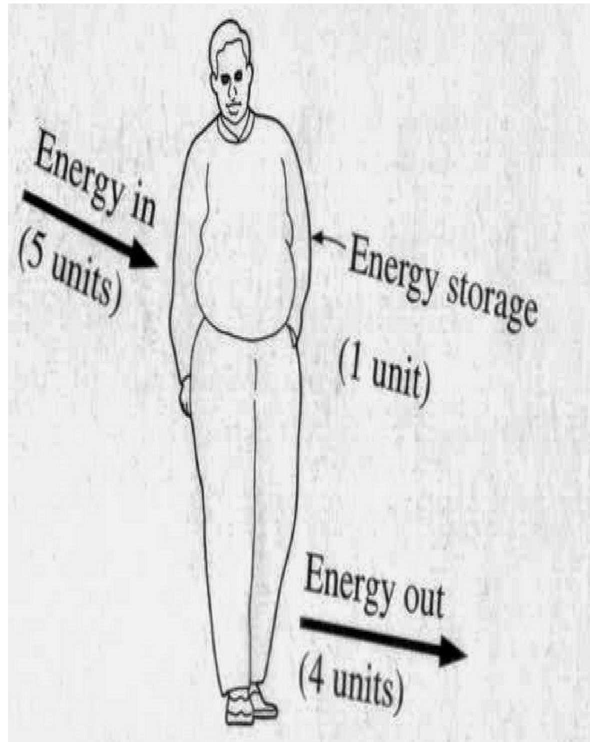


FIGURE 1–2 Conservation of energy principle for the human body

The **first law of thermodynamics** is simply an expression of the conservation of energy principle, and it asserts that ***energy*** is a thermodynamic **property**.

The **second law of thermodynamics** asserts that energy has ***quality*** as well as ***quantity***, and actual processes occur in the direction of decreasing quality of energy.

For example, a cup of hot coffee left on a table eventually cools, but a cup of cool coffee in the same room never gets hot by itself (Fig. 1–3). The high-temperature energy of the coffee is degraded (transformed into a less useful form at a lower temperature) once it is transferred to the surrounding air.

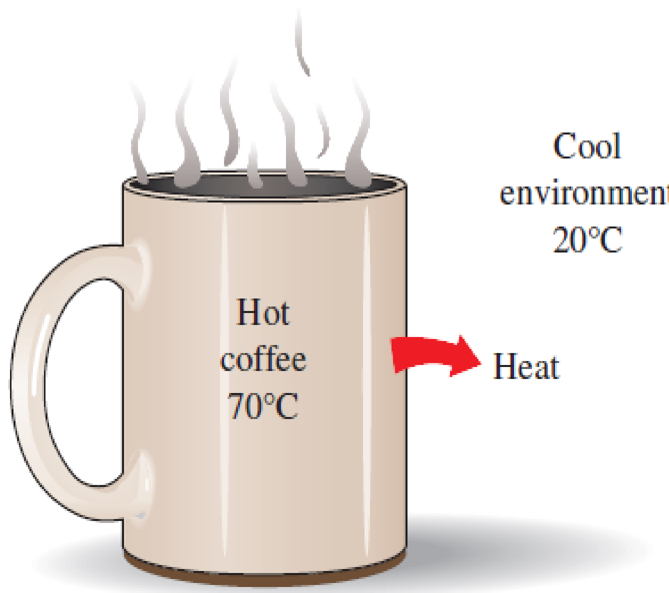


FIGURE 1–3 Heat flows in the direction of decreasing temperature.

It is well known that a **substance** consists of a large number of particles called ***molecules***.
The properties of the substance naturally depend on the behavior of these particles.

For example, the pressure of a gas in a container is the result of momentum transfer between the molecules and the walls of the container. However, one does not need to know the behavior of the gas particles to determine the pressure in the container. It would be sufficient to attach a pressure gage to the container.
This macroscopic approach to the study of thermodynamics that does not require a knowledge of the behavior of individual particles is called **classical thermodynamics**. It provides a direct and easy way to solve engineering problems. A more elaborate approach, based on the average behavior of large groups of

individual particles, is called **statistical thermodynamics**. This microscopic approach is rather involved and is used in this text only in a supporting role.

Application Areas of Thermodynamics

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. Therefore, developing a good understanding of basic principles of thermodynamics has long been an essential part of engineering education.

Thermodynamics is commonly encountered in many engineering systems and other aspects of life, and one does not need to go very far to see some application areas of it. In fact, one does not need to go anywhere. The heart is constantly pumping blood to all parts of the human body, various energy conversions occur in trillions of body cells, and the body heat generated is constantly rejected to the environment. Human comfort is closely tied to the rate of this metabolic heat rejection. We try to control this heat transfer rate by adjusting our clothing to the environmental conditions.

Other applications of thermodynamics are right where one lives.

An ordinary house is, in some respects, an exhibition hall filled with wonders of thermodynamics (Fig. 1–4). Many ordinary household utensils and appliances are designed, in whole or in part, by using the principles of thermodynamics. Some examples include the electric or gas range, the heating and air-conditioning systems, the refrigerator, the humidifier, the pressure cooker, the water heater, the shower, the iron, and even the computer and the TV.

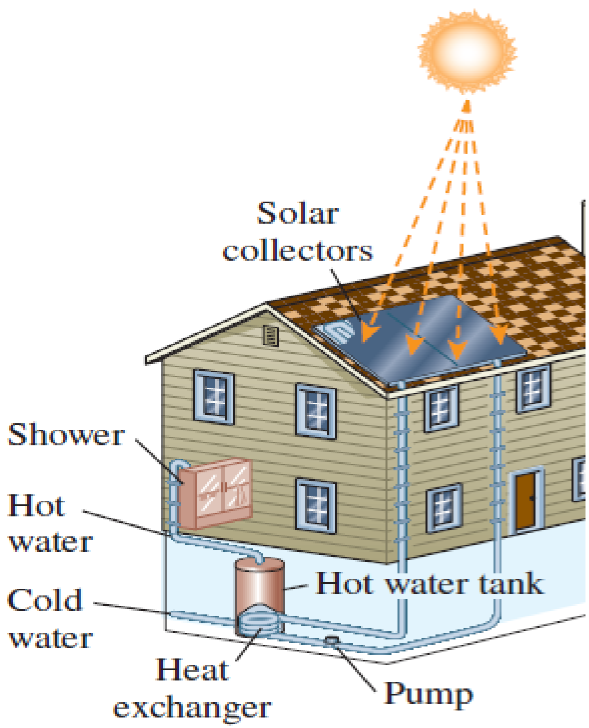
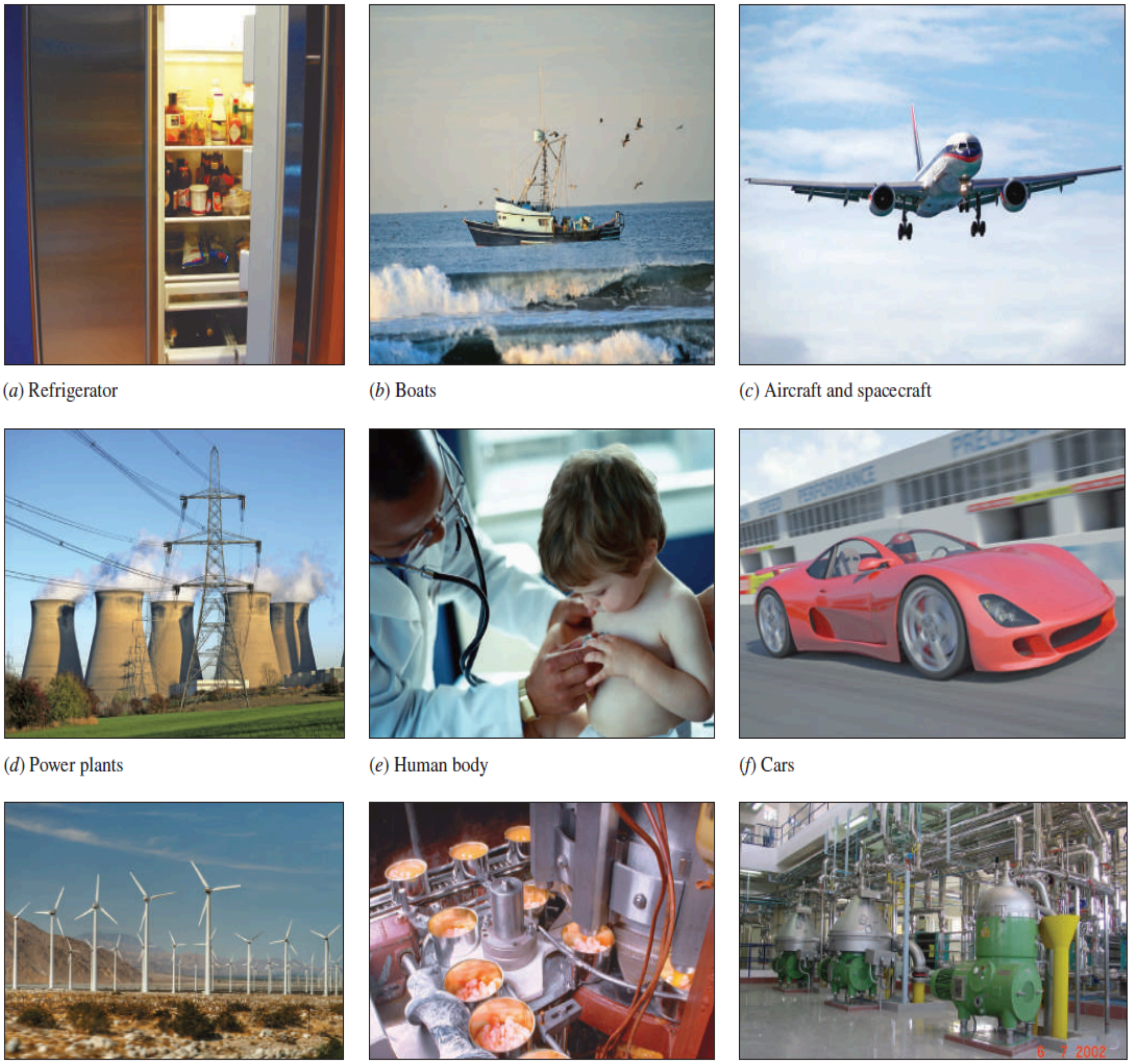


FIGURE 1–4 The design of many engineering systems, such as this solar hot water system, involves thermodynamics.

On a larger scale, thermodynamics plays a major part in the design and analysis of automotive engines, rockets, jet engines, and conventional or nuclear power plants, solar collectors, and the design of vehicles from ordinary cars to airplanes (Fig.1–5). The energy-efficient home that you may be living in, for example, is designed on the basis of minimizing heat loss in winter and heat gain in summer. The size, location, and the power input of the fan of your computer is also selected after an analysis that involves thermodynamics.



(*a*) Refrigerator (*b*) Boats (*c*) Aircraft and spacecraft

(*d*) Power plants (*e*) Human body (*f*) Cars

(*g*) Wind turbines (*h*) Food processing (*i*) A piping network in an industrial facility.

FIGURE 1–5 Some application areas of thermodynamics.

1.2 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**.

A number of unit systems have been developed over the years. Despite strong efforts in the scientific and engineering community to unify the world with a single unit system, two sets of units are still in common use today: the **English system**, which is also known as the *United States Customary System* (USCS), and the **metric SI** (from *Le Systeme International d' Unites*), which is also known as the *International System.*

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, 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

EXAMPLE 1–1 Electric Power Generation by a Wind Turbine

A school is paying $0.12/kWh for electric power. To reduce its power bill, the school installs a wind turbine (Fig. 1–12) with a rated power of 30 kW. If the turbine operates 2200 hours per year at the rated power, determine the amount of electric power generated by the wind turbine and the money saved by the school per year.

SOLUTION A wind turbine is installed to generate electricity. The amount of electric energy generated and the money saved per year are to be determined.

Analysis The wind turbine generates electric energy at a rate of 30 kW or 30 kJ/s. Then the total amount of electric energy generated per year becomes

$$\begin{aligned}\text{Total energy} &= (\text{Energy per unit time})(\text{Time interval}) \\ &= (30\ \text{kW})(2200\ \text{h}) \\ &= \mathbf{66{,}000\ kWh}\end{aligned}$$

The money saved per year is the monetary value of this energy determined as

$$\begin{aligned}\text{Money saved} &= (\text{Total energy})(\text{Unit cost of energy}) \\ &= (66{,}000\ \text{kWh})(\$0.12/\text{kWh}) \\ &= \mathbf{\$7920}\end{aligned}$$

Discussion The annual electric energy production also could be determined in kJ by unit manipulations as

$$\text{Total energy} = (30\ \text{kW})(2200\ \text{h})\left(\frac{3600\ \text{s}}{1\ \text{h}}\right)\left(\frac{1\ \text{kJ/s}}{1\ \text{kW}}\right) = 2.38 \times 10^{8}\ \text{kJ}$$

which is equivalent to 66,000 kWh (1 kWh = 3600 kJ).

FIGURE 1–12 A wind turbine, as discussed in Example 1–1.

EXAMPLE 1–2 **Obtaining Formulas from Unit Considerations**

A tank is filled with oil whose density is $\rho = 850\ \text{kg/m}^3$. If the volume of the tank is $V = 2\ \text{m}^3$, determine the amount of mass m in the tank.

SOLUTION The volume of an oil tank is given. The mass of oil is to be determined.
Assumptions Oil is a nearly incompressible substance and thus its density is constant.
Analysis A sketch of the system just described is given in Fig. 1–13. Suppose we forgot the formula that relates mass to density and volume. However, we know that mass has the unit of kilograms. That is, whatever calculations we do, we should end up with the unit of kilograms. Putting the given information into perspective, we have

$$\rho = 850\ \text{kg/m}^3 \quad \text{and} \quad V = 2\ \text{m}^3$$

It is obvious that we can eliminate m^3 and end up with kg by multiplying these two quantities. Therefore, the formula we are looking for should be

$$m = \rho V$$

Thus,

$$m = (850\ \text{kg/m}^3)(2\ \text{m}^3) = \mathbf{1700\ kg}$$

Discussion Note that this approach may not work for more complicated formulas. Nondimensional constants also may be present in the formulas, and these cannot be derived from unit considerations alone.

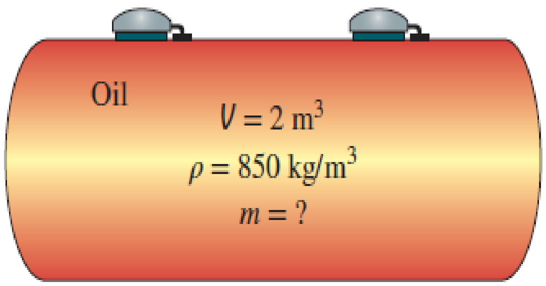


FIGURE 1–13 Schematic for Example 1–2.

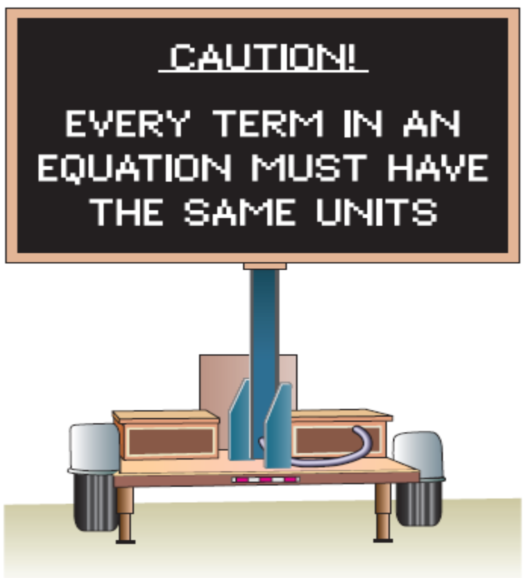


FIGURE 1–14 Always check the units in your calculations.

1.3 SYSTEMS AND CONTROL VOLUMES

A **system** is defined as a *quantity of matter or a region in space chosen for study.*

Surroundings is defined as *the mass or region outside the system.*

Boundary is defined as *the real or imaginary surface that separates the system from its surroundings.*

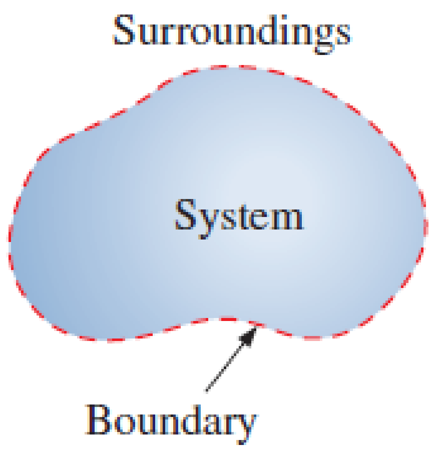


FIGURE 1–18 System, surroundings, and boundary.

Systems may be considered to be ***closed*** or ***open****,* depending on whether a fixed mass or a fixed volume in space is chosen for study.

A **closed system** (also known as a **control mass** or just *system* when the context makes it clear) consists of a fixed amount of mass, and no mass can cross its boundary.

That is, no mass can enter or leave a closed system, as shown in Fig. 1–19. But energy, in the form of heat or work, can cross the boundary; and the volume of a closed system does not have to be fixed.

If, as a special case, even energy is not allowed to cross the boundary, that system is called an **isolated system**.

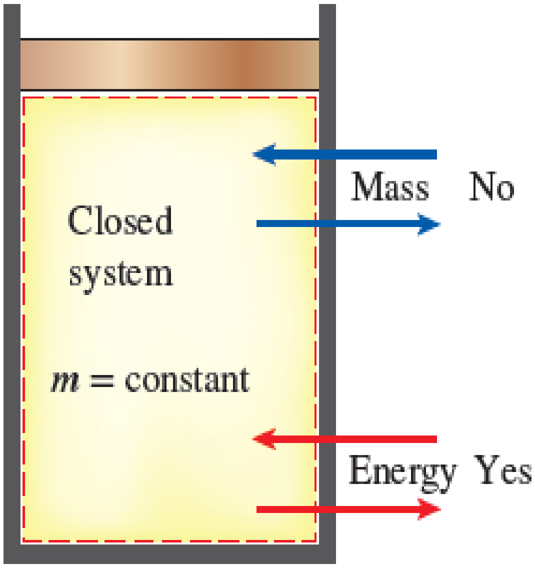


FIGURE 1–19 Mass cannot cross the boundaries of a closed system, but energy can.

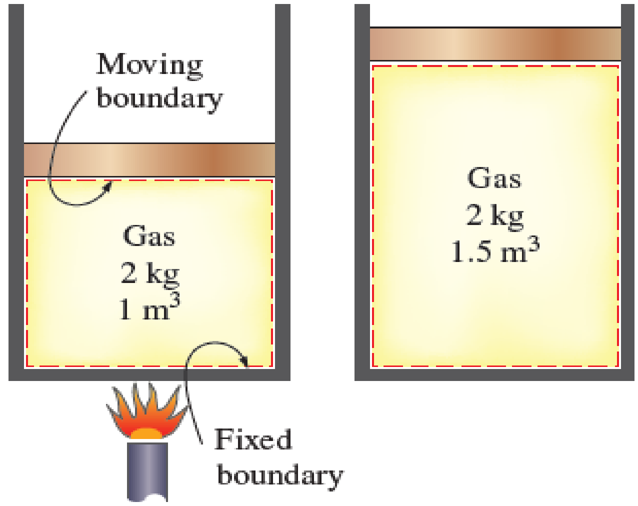


FIGURE 1–20 A closed system with a moving boundary.

An **open system**, or a **control volume**, as it is often called, is a properly selected region in space. It usually encloses a device that involves mass flow such as a compressor, turbine, or nozzle.

Flow through these devices is best studied by selecting the region within the device as the control volume. Both mass and energy can cross the boundary of a control volume.

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

1.4 PROPERTIES OF A SYSTEM

Any characteristic of a system is called a **property**. Some familiar properties are pressure *P,* temperature *T,* volume *V*, and mass *m*. The list can be extended to include less familiar ones such as viscosity, thermal conductivity, modulus of elasticity, thermal expansion coefficient, electric resistivity, and even velocity and elevation.

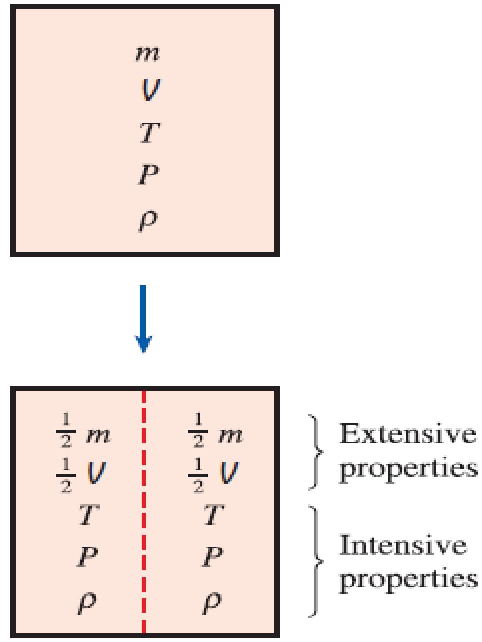
Properties are considered to be either *intensive* or *extensive.*

Intensive properties are those that are independent of the mass of a system, such as temperature, pressure, and density.

Extensive properties are those whose values depend on the size—or extent—of the system. Total mass, total volume, and total momentum are some examples of extensive properties.

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. 1–23. Each part will have the same value of intensive properties as the original system, but half the value of the extensive properties.

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



1.5 DENSITY AND SPECIFIC GRAVITY

Density is defined as *mass per unit volume* (Fig. 1–25).

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

The reciprocal of density is the **specific volume** v, which is defined as *volume per unit mass.* That is,

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

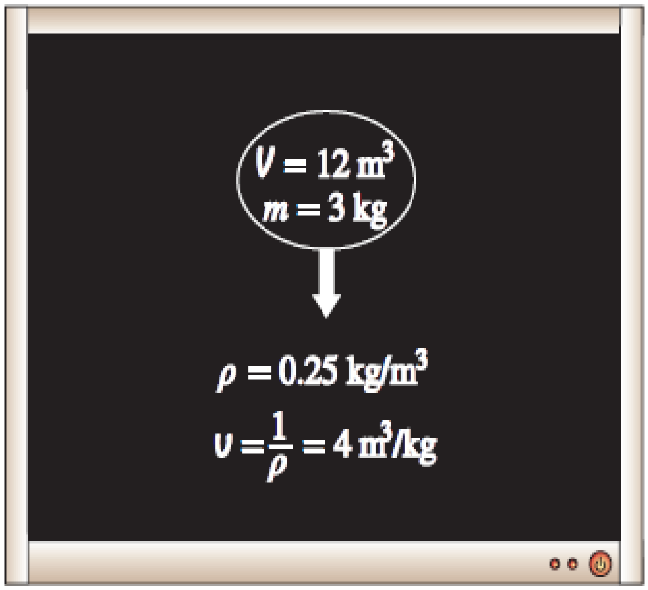


FIGURE 1–25 Density is mass per unit volume; specific volume is volume per unit mass.

Sometimes the density of a substance is given relative to the density of a well-known substance. Then it is called **specific gravity**, or **relative density**, and is defined as *the ratio of the density of a substance to the density of some standard substance at a specified temperature* (usually water at 4°C, for which $\rho_{H2O} = 1000$ kg/m^3). That is,

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

Note that the specific gravity of a substance is a dimensionless quantity.

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

The weight of a unit volume of a substance is called **specific weight** and is expressed as

Specific weight: $$\gamma_s = \rho g \qquad (\text{N/m}^3)$$

where g is the gravitational acceleration. The densities of liquids are essentially constant, and thus they can often be approximated as being incompressible substances during most processes without sacrificing much in accuracy.