# Chapter 1

## Quantities and Units

### INTRODUCTION

Most of the measurements and calculations in chemistry and physics are concerned with different kinds of *quantities*, e.g., length, velocity, volume, mass, energy. Every measurement includes both a number and a unit. The *unit* simultaneously identifies the kind of dimension and the magnitude of the reference quantities used as a basis for comparison. Many units are commonly used for the dimension of length, e.g., inch, yard, mile, centimeter, kilometer. The *number* obviously indicates how many of the reference units are contained in the quantity being measured. Thus the statement that the length of a room is 20 feet means that the length of the room is 20 times the length of the foot, which in this case is the unit of length chosen for comparison. Although *20 feet* has the dimension of length, *20* is a pure number and is dimensionless, being the ratio of two lengths, that of the room and that of the reference foot.

It will be assumed that readers are familiar with the use of exponents, particularly powers-of-ten notation, and with the rules for significant figures. If not, Appendices A and B should be studied in conjunction with Chapter 1.

### SYSTEMS OF MEASUREMENT

Dimensional calculations are greatly simplified if the unit for each kind of measure is expressed in terms of the units of selected reference dimensions. The three independent reference dimensions for mechanics are *length, mass*, and *time*. As examples of relating other quantities to the reference dimensions, the unit of speed is defined as unit length per unit time, the unit of volume is the cube of the unit of length, etc. Other reference dimensions, such as those used to express electrical and thermal phenomena, will be introduced later. There are several systems of units still in use in the English-speaking nations, so that one must occasionally make calculations to convert values from one system to another, e.g., inches to centimeters, or pounds to kilograms.

### INTERNATIONAL SYSTEM OF UNITS

Considerable progress is being made in the acceptance of a common international system of reference units within the world scientific community. This system, known as SI from the French name, Système International d'Unités, has been adopted by many international bodies, including the International Union of Pure and Applied Chemistry. In SI, the reference units for *length, mass,* and *time* are the *meter, kilogram,* and *second*, with the symbols m, kg, and s, respectively.

To express quantities much larger or smaller than the standard units, use may be made of multiples or submultiples of these units, defined by applying as multipliers of these units certain recommended powers of ten, listed in Table 1-1. The multiplier abbreviation is to precede the symbol of the base unit without any space or punctuation. Thus, picosecond ($10^{-12}$ s) is ps, and kilometer ($10^3$ m) is km. Since for historical reasons the SI reference unit for mass, kilogram, already has a prefix, multiples for mass should be derived by applying the multiplier to the unit *gram* rather than to the *kilogram*. Thus $10^{-9}$ kg is a microgram ($10^{-6}$ g), abbreviated μg.

Compound units can be derived by applying algebraic operations to the simple units.

**EXAMPLE 1** The unit for volume in SI is the cubic meter ($m^3$), since

$$\text{Volume} = \text{length} \times \text{length} \times \text{length} = m \times m \times m = m^3$$

**Table 1-1. Multiples and Submultiples for Units**

| Prefix | Abbreviation | Multiplier | Prefix | Abbreviation | Multiplier |
|---|---|---|---|---|---|
| deci | d | $10^{-1}$ | deka | da | 10 |
| centi | c | $10^{-2}$ | hecto | h | $10^{2}$ |
| millli | m | $10^{-3}$ | kilo | k | $10^{3}$ |
| micro | $\mu$ | $10^{-6}$ | mega | M | $10^{6}$ |
| nano | n | $10^{-9}$ | giga | G | $10^{9}$ |
| pico | p | $10^{-12}$ | tera | T | $10^{12}$ |
| femto | f | $10^{-15}$ | peta | P | $10^{15}$ |
| atto | a | $10^{-18}$ | exa | E | $10^{18}$ |

The unit for speed is the unit for length (distance) divided by the unit for time, or the meter per second (m/s), since

$$\text{Speed} = \frac{\text{distance}}{\text{time}} = \frac{\text{m}}{\text{s}}$$

The unit for density is the unit for mass divided by the unit for volume, or the kilogram per cubic meter ($kg/m^3$), since

$$\text{Density} = \frac{\text{mass}}{\text{volume}} = \frac{\text{kg}}{\text{m}^3}$$

**Table 1-2. Some SI and Non-SI Units**

| Physical Quantity | Unit name | Unit Symbol | Definition |
|---|---|---|---|
| Length | angstrom<br>inch | Å<br>in | $10^{-10}$ m<br>$2.54 \times 10^{-2}$ m exactly |
| Area | square meter (SI) | $m^2$ | |
| Volume | cubic meter (SI)<br>liter<br>cubic centimeter | $m^3$<br>L<br>$cm^3$, mL | <br>$dm^3$, $10^{-3}$ $m^3$ |
| Mass | atomic mass unit (dalton)<br>pound | u<br>lb | $1.660\,54 \times 10^{-27}$ kg<br>0.453 592 37 kg |
| Density | kilogram per cubic meter (SI)<br>gram per milliliter, *or*<br>gram per cubic centimeter | $kg/m^3$<br>g/mL, *or*<br>$g/cm^3$ | |
| Force | newton (SI) | N | $kg \cdot m/s^2$ |
| Pressure | pascal (SI)<br>bar<br>atmosphere<br>torr (millimeter of mercury) | Pa<br>bar<br>atm<br>torr (mm Hg) | $N/m^2$<br>$10^5$ Pa<br>101 325 Pa<br>atm/760 *or* 133.32 Pa |

Symbols for compound units may be expressed in any of the following formats.

1. Multiple of units. Example: *kilogram second.*
   (a) Dot $\mathrm{kg \cdot s}$
   (b) Spacing $\mathrm{kg\ s}$
   (*not used in this book*)
2. Division of units. Example: *meter per second.*
   (a) Division sign $\dfrac{\mathrm{m}}{\mathrm{s}}$ or m/s
   (b) Negative power $\mathrm{m \cdot s^{-1}}$ (or $\mathrm{m\,s^{-1}}$)

Note that the term *per* in a word definition is equivalent to *divide by* in the mathematical notation. Note also that symbols are not followed by a period, except at the end of a sentence.

In recognition of long-standing traditions, the various international commissions have acknowledged that a few non-SI units will remain in use in certain fields of science and in certain countries during a transitional period. Table 1-2 lists some units, both SI and non-SI, which will be used in this book, involving the quantities length, mass, and time. Other units will be introduced in subsequent chapters.

## TEMPERATURE

*Temperature* may be defined as that property of a body which determines the flow of heat. Two bodies are at the same temperature if there is no transfer of heat when they are placed together. Temperature is an independent dimension which cannot be defined in terms of mass, length, and time. The SI unit of temperature is the *kelvin*, and 1 kelvin (K) is defined as 1/273.16 times the *triple point* temperature. The *triple point* is the temperature at which water coexists in equilibrium with ice at the pressure exerted by water vapor only. The *triple point* is 0.01 K above the *normal freezing point* of water, at which water and ice coexist in equilibrium with air at standard atmospheric pressure. The SI unit of temperature is so defined that 0 K is the absolute zero of temperature; the SI or Kelvin scale is often called the *absolute temperature scale*. Although absolute zero is never actually attainable, it has been approached to within $10^{-4}$ K.

## OTHER TEMPERATURE SCALES

On the commonly used *Celsius* scale (also called the *centigrade* scale), a temperature difference of one degree is 1 K (exactly). The normal boiling point of water is 100 °C, the normal freezing point 0 °C, and absolute zero −273.15 °C.

A temperature difference of one degree on the *Fahrenheit* scale is 5/9 K (exactly). The boiling point and freezing point of water, and absolute zero are 212 °F, 32 °F, and −459.67 °F, respectively.

The relationships among these three scales, illustrated in Fig. 1-1, are described by the following linear equations, in which temperature on the SI scale is designated by $T$, and on the other scales by $t$.

$$\frac{t}{^\circ\mathrm{C}} = \frac{T}{\mathrm{K}} - 273.15 \qquad \text{or} \qquad t = \left(\frac{T}{\mathrm{K}} - 273.15\right)^\circ\mathrm{C}$$

$$\frac{t}{^\circ\mathrm{F}} = \frac{9}{5}\left(\frac{t}{^\circ\mathrm{C}}\right) + 32 \qquad \text{or} \qquad t = \left[\frac{9}{5}\left(\frac{t}{^\circ\mathrm{C}}\right) + 32\right]^\circ\mathrm{F}$$

$$\frac{t}{^\circ\mathrm{C}} = \frac{5}{9}\left(\frac{t}{^\circ\mathrm{F}} - 32\right) \qquad \text{or} \qquad t = \frac{5}{9}\left(\frac{t}{^\circ\mathrm{F}} - 32\right)^\circ\mathrm{C}$$

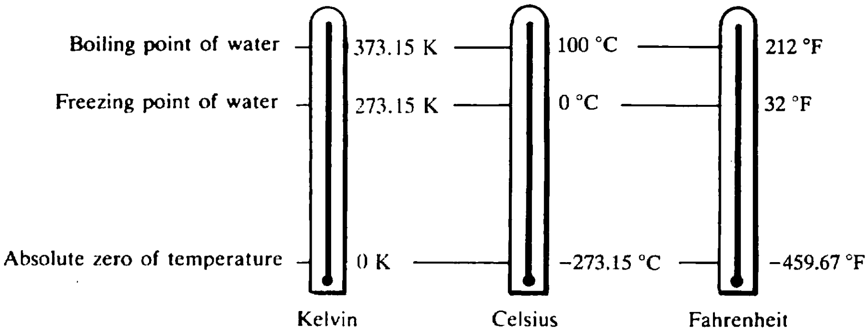


**Fig. 1-1**

Here the ratios $T/\mathrm{K}$, $t/{}^\circ\mathrm{C}$, $t/{}^\circ\mathrm{F}$ are the dimensionless numerical measures of the temperature on the Kelvin, Celsius, and Fahrenheit scales, respectively. Read the upper left equation as follows: The temperature in degrees *Celsius* equals the temperature in kelvins minus 273.15.

## USE AND MISUSE OF UNITS

The units (e.g., cm, kg, g/mL, ft/s) must be regarded as a necessary part of the complete specification of a physical quantity. It is as foolish to separate the number of a measure from its unit as it is to separate a laboratory reagent bottle from its label. When physical quantities are subjected to mathematical operations, the units must be carried along with the numbers and must undergo the same operations as the numbers. Quantities cannot be added or subtracted directly unless they have not only the same dimensions but also the same units.

**EXAMPLE 2** It is obvious that we cannot add 5 hours (time) to 20 miles/hour (speed) since *time* and *speed* have different physical significance. If we are to add 2 lb (mass) and 4 kg (mass), we must first convert lb to kg or kg to lb. Quantities of various types, however, can be combined in multiplication or division, in which *the units as well as the numbers* obey the algebraic laws of squaring, cancellation, etc. Thus:

1. $6\ \mathrm{L} + 2\ \mathrm{L} = 8\ \mathrm{L}$
2. $(5\ \mathrm{cm})(2\ \mathrm{cm}^2) = 10\ \mathrm{cm}^3$
3. $(3\ \mathrm{ft}^3)(200\ \mathrm{lb/ft}^3) = 600\ \mathrm{lb}$
4. $(2\ \mathrm{s})(3\ \mathrm{m/s}^2) = 6\ \mathrm{m/s}$
5. $\dfrac{15\ \mathrm{g}}{3\ \mathrm{g/cm}^3} = 5\ \mathrm{cm}^3$

## FACTOR-LABEL METHOD

In solving problems, one can be guided consciously by the units to the proper way of combining the given values. Such techniques are referred to in textbooks as the *factor-label method*, the *unit-factor method*, or *dimensional analysis*. In essence one goes from a given unit to the desired unit by multiplying by a fraction called a *unit-factor* in which the numerator and the denominator must represent the same quantity.

**EXAMPLE 3** Convert 5.00 inches to centimeters. The appropriate unit-factor is 2.54 cm/1 in, and $5.00\ \mathrm{in} \times 2.54\ \mathrm{cm/1\ in} = 12.7\ \mathrm{cm}$. Note that 1 in and its equal, 2.54 cm, clearly represent the same quantity. Also note that the reciprocal of a unit-factor must also be a unit-factor. If one used the reciprocal by mistake in the above calculation, however, the answer would have been $1.97\ \mathrm{in}^2/\mathrm{cm}$, and these ridiculous units would reveal that a mistake had been made.

The *factor-label* method can be extended to the use of *unit-factors* (or *conversion factors*) in which numerator and denominator are equivalent but of different dimensions.

**EXAMPLE 4** What is the weight in grams of seven nails, which weigh 0.765 kg per gross?

$$7\text{ nails} \times \frac{1\text{ gross nails}}{144\text{ nails}} \times \frac{0.765\text{ kg}}{1\text{ gross nails}} \times \frac{1000\text{ g}}{1\text{ kg}} = 37.2\text{ g}$$

The fraction in the middle above is a *unit-factor* of mixed dimensions. Also, in this case the numerator and denominator are not universally equivalent, but are associated measures for this particular batch of nails. Many similar examples are encountered in the chemical calculations shown in subsequent chapters.

## ESTIMATION OF NUMERICAL ANSWERS

If one's calculator is working correctly and is accurately used, the answer will be correct. But if not, will an incorrect answer be recognized? A very important skill is to determine first, by visual inspection, an approximate answer. Especially important is the correct order of magnitude, represented by the location of the decimal point or the power of 10, which may go astray even though the digits are correct.

**EXAMPLE 5** Consider the multiplication: $122\text{ g} \times 0.051\,8 = 6.32\text{ g}$. Visual inspection shows that 0.051 8 is a little more than $\frac{1}{20}$, and $\frac{1}{20}$ of 122 is a little more than 6. Hence the answer should be a little more than 6 g, which it is. If the answer were given incorrectly as 63.2 g or 0.632 g, visual inspection or mental checking of the result would indicate that the decimal point had been misplaced.

**EXAMPLE 6** Calculate the power required to raise a 639 kg mass 20.74 m in 2.120 minutes. The solution is:

$$\frac{639\text{ kg} \times 20.74\text{ m} \times 9.81\text{ m}\cdot\text{s}^{-2}}{2.120\text{ min} \times 60\text{ s/min}} = 1\,022\text{ J/s} = 1\,022\text{ watts}$$

Check the numerical answer by estimation.

This example involves concepts and units unfamiliar to you, so that you can't easily judge whether the result "makes sense" or not. Write each term in exponential notation, using one significant figure. Then mentally combine the powers of ten and the multipliers separately to estimate the result, as shown below.

$$\text{NUM} = 6 \times 10^2 \times 2 \times 10^1 \times 1 \times 10^1 = 12 \times 10^4$$

$$\text{DEN} = 2 \times 6 \times 10^1 = 12 \times 10^1$$

$$\text{NUM/DEN} = 1\,000 \text{ estimated, compared to } 1\,022 \text{ calculated}$$

# Solved Problems

## UNITS BASED ON MASS OR LENGTH

**1.1.** The following examples illustrate conversions among various units of length, volume, or mass.

1 inch = 2.54 cm = 0.025 4 m = 25.4 mm = $2.54 \times 10^7$ nm
1 foot = 12 in = 12 in × 2.54 cm/in = 30.48 cm = 0.304 8 m = 304.8 mm
1 liter = 1 $dm^3$ = $10^{-3}$ $m^3$
1 mile = 5 280 ft = $1.609 \times 10^5$ cm = $1.609 \times 10^3$ m = 1.609 km = $1.609 \times 10^6$ mm
1 pound = 0.453 6 kg = 453.6 g = $4.536 \times 10^5$ mg
1 metric ton = 1 000 kg = $10^6$ g

**1.2.** Convert 3.50 yards to (*a*) millimeters, (*b*) meters. The bridge between the English units of length and the SI (metric system) is the unit factor (see Table 1-2) 1 in/2.54 cm.

(*a*)
$$3.50\text{ yd} \times \frac{36\text{ in}}{1\text{ yd}} \times \frac{2.54\text{ cm}}{1\text{ in}} \times \frac{10\text{ mm}}{1\text{ cm}} = 3.20 \times 10^3\text{ mm}$$

Note that the use of three successive conversion factors was necessary. The units yd, in, and cm canceled out leaving the desired unit, mm.

(*b*)
$$3.20 \times 10^3\text{ mm} \times \frac{1\text{ m}}{10^3\text{ mm}} = 3.20\text{ m}$$

**1.3.** Convert (*a*) 14.0 cm and (*b*) 7.00 m to inches.

(*a*)
$$14.0\text{ cm} = (14.0\text{ cm})\left(\frac{1\text{ in}}{2.54\text{ cm}}\right) = 5.51\text{ in} \quad \text{or} \quad 14.0\text{ cm} = \frac{14.0\text{ cm}}{2.54\text{ cm/in}} = 5.51\text{ in}$$

Factors such as $\frac{1\text{ in}}{2.54\text{ cm}}$ will frequently appear in the form 1 in/2.54 cm, especially in computer displays, because it allows the entire calculation to appear on one line of type, i.e., (14.0 cm)(1 in/2.54 cm) = 5.51 in.

(*b*)
$$7.00\text{ m} = (7.00\text{ m})(100\text{ cm}/1\text{ m})(1\text{ in}/2.54\text{ cm}) = 276\text{ in}$$

**1.4.** How many square inches are in one square meter?

$$1\text{ m} = (1\text{ m})(100\text{ cm}/1\text{ m})(1\text{ in}/2.54\text{ cm}) = 39.37\text{ in}$$

$$1\text{ m}^2 = (1\text{ m})^2 = (39.37\text{ in})^2 = 1\,550\text{ in}^2$$

alternatively,

$$1\text{ m}^2 = (1\text{ m})^2(100\text{ cm}/1\text{ m})^2(1\text{ in}/2.54\text{ cm})^2$$
$$= [(100)^2/(2.54)^2]\text{ in}^2 = 1\,550\text{ in}^2$$

Note that since a conversion factor is equal to 1, it may be squared (or raised to any power) without changing its value.

**1.5.** (*a*) How many cubic centimeters are in one cubic meter? (*b*) How many liters are in one cubic meter? (*c*) How many cubic centimeters are in one liter?

(*a*)
$$1\text{ m}^3 = (1\text{ m})^3\left(\frac{100\text{ cm}}{1\text{ m}}\right)^3 = (10^2\text{ cm})^3 = 10^6\text{ cm}^3$$

(*b*)
$$1\text{ m}^3 = (1\text{ m})^3\left(\frac{10\text{ dm}}{1\text{ m}}\right)^3\left(\frac{1\text{ L}}{1\text{ dm}^3}\right) = 10^3\text{ L}$$

(*c*)
$$1\text{ L} = 1\text{ dm}^3 = (1\text{ dm})^3\left(\frac{10\text{ cm}}{1\text{ dm}}\right)^3 = 10^3\text{ cm}^3$$

**1.6.** Find the capacity in liters of a tank 0.6 m long, 10 cm wide, and 50 mm deep.

Convert to decimeters, since 1 L = 1 dm$^3$.

$$\text{Volume} = (0.6\text{ m})(10\text{ cm})(50\text{ mm})$$
$$= (0.6\text{ m})\left(\frac{10\text{ dm}}{1\text{ m}}\right) \times (10\text{ cm})\left(\frac{1\text{ dm}}{10\text{ cm}}\right) \times (50\text{ mm})\left(\frac{1\text{ dm}}{100\text{ mm}}\right)$$
$$= (6\text{ dm})(1\text{ dm})(0.5\text{ dm}) = 3\text{ dm}^3 = 3\text{ L}$$

**1.7.** Determine the mass of 66 lb of sulfur in (*a*) kilograms and (*b*) grams. (*c*) Find the mass of 3.4 kg of copper in pounds.

(*a*) $$66\text{ lb} = (66\text{ lb})(0.453\,6\text{ kg/lb}) = 30\text{ kg} \quad \text{or} \quad 66\text{ lb} = (66\text{ lb})(1\text{ kg}/2.2\text{ lb}) = 30\text{ kg}$$

(*b*) $$66\text{ lb} = (66\text{ lb})(453.6\text{ g/lb}) = 30\,000\text{ g, or } 3.0 \times 10^4\text{ g}$$

(*c*) $$3.4\text{ kg} = (3.4\text{ kg})(2.2\text{ lb/kg}) = 7.5\text{ lb}$$

## COMPOUND UNITS

**1.8.** Fatty acids spread spontaneously on water to form a monomolecular film. A benzene solution containing 0.10 $mm^3$ of stearic acid is dropped into a tray full of water. The acid is insoluble in water but spreads on the surface to form a continuous film of area 400 $cm^2$ after all of the benzene has evaporated. What is the average film thickness in (*a*) nanometers, (*b*) angstroms?

$$1\text{ mm}^3 = (10^{-3}\text{ m})^3 = 10^{-9}\text{ m}^3 \qquad 1\text{ cm}^2 = (10^{-2}\text{ m})^2 = 10^{-4}\text{ m}^2$$

(*a*) $$\text{Film thickness} = \frac{\text{volume}}{\text{area}} = \frac{(0.10\text{ mm}^3)(10^{-9}\text{ m}^3/\text{mm}^3)}{(400\text{ cm}^2)(10^{-4}\text{ m}^2/\text{cm}^2)} = 2.5 \times 10^{-9}\text{ m} = 2.5\text{ nm}$$

(*b*) $$= 2.5 \times 10^{-9}\text{ m} \times 10^{10}\text{Å/m} = 25\text{ Å}$$

**1.9.** A pressure of one atmosphere is equal to 101.3 kPa. Express this pressure in pounds force (lbf) per square inch.

The pound force (lbf) is equal to 4.448 N.

$$1\text{ atm} = 101.3\text{ kPa} = (101.3 \times 10^3\text{ N/m}^2)\left(\frac{1\text{ lbf}}{4.448\text{ N}}\right)\left(\frac{2.54 \times 10^{-2}\text{ m}}{1\text{ in}}\right)^2 = 14.69\text{ lbf/in}^2$$

Notice that the conversion factor between m and in is squared to give the conversion factor between $m^2$ and $in^2$.

**1.10.** An Olympic-class sprinter can run 100 meters in about 10.0 seconds. Express this speed in (*a*) miles per hour, and (*b*) kilometers per hour. Part (*b*) should be solved first, for it involves only metric units.

(*b*) $$\frac{100\text{ m}}{10.0\text{ s}} \times \frac{1\text{ km}}{1000\text{ m}} \times \frac{60\text{ s}}{1\text{ min}} \times \frac{60\text{ min}}{1\text{ h}} = 36.0\text{ km/h}$$

(*a*) Using the information in problem 1.1:

$$36.0\text{ km/h} \times 1\text{ mi}/1.609\text{ km} = 22.4\text{ mi/h}$$

**1.11.** New York City's 7.9 million people in 1978 had a daily per capita consumption of 656 liters of water. How many metric tons ($10^3$ kg) of sodium fluoride (45% fluorine by weight) would be required per year to give this water a tooth-strengthening dose of 1 part (by weight) fluorine per *million* parts water? The density of water is 1.000 $g/cm^3$, or 1.000 kg/L.

Mass of water, in tons, required per year

$$= (7.9 \times 10^6 \text{ persons})\left(\frac{656 \text{ L water}}{\text{person}\cdot\text{day}}\right)\left(\frac{365 \text{ days}}{\text{yr}}\right)\left(\frac{1 \text{ kg water}}{1 \text{ L water}}\right)\left(\frac{1 \text{ metric ton}}{1000 \text{ kg}}\right)$$

$$= 1.89 \times 10^9 \frac{\text{metric tons water}}{\text{yr}}$$

Note that all units cancel out except metric tons water/yr, which appears in the result.

Mass of sodium fluoride, in tons, required per year

$$= \left(1.89 \times 10^9 \frac{\text{tons (metric) water}}{\text{yr}}\right)\left(\frac{1 \text{ ton fluorine}}{10^6 \text{ tons water}}\right)\left(\frac{1 \text{ ton sodium fluoride}}{0.45 \text{ ton fluorine}}\right)$$

$$= 4.2 \times 10^3 \frac{\text{tons (metric) sodium fluoride}}{\text{yr}}$$

**1.12.** In a measurement of air pollution, air was drawn through a filter at the rate of 26.2 liters per minute for 48.0 hours. The filter gained 0.0241 grams in mass because of entrapped solid particles. Express the concentration of solid contaminants in the air in units of micrograms per cubic meter.

$$[(0.0241 \text{ g})(10^6 \ \mu\text{g}/1 \text{ g})/(48.0 \text{ h})(60 \text{ min/h})]$$
$$\times(1 \text{ min}/26.2 \text{ L}) \times (1 \text{ L}/1 \text{ dm}^3) \times (10 \text{ dm}/1 \text{ m})^3 = 319 \ \mu\text{g/m}^3$$

The answer was estimated as follows:

$$\text{NUM} = 2 \times 10^{-2} \times 10^6 \times 1 \times 1 \times 1 \times 10^3 = 2 \times 10^7$$
$$\text{DEN} = 5 \times 10^1 \times 6 \times 10^1 \times 3 \times 10^1 = 9 \times 10^4$$
$$\text{NUM/DEN} = 222, \text{ or approximately } 200$$

**1.13.** Calculate the density, in g/cm$^3$, of a body that weighs 420 g (i.e., has a mass of 420 g) and has a volume of 52 cm$^3$.

$$\text{Density} = \frac{\text{mass}}{\text{volume}} = \frac{420 \text{ g}}{52 \text{ cm}^3} = 8.1 \text{ g/cm}^3$$

**1.14.** Express the density of the above body in the standard SI unit, kg/m$^3$.

$$(8.1 \text{ g/cm}^3)\left(\frac{1 \text{ kg}}{1\,000 \text{ g}}\right)\left(\frac{100 \text{ cm}}{1 \text{ m}}\right)^3 = 8.1 \times 10^3 \text{ kg/m}^3$$

**1.15.** What volume will 300 g of mercury occupy? Density of mercury is 13.6 g/cm$^3$.

$$\text{Volume} = \frac{\text{mass}}{\text{density}} = \frac{300 \text{ g}}{13.6 \text{ g/cm}^3} = 22.1 \text{ cm}^3$$

**1.16.** The density of cast iron is 7 200 kg/m$^3$. Calculate its density in pounds per cubic foot.

$$\text{Density} = \left(7\,200 \frac{\text{kg}}{\text{m}^3}\right)\left(\frac{1 \text{ lb}}{0.453\,6 \text{ kg}}\right)\left(\frac{0.304\,8 \text{ m}}{1 \text{ ft}}\right)^3 = 449 \text{ lb/ft}^3$$

The two conversion factors were taken from Problem 1.1.

**1.17.** A casting of an alloy in the form of a disk weighed 50.0 g. The disk was 0.250 inch thick and had a circular cross section of diameter 1.380 in. What is the density of the alloy, in $g/cm^3$?

$$\text{Volume} = \left(\frac{\pi d^2}{4}\right)h = \left(\frac{\pi(1.380\ \text{in})^2(0.250\ \text{in})}{4}\right)\left(\frac{2.54\ \text{cm}}{1\ \text{in}}\right)^3 = 6.13\ \text{cm}^3$$

$$\text{Density of the alloy} = \frac{\text{mass}}{\text{volume}} = \frac{50.0\ \text{g}}{6.13\ \text{cm}^3} = 8.15\ \text{g/cm}^3$$

**1.18.** The density of zinc is 455 $lb/ft^3$. Find the mass in grams of 9.00 $cm^3$ of zinc.

First express the density in $g/cm^3$.

$$\left(455\ \frac{\text{lb}}{\text{ft}^3}\right)\left(\frac{1\ \text{ft}}{30.48\ \text{cm}}\right)^3\left(\frac{453.6\ \text{g}}{1\ \text{lb}}\right) = 7.29\frac{\text{g}}{\text{cm}^3}$$

$$(9.00\ \text{cm}^3)(7.29\ \text{g/cm}^3) = 65.6\ \text{g}$$

**1.19.** Battery acid has a density of 1.285 $g/cm^3$ and contains 38.0% by weight $H_2SO_4$. How many grams of pure $H_2SO_4$ are contained in a liter of battery acid?

1 $cm^3$ of acid has a mass of 1.285 g. Then 1 L of acid (1 000 $cm^3$) has a mass of 1 285 g. Since 38.0% by weight (or by mass) of the acid is pure $H_2SO_4$, the number of grams of $H_2SO_4$ in 1 L of battery acid is

$$0.380 \times 1\,285\ \text{g} = 488\ \text{g}$$

Formally, the above solution can be written as follows:

$$\text{Mass of } H_2SO_4 = (1\,285\ \text{g acid})\left(\frac{38\ \text{g}\ H_2SO_4}{100\ \text{g acid}}\right) = 488\ \text{g}\ H_2SO_4$$

Here the conversion factor

$$\frac{38\ \text{g}\ H_2SO_4}{100\ \text{g acid}}$$

is taken to be equal to 1. Although the condition 38 g $H_2SO_4$ = 100 g acid is not a universal truth in the same sense that 1 in always equals 2.54 cm, the condition is a rigid one of association of 38 g $H_2SO_4$ with every 100 g acid for this particular acid preparation. Mathematically, these two quantities may be considered to be equal for this problem, since one of the quantities implies the other. Liberal use will be made in subsequent chapters of conversion factors that are valid only for particular cases, in addition to the conversion factors that are universally valid.

**1.20.** (*a*) Calculate the mass of pure $HNO_3$ per $cm^3$ of the concentrated acid which assays 69.8% by weight $HNO_3$ and has a density of 1.42 $g/cm^3$. (*b*) Calculate the mass of pure $HNO_3$ in 60.0 $cm^3$ of concentrated acid. (*c*) What volume of the concentrated acid contains 63.0 g of pure $HNO_3$?

(*a*) 1 $cm^3$ of acid has a mass of 1.42 g. Since 69.8% of the total mass of the acid is pure $HNO_3$, then the number of grams of $HNO_3$ in 1 $cm^3$ of acid is

$$0.698 \times 1.42\ \text{g} = 0.991\ \text{g}$$

(*b*) Mass of $HNO_3$ in 60.0 $cm^3$ of acid = $(60.0\ \text{cm}^3)(0.991\ \text{g/cm}^3) = 59.5\ \text{g}\ HNO_3$

(*c*) 63.0 g $HNO_3$ is contained in

$$\frac{63.0\ \text{g}}{0.991\ \text{g/cm}^3} = 63.6\ \text{cm}^3\ \text{acid}$$

## TEMPERATURE

**1.21.** Ethyl alcohol (*a*) boils at 78.5 °C and (*b*) freezes at −117 °C, at one atmosphere pressure. Convert these temperatures to the Fahrenheit scale.

Use $$t = \left[\frac{9}{5}\left(\frac{t}{^\circ\mathrm{C}}\right) + 32\right]\,^\circ\mathrm{F}$$

(*a*) $$t = [\tfrac{9}{5}(78.5) + 32]\,^\circ\mathrm{F} = (141 + 32)\,^\circ\mathrm{F} = 173\,^\circ\mathrm{F}$$

(*b*) $$t = [\tfrac{9}{5}(-117) + 32]\,^\circ\mathrm{F} = (-211 + 32)\,^\circ\mathrm{F} = -179\,^\circ\mathrm{F}$$

**1.22.** Mercury (*a*) boils at 675 °F and (*b*) solidifies at −38.0 °F, at one atmosphere pressure. Express these temperatures in degrees Celsius.

Use $$t = \frac{5}{9}\left(\frac{t}{^\circ\mathrm{F}} - 32\right)\,^\circ\mathrm{C}$$

(*a*) $$t = \tfrac{5}{9}(675 - 32)\,^\circ\mathrm{C} = \tfrac{5}{9}(643)\,^\circ\mathrm{C} = 357\,^\circ\mathrm{C}$$

(*b*) $$t = \tfrac{5}{9}(-38.0 - 32.0)\,^\circ\mathrm{C} = \tfrac{5}{9}(-70.0)\,^\circ\mathrm{C} = -38.9\,^\circ\mathrm{C}$$

**1.23.** Change (*a*) 40 °C and (*b*) −5 °C to the Kelvin scale.

Use $$T = \left(\frac{t}{^\circ\mathrm{C}} + 273\right)\,\mathrm{K}$$

(*a*) $$T = (40 + 273)\,\mathrm{K} = 313\,\mathrm{K}$$

(*b*) $$T = (-5 + 273)\,\mathrm{K} = 268\,\mathrm{K}$$

**1.24.** Convert (*a*) 220 K and (*b*) 498 K to the Celsius scale.

Use $$t = \left(\frac{T}{\mathrm{K}} - 273\right)\,^\circ\mathrm{C}$$

(*a*) $$t = (220 - 273)\,^\circ\mathrm{C} = -53\,^\circ\mathrm{C}$$

(*b*) $$t = (498 - 273)\,^\circ\mathrm{C} = 225\,^\circ\mathrm{C}$$

**1.25.** During the course of an experiment, laboratory temperature rose 0.8 °C. Express this rise in degrees Fahrenheit.

Temperature *intervals* are converted differently than temperature *readings*. For intervals, it is seen from Fig. 1-1 that

$$100\,^\circ\mathrm{C} = 180\,^\circ\mathrm{F} \qquad \text{or} \qquad 5\,^\circ\mathrm{C} = 9\,^\circ\mathrm{F}$$

Hence $$0.8\,^\circ\mathrm{C} = (0.8\,^\circ\mathrm{C})\left(\frac{9\,^\circ\mathrm{F}}{5\,^\circ\mathrm{C}}\right) = 1.4\,^\circ\mathrm{F}$$

# Supplementary Problems

## UNITS BASED ON MASS OR LENGTH

**1.26.** (*a*) Express 3.69 m in kilometers, in centimeters, and in millimeters. (*b*) Express 36.24 mm in centimeters and in meters.

*Ans.* (*a*) 0.003 69 km, 369 cm, 3 690 mm; (*b*) 3.624 cm, 0.036 24 m

**1.27.** Determine the number of (*a*) millimeters in 10 in, (*b*) feet in 5 m, (*c*) centimeters in 4 ft 3 in.

*Ans.* (*a*) 254 mm; (*b*) 16.4 ft; (*c*) 130 cm

**1.28.** Convert the molar volume, 22.4 liters, to cubic centimeters, to cubic meters, and to cubic feet.

*Ans.* 22 400 $cm^3$, 0.022 4 $m^3$, 0.791 $ft^3$

**1.29.** Express the weight (mass) of 32 g of oxygen in milligrams, in kilograms, and in pounds.

*Ans.* 32 000 mg, 0.032 kg, 0.070 5 lb

**1.30.** How many grams in 5.00 lb of copper sulfate? How many pounds in 4.00 kg of mercury? How many milligrams in 1 lb 2 oz of sugar?

*Ans.* 2 270 g, 8.82 lb, 510 000 mg

**1.31.** Convert the weight (mass) of a 2 176 lb compact car to (*a*) kilograms, (*b*) metric tons, (*c*) U.S. tons (1 ton = 2 000 lb).

*Ans.* (*a*) 987 kg; (*b*) 0.987 metric ton; (*c*) 1.088 ton (U.S.)

**1.32.** The color of light depends on its wavelength. The longest visible rays, at the red end of the visible spectrum, are $7.8 \times 10^{-7}$ m in length. Express this length in micrometers, in nanometers, and in angstroms.

*Ans.* 0.78 $\mu$m, 780 nm, 7 800 Å

**1.33.** An average person should have no more than 60 grams of fat in his or her daily diet. A certain package of chocolate chip cookies is labeled "1 portion is 3 cookies" and also "fat: 6 grams per portion." How many cookies may one eat before exceeding 50% of one's recommended fat intake?

*Ans.* 15 cookies

**1.34.** In a crystal of platinum, centers of individual atoms are 2.8 Å apart along the direction of closest packing. How many atoms would lie on a one-centimeter length of a line in this direction?

*Ans.* $3.5 \times 10^7$

**1.35.** The blue iridescence of butterfly wings is due to striations that are 0.15 $\mu$m apart, as measured by the electron microscope. What is this distance in centimeters? How does this spacing compare with the wavelength of blue light, about 4 500 Å

*Ans.* $1.5 \times 10^{-5}$ cm, $\frac{1}{3}$ wavelength of blue light

**1.36.** An average man requires about 2.00 mg of riboflavin (vitamin $B_2$) per day. How many pounds of cheese would a man have to eat per day if this were his only source of riboflavin and if the cheese contained 5.5 $\mu$g riboflavin per gram?

*Ans.* 0.80 lb/day

**1.37.** When a sample of healthy human blood is diluted to 200 times its initial volume and microscopically examined in a layer 0.10 mm thick, an average of 30 red corpuscles are found in each $100 \times 100$ micrometer square. (*a*) How many red cells are in a cubic millimeter of blood? (*b*) The red blood cells have an average life of 1 month, and the adult blood volume is about 5 L. How many red cells are generated every second in the bone marrow of the adult?

*Ans.* (*a*) $6 \times 10^6$ cells/mm$^3$; (*b*) $1 \times 10^7$ cells/s

**1.38.** A porous catalyst for chemical reactions has an internal surface area of 800 m$^2$ per cm$^3$ of bulk material. Fifty percent of the bulk volume consists of the pores (holes), while the other 50 percent of the volume is made up of the solid substance. Assume that the pores are all cylindrical tubules of uniform diameter $d$ and length $l$, and that the measured internal surface area is the total area of the curved surfaces of the tubules. What is the diameter of each pore? (*Hint*: Find the number of tubules per bulk cm$^3$, $n$, in terms of $l$ and $d$, by using the formula for the volume of a cylinder. $V = \frac{1}{4}\pi d^2 l$. Then apply the surface-area formula, $S = \pi dl$, to the cylindrical surfaces of $n$ tubules.)

*Ans.* 25 Å

**1.39.** Suppose that a rubber tire loses from its surface, on the average, a layer one molecule thick each time it goes around on the pavement. (By "molecule" you should infer one monomer unit.) Assume that the molecules average 7.50 Å in thickness, and that the tire tread is 35.6 cm in radius and 19.0 cm wide. On a 483 km drive from Pittsburgh to Philadelphia (*a*) how much is the radius reduced (in mm), and (*b*) what volume of rubber (in cm$^3$) is lost from each tire?

*Ans.* (*a*) 0.162 mm; (*b*) 68.8 cm$^3$

## COMPOUND UNITS

**1.40.** The density of water is 1.000 g/cm$^3$ at 4 °C. Calculate the density of water in pounds per cubic foot at the same temperature.

*Ans.* 62.4 lb/ft$^3$

**1.41.** Refer to problem 1.39. If the tire tread has a density of 963 kg/m$^3$, calculate the mass in grams lost by each tire on the trip.

*Ans.* 66.3 g

**1.42.** The silica gel which is used to protect sealed overseas shipments from moisture seepage has a surface area of $6.0 \times 10^5$ m$^2$ per kilogram. What is this surface area in square feet per gram?

*Ans.* $6.5 \times 10^3$ ft$^2$/g

**1.43.** There is reason to think that the length of the day, determined from the earth's period of rotation, is increasing uniformly by about 0.001 s every century. What is this variation in parts per billion?

*Ans.* $3 \times 10^{-4}$ s per $10^9$ s

**1.44.** The bromine content of average ocean water is 65 parts by weight per million. Assuming 100 percent recovery, how many cubic meters of ocean water must be processed to produce 0.61 kg of bromine? Assume that the density of seawater is $1.0 \times 10^3$ kg/m$^3$.

*Ans.* 9.4 m$^3$

**1.45.** An important physical quantity has the value 8.314 joules or 0.082 06 liter · atmosphere. What is the conversion factor from liter · atmospheres to joules?

*Ans.* 101.3 J/L · atm

**1.46.** Find the density of ethyl alcohol if 80.0 $cm^3$ weighs 63.3 g.

*Ans.* 0.791 $g/cm^3$

**1.47.** Find the volume in liters of 40 kg of carbon tetrachloride, whose density is 1.60 $g/cm^3$.

*Ans.* 25 L

**1.48.** A type of plastic foam has a density of 17.7 $kg/m^3$. Calculate the mass in pounds of an insulating slab 4.0 ft wide, 8.0 ft long, and 4.0 in thick.

*Ans.* 11.8 lb

**1.49.** Air weighs about 8 lb per 100 cubic feet. Find its density in (*a*) grams per cubic foot, (*b*) grams per liter, (*c*) kilograms per cubic meter.

*Ans.* (*a*) 36 $g/ft^3$; (*b*) 1.3 g/L; (*c*) 1.3 $kg/m^3$

**1.50.** The estimates for the caloric content of food are: 9.0 Cal/g for fat, and 5.0 Cal/g for carbohydrates and protein. A certain breakfast muffin contains 14% by weight of fat, 64% carbohydrate, and 7% protein (the rest being water, which has no calories). Does it meet the criterion of 30% or less calories from fat, which is recommended for the U.S. population?

*Ans.* Yes, 26% of the calories are from fat.

**1.51.** A wood block, 10 in × 6.0 in × 2.0 in, weights 3 lb 10 oz. What is the density of the wood in SI units?

*Ans.* 840 $kg/m^3$

**1.52.** An alloy was machined into a flat disk. 31.5 mm in diameter and 4.5 mm thick, with a hole 7.5 mm in diameter drilled through the center. The disk weighed 20.2 g. What is the density of the alloy in SI units?

*Ans.* 6 100 $kg/m^3$

**1.53.** A glass vessel weighed 20.2376 g when empty and 20.3102 g when filled to an etched mark with water at 4 °C. The same vessel was then dried and filled to the same mark with a solution at 4 °C. The vessel was now found to weigh 20.3300 g. What is the density of the solution?

*Ans.* 1.273 $g/cm^3$

**1.54.** A sample of lead shot weighing 321 g was added to a graduated cylinder partially filled with isopropyl alcohol (enough to immerse the lead completely). As a result the alcohol level rose 28.3 mL. What is the density of the lead in SI units? (The density of isopropyl alcohol is 0.785 $g/cm^3$.)

*Ans.* $1.13 \times 10^4$ $kg/m^3$

**1.55.** A sample of concentrated sulfuric acid is 95.7% $H_2SO_4$ by weight and its density is 1.84 $g/cm^3$. (*a*) How many grams of pure $H_2SO_4$ are contained in one liter of the acid? (*b*) How many cubic centimeters of acid contain 100 g of pure $H_2SO_4$?

*Ans.* (*a*) 1 760 g; (*b*) 56.8 $cm^3$

**1.56.** A quick method of determining density utilizes Archimedes' principle, which states that the buoyant force on an immersed object is equal to the weight of the liquid displaced. A bar of magnesium metal attached to a balance by a fine thread weighed 31.13 g in air and 19.35 g when completely immersed in hexane (density 0.659 $g/cm^3$). See Fig. 1-2. Calculate the density of this sample of magnesium in SI units.

*Ans.* 1 741 $kg/m^3$

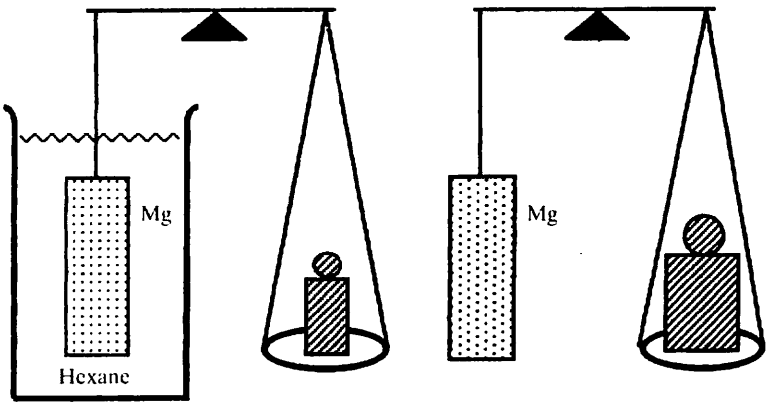


**Fig. 1-2**

**1.57.** An electrolytic tin-plating process gives a coating 30 millionths of an inch thick. How many square meters can be coated with one kilogram of tin, density 7 300 kg/m$^3$?

*Ans.* 180 m$^2$

**1.58.** A piece of gold leaf (density 19.3 g/cm$^3$) weighing 1.93 mg can be beaten further into a transparent film covering an area of 14.5 cm$^2$. (*a*) What is the volume of 1.93 mg of gold? (*b*) What is the thickness of the transparent film, in angstroms?

*Ans.* (*a*) $1.00 \times 10^{-4}$ cm$^3$; (*b*) 690 Å

**1.59.** A piece of capillary tubing was calibrated in the following manner. A clean sample of the tubing weighed 3.247 g. A thread of mercury, drawn into the tube, occupied a length of 23.75 mm, as observed under a microscope. The weight of the tube with the mercury was 3.489 g. The density of mercury is 13.60 g/cm$^3$. Assuming that the capillary bore is a uniform cylinder, find the diameter of the bore.

*Ans.* 0.98 mm

**1.60.** The General Sherman tree, located in Sequoia National Park, is believed to be the most massive of living things. If the overall density of the tree trunk is assumed to be 850 kg/m$^3$, calculate the mass of the trunk by assuming that it may be approximated by two right conical frusta having lower and upper diameters of 11.2 and 5.6 m, and 5.6 and 3.3 m, respectively, and respective heights of 2.4 and 80.6 m. A frustum is a portion of a cone bounded by two planes, both perpendicular to the axis of the cone. The volume of a frustum is given by

$$\tfrac{1}{3}\pi h(r_1^2 + r_2^2 + r_1 r_2)$$

where $h$ is the height and $r_1$ and $r_2$ are the radii of the circular ends of the frusta.

*Ans.* $1.20 \times 10^6$ kg = 1 200 metric tons

## TEMPERATURE

**1.61.** (*a*) Convert 88 °F to °C; 16 °F to °C; 130 °F to °C. (*b*) Convert 35 °C to °F; 2 °C to °F; −29 °C to °F.

*Ans.* (*a*) 31 °C, −9 °C, 54 °C; (*b*) 95 °F, 36 °F, −20 °F

**1.62.** Convert the following temperatures: −149.7 °C to °F; −396.0 °F to °C; 1 555 °C to °F.

*Ans.* −237.5 °F, −237.8 °C, 2 831 °F

**1.63.** The temperature of dry ice (sublimation temperature at normal pressure) is $-109\ ^\circ F$. Is this higher or lower than the temperature of boiling ethane (a component of bottled gas), which is $-88\ ^\circ C$?

*Ans.* higher

**1.64.** Gabriel Fahrenheit in 1714 suggested for the zero point on his scale the lowest temperature then obtainable from a mixture of salts and ice, and for his $100^\circ$ point he suggested the highest known normal animal temperature. Express these "extremes" in degrees Celsius.

*Ans.* $-17.8\ ^\circ C$, $37.8\ ^\circ C$

**1.65.** Sodium metal has a very wide liquid range, melting at $98\ ^\circ C$ and boiling at $892\ ^\circ C$. Express the liquid range in degrees Celsius, kelvins, and degrees Fahrenheit.

*Ans.* $794\ ^\circ C$, 794 K, $1\,429\ ^\circ F$

**1.66.** Convert 298 K, 892 K, 163 K, to degrees Celsius.

*Ans.* $25\ ^\circ C$, $619\ ^\circ C$, $-110\ ^\circ C$

**1.67.** Express 11 K, 298 K, in degrees Fahrenheit.

*Ans.* $-440\ ^\circ F$, $77\ ^\circ F$

**1.68.** Convert $23\ ^\circ F$ to degrees Celsius and kelvins.

*Ans.* $-5\ ^\circ C$, 268 K

**1.69.** At what temperature have the Celsius and Fahrenheit readings the same numerical value?

*Ans.* $-40^\circ$

**1.70.** A water-stabilized electric arc was reported to have reached a temperature of $25\,600\ ^\circ F$. On the absolute scale, what is the ratio of this temperature to that of an oxyacetylene flame, $3\,500\ ^\circ C$?

*Ans.* 3.84

**1.71.** Construct a temperature scale on which the freezing and boiling points of water are $100^\circ$ and $400^\circ$, respectively, and the degree interval is a constant multiple of the Celsius degree interval. What is the absolute zero on this scale, and what is the melting point of sulfur, which is $444.6\ ^\circ C$?

*Ans.* $-719^\circ$, $1\,433.8^\circ$