CHAPTER 1

Fire Measurement and the SI System of Units

OBJECTIVES

After studying this chapter, you should be able to:

- Explain the importance of measurement in understanding fire behavior.
- Name the basic SI units of measurement and covert between values in SI units and English units.
- Understand the precision of a measurement and the reduced precision used in estimations.
- Explain the differences between mass and weight and among energy, heat, and enthalpy.

Introduction

In 1999, the *Mars Climate Orbiter* miscalculated the distance to the planet's surface and disintegrated in the planetary atmosphere. The cause was human error. The spacecraft was programmed with English units, but NASA used metric units. The difference in measuring units led to the incorrect transfer of the navigational information between the spacecraft's manufacturer team in Denver, Colorado, and the flight team in Pasadena, California—and the ultimate destruction of the spacecraft. Input data for engineering calculations can be tabulated in a variety of units. To avoid serious consequences, it is critical that the input data, the calculation method, and the calculated values all use a consistent set of units.

About Measurement

Measurement is the key to understanding fire phenomena and to translating that understanding into fire safety practice. To help understand the phenomena, it is important to ask when the fire started, how rapidly it grew, how hot it became, and how severe the threat to the population was. The answers to all of these (and many other) questions are rooted in an ability to quantify. The meaning of relative terms, such as "fast moving" or "big," varies widely depending on people's experiences and perceptions. To a gardener, a big fire may involve a large pile of leaves; in contrast, to an insurance company, a big fire may be one that destroys a house.

Given the many different languages of the world, it is not surprising that the early cultures made up their own methods to measure objects, frequently cast in terms of properties of the human body. (That way, you always had your "yardstick" with you.) The units of measurement varied from region to region and often from person to person. For example, the Chinese measured length using the bu (about 1.67 m), the Anglo-Saxons used the ell (about 1.14 m), and the Spaniards used the vara (about 0.86 m). As cultures expanded to the point of geographical contiguity, and as trade among multiple cultures began to prosper, the need for a common set of measurements grew.

The current international measurement system, also known as the metric system, was introduced in France by Napoleon at the beginning of the 19th century. It was refined further in the 1960s, and certain units, referred to as **SI units**, were agreed upon. *SI* comes from the French name *Système International d' Unités.*

All industrialized countries, with the exception of the United States and to some extent the United Kingdom, have chosen SI units to express mass, length, time, electrical current, temperature, and other measures. Adoption of the SI system facilitates the following:

- Quantitative communication regarding nearly everything, from the weather to the multitudinous forms of life.
- Exchange of manufactured products among countries.
- Computations, due to the use of factors of 10 for each unit. Instead of 12 inches in 1 foot and 5280 feet in a mile, SI uses 1000 millimeters in 1 meter and 1000 meters in 1 kilometer.

In the United States, the primary users of SI units today are scientists and engineers. In other countries, both scientists and ordinary citizens primarily use SI units or are in the process of changing over to their use. Because the data compiled in different engineering references are in either SI or English units, it is important that the U.S. reader learn to convert between the two systems.[1]

When a quantity is measured, there is a limit to the **precision** of the value that is obtained. If a length measurement is performed with an inexpensive ruler, it may be possible to read only the nearest millimeter marking. A value might then be reported as 147 mm, in which case the length is represented by three **significant figures**. With a more meticulously marked ruler and a magnifying glass, it would be possible to estimate the length more precisely and report the value to four significant figures—for example, 147.3 mm. One should report a value to the number of significant figures. Using an electronic measuring device with a 10-digit display does not increase the number of significant figures. Similarly, entering a number into a computer spreadsheet in which the cells are set to display 10 digits does not increase the number of significant figures in the value.

When *estimating* a calculated value, it is acceptable to speed the calculation by using fewer than the actual number of significant figures. Thus, in estimating the total surface area of the Earth, one might assume that the planet is a perfect sphere with a radius of about 6000 km. The surface area is given by the formula $4\pi r^2$ (where r = the planet's radius), and the value of π is close to 3. The magnitude of the surface area can then be estimated at approximately 500,000,000 km^2, reported to one significant figure.

Length, Area, and Volume Units

The basic SI unit of *length* is the **meter (m)**. Originally, the meter was selected as 1/10,000,000 of the distance from the Earth's equator to the North Pole. Toward the end of the 19th century, however, it was redefined as the distance between two lines on a standard bar composed of an alloy of 90 percent platinum and 10 percent iridium, measured when the bar is at the melting temperature of ice. The meter is currently defined as the length of the path traveled by light in 1/299,792,458 of 1 second. Table 1-1 shows various SI "meter" units as they relate to the English equivalents. References [1] and [2] at the end of the chapter contain more conversions among length (and other) units.

Table 1-1 SI Length Units as Related to the Meter, with English Equivalents

SI Unit	Abbreviation	Metric Equivalent	English Equivalent
kilometer	km	1000 m	0.621 mi; 3280 ft
meter	m	1 m	39.37 in.; 3.28 ft
decimeter	dm	0.1 m	3.94 in.
centimeter	cm	0.01 m	0.394 in.
millimeter	mm	10^{-3} m	0.0394 in.
micrometer	μm	10^{-6} m	3.94×10^{-5} in.
nanometer	nm	10^{-9} m	10 Å (angstrom), 3.94×10^{-8} in.

[1] The relationships among the units of these fundamental properties are quite precise. The conversion factors in this chapter have been rounded to a number of significant figures that provides sufficient precision while maintaining ease of computation. For sources of conversion factors of higher precision, type "SI units" in a web browser and visit the presented sites or see References [1] and [2] at the end of this chapter.

Notice that "in." is the abbreviation for inches. The period is included to distinguish it from the preposition "in"; it is the only abbreviation that is followed by a period.

Formally, SI dimensions are given in multiples of 1000 (km, m, mm, and so on). Nevertheless, some intermediate factors of 10 (e.g., cm, dm) are widely used.

Area is two-dimensional and, for a rectangular flat surface, is the length of the surface times its width. In the SI system, small areas can be expressed in square meters (m^2), square centimeters (cm^2), and so on. In the English system, areas of similar size are expressed in square inches ($in.^2$) or square feet (ft^2). Larger areas, such as tracts of land, are expressed in hectares (ha) in the metric system; 1 hectare is 10,000 m^2. The English equivalent of one hectare is 2.47 acres. In fire dynamics, the cross-sectional area of a vent is used to calculate the flow through the vent, and the area of a hot surface is used to calculate the heat transferred to a colder object.

Volume is three-dimensional. For a rectangular space, such as a room, it is the length times the width times the height. Volume can be expressed in cubic meters (m^3), cubic centimeters (cm^3), and so on. The liter (L) is commonly used as a unit of liquid and gas volume, and is the same as 1 cubic decimeter (dm^3) or 1000 cubic centimeters (1000 cm^3). One liter is equivalent to 0.264 U.S. gallon or 1.056 quarts.

Mass and Density Units

The basic SI unit of mass is the **kilogram (kg)**. The kilogram was selected because it is approximately the mass of 1 liter of water. (The mass of a volume of water varies because water expands or contracts slightly as its temperature changes.) The gram (g), also widely used, is 1/1000 of a kilogram, and is approximately the mass of 1 cubic centimeter (cc) of water. Table 1-2 shows the relationship of various mass units to the kilogram (with their English equivalents). To convert from metric units to English units, multiply the metric value by the number in the right column. To convert from English units to metric units, divide the English value by the number in the right column.

Table 1-2 SI Mass Units as Related to the Gram, with English Equivalents

SI Unit	Abbreviation	Metric Equivalent	English Equivalent
metric ton	t	10^3 kg	1.10 U.S. ton
kilogram	kg	10^3 g	2.20 lb
gram	g	1 g	0.0353 oz
milligram	mg	10^{-3} g	2.2×10^{-6} lb
microgram	μg	10^{-6} g	2.2×10^{-9} lb
nanogram	ng	10^{-9} g	2.2×10^{-12} lb

The concepts of mass and weight are often confused. The **mass** of an object is a fundamental property of the object, representing the quantity of matter in the object. An object's mass is invariant (except in a nuclear bomb explosion, when mass changes into energy). By comparison, **weight** refers to the force acting on an object because of gravity attraction and is a convenient way to measure mass on Earth at sea level. If an object were on the moon, its weight would be only about one-sixth of its weight on Earth, and if the same object were in an orbiting space station; it would be nearly weightless. However, its mass would be the same in all three cases.

Density is the mass of a substance in a unit volume. It is generally is expressed in grams per cubic centimeter (g/cm^3), kilograms per cubic meter (kg/m^3) or, in English units, pounds per cubic foot (lb/ft^3). The term **specific gravity** refers to the ratio of the density of a substance to that of a reference substance. For liquids and solids, the reference substance is usually water; for gases, the reference substance is air. Especially for gases and liquids, the temperature and pressure must also be specified, because the densities of the substance of

Table 1-3 Densities of Selected Materials [2]

Material	Density (g/cm^3)	Temperature (K)	Pressure (bar)
air	0.00118	300	1.00
water	1.00	273	1.00
oils	0.90 to 0.97	288	≈ 1
balsa wood	0.11 to 0.14		
oak	0.6 to 0.9		
window glass	2.4 to 3.8		
aluminum	2.7		
iron	7.9		
granite	2.6 to 2.8		

interest and the reference substance depend on the temperature and pressure (Table 1-3). The densities of most solids are less sensitive to temperature and pressure.

For mixtures of two or more substances, there are multiple ways of denoting the relative prevalence of each component.

- **Concentration**: the mass of a component per unit volume.
- **Volume fraction** (gases): the ratio of the volume that a gas in the mixture would occupy (at standard temperature and pressure) to the total volume of the system. This is sometimes multiplied by 100 to obtain the *volume percent*. Thus the volume fraction of oxygen in dry air is 0.209, and the volume percent of oxygen in dry air is 20.9 percent. (There is more on the composition of air in the *Physical and Chemical Change* chapter.)
- **Mass fraction**: the ratio of the mass of a component in a mixture to the total mass of the mixture. This can also be multiplied by 100 to obtain the *mass percent*. Thus, for dry air, the mass fraction of oxygen is 0.233 and the mass percent is 23.3 percent.

Note

Historically, there has been extensive use of units like ppm (parts per million), such as to indicate a concentration of a toxic gas in fire smoke, or pph (parts per hundred), such as to indicate the amount of fire retardant added to a plastic material. There is a critical ambiguity in these units: "ppm" might refer to 1 g of material X in 1000 kg material Y or 1 cm^3 of material X in 1000 L of material Y. As a result, the use of these types of units is discouraged. The units to be used instead of ppm are μL/L for volume fractions and mg/kg for mass fractions. These are numerically identical: 1 mg/kg = 1 ppm by mass.

Time Units

Units for *time* are the same in the SI system and the English system. The basic unit is the second (s). Table 1-4 shows abbreviations for related time units.

Speed is the rate at which an object is moving, with typical metric units being m/s or km/h. *Velocity* is speed in a chosen direction. Thus, if a train is moving to the northeast at a speed of 150 km/h, its velocity in the east direction is 106 km/h ($150/\sqrt{2}$). (An alternative wording is that the train is moving eastward at 106 km/h.) Colloquially, when the speaker and the audience both understand the direction of movement, the terms may be used synonymously.

Table 1-4 Time Units (SI and English)

Time Unit	Abbreviation
hour	h
minute	min
second	s
millisecond	ms
microsecond	μs
nanosecond	ns

Acceleration is the rate of change of speed. Typical metric units are m/s^2 and km/h.

Note

SI units named for a person are abbreviated using a capital letter. When the unit is spelled out, it begins with a lowercase letter except when it appears at the beginning of a sentence or in a title.

Force and Pressure Units

The basic unit of **force** in the SI system is the **newton (N)**. A newton is the force needed to accelerate a mass of 1 kg at the rate of 1 m/s^2. In the English system, 1 lb of force is the force that will accelerate 1 lb of mass at the rate of 32.2 ft/s^2. This definition was selected so that 1 lb of mass at sea level would feel a gravitational attraction of 1 lb of force. (Note the use of the same term, lb, to denote two different types of units.)

From the relation between the pound of mass and the kilogram, and the relation between the foot and the meter, it is easy to show that 1 newton is equal to 0.224 pound of force. The gravitational force on 1 kg at sea level is 9.81 N.

Pressure is force per unit area. The basic SI unit of pressure is the **pascal (Pa)**, which is 1 N/m^2. One Pa is a very low pressure, so a unit called the **bar** is also used. A bar is defined as 100,000 Pa or 100 kilopascals (kPa). One bar is only 1.3 percent greater than normal atmospheric pressure at sea level (101.3 kPa); therefore, for approximate calculations, 1 bar is often equated to 1 atmosphere (atm).

Several English units of pressure arose out of convenience in particular applications. The following describes the more common ones:

- Testing of the fracture or deformation condition for materials gave rise to the unit of pounds per square inch (psi). The pressure of compressed gases in their storage cylinders is commonly monitored in psig, where the "g" stands for "gauge." This is the pressure above atmospheric pressure. Pressures in psig are 14.7 psi lower than pressures in psia, where "a" stands for "absolute."
- Manometers (glass U-shaped tubes filled with a fluid) were frequently used to measure pressure differences or absolute atmospheric pressure. When using a manometer, the measured height of the liquid column is proportional to the gas pressure. The two commonly used fluids were mercury (Hg) and water (H_2O). The conversion factors from SI units are as follows:

  101 kPa = 760 mm Hg (also referred to as *torr*)
  101 kPa = 4020 in. H_2O

  The latter units are often used to measure the small pressure differences that arise within buildings due to the heating and air conditioning systems. Manometers are no longer in general use: mercury is toxic and must be disposed as hazardous waste, while a water manometer can be very large.

SI pressure units are becoming more widely used in these applications, but they have not fully displaced these English units in engineering practice and reference tables.

Energy and Enthalpy Units

A fire in a closed, *constant-volume* system generates **energy**. The increase in energy transfers heat to the system, raising the pressure within the volume, and increasing the temperature of the gases, the combustibles, and the "box" itself. Of course, most fires occur in an environment of nearly constant pressure, as even a small pressure increase breaks windows and otherwise spreads the combustion products out of the room of fire origin. Additional energy release is needed to expand the gases to keep the system at the starting pressure. This augmented energy release is defined as the increase in **enthalpy**, and it is the parameter that is properly considered in characterizing a fire. (The use of the term "energy release" has been widely misused to be synonymous.) If the enthalpy increase as a whole simply raises the temperature and expands any gases that are present, then the enthalpy change is equal to the **heat** released.

The basic SI unit of enthalpy, energy, or heat is the **joule (J)**. A joule is the quantity of energy expended when applying a force of 1 N through a distance of 1 m. Thermal energy as well as mechanical energy can be expressed in joules. One joule equals 0.239 calorie (cal), or 4.187 J equals 1 cal. A calorie is the energy needed to heat 1 g of water by 1 °C. (A dietary "calorie" is actually 1000 calories.)

A particularly important type of enthalpy or heat release is the **heat of combustion**. This quantity is the maximum heat that can be generated in the burning of a material. As such, it represents the upper limit of the contribution of a combustible item to a fire. Under some fire conditions, a combustible item will burn inefficiently, releasing less than the full heat of combustion; this smaller value is called the effective heat of combustion. The units for both heat releases are typically kJ/g. This subject will be developed further in the *Physical and Chemical Change* chapter.

In English units, enthalpy is expressed in foot-pounds (ft-lb) or British thermal units (Btu). One ft-lb is equal to 1.355 J, and 1 Btu is equal to 1055 J or 252 cal.

Power Units

Power is the rate at which enthalpy or energy is expended. In SI units, power is expressed in **watts (W)**. One watt is 1 J/s. The kilowatt (1000 W) and the megawatt (MW; equal to 1,000,000 W) are used frequently. The heat generated in a fire is generally expressed in kW or MW.

In English units, horsepower (hp) and British thermal units (Btu) are still used. One horsepower equals 745 W. One Btu/s is equal to 1.055 kW; thus, when estimating power generation or consumption, it is reasonable to approximate 1 kW was being equal to 1 Btu/s.

Temperature Units

Temperature is a measure of the warmth or coldness of a substance. Two temperature scales are used in the SI system: the **Celsius scale (°C)** and the **Kelvin scale (K).**

On the Kelvin scale, sometimes called the *thermodynamic temperature scale*, negative temperatures do not occur. The zero point on the Kelvin scale is called **absolute zero** and equals −273.15 °C on the Celsius scale. No temperature colder than this is possible.

Other features of the Kelvin scale indicate its basic nature:

- The volume occupied by a gas is proportional to its temperature on the Kelvin scale, as long as its pressure is maintained constant.
- The thermal radiation emitted by a flame or a hot surface is proportional to the fourth power of the Kelvin temperature.
- The velocity of sound through a gas is proportional to the square root of its Kelvin temperature.

Because of these and other scientific facts, it would be logical to use only the Kelvin scale for temperature. However, the Celsius scale (previously called the *Centigrade scale*) was used for more than a century before these facts were discovered, so the world continues to use both scales. On the Celsius scale (at sea level), water freezes at 0 °C and boils at 100 °C. Negative temperatures as low as –273.15 °C are possible.

Temperature using the Kelvin scale is expressed in "kelvins," not "degrees Kelvin." The magnitude of 1 K is the same as 1 °C. To convert from K to °C, subtract 273.15 (generally simplified as 273). To convert from °C to K, add 273 (Equation 1-1):

$$°C + 273 = K \qquad \text{(Equation 1-1)}$$

For example, 20 °C = 293 K, and −10 °C = 263 K.

The English system uses the Fahrenheit scale (°F), where 0 °F was chosen as the temperature at which a brine solution (reached by mixing water and salt) would freeze. On this scale (at sea level), water freezes at 32 °F and boils at 212 °F. Conversions from °F to °C are computed using the formula in Equation 1-2:

$$(°F - 32)/1.8 = °C \qquad \text{(Equation 1-2)}$$

Conversions from °C to °F are computed using the formula in Equation 1-3:

$$1.8(°C) + 32 = °F \qquad \text{(Equation 1-3)}$$

For example, 86 °F = (86 – 32)/1.8 = 30 °C, and 25 °C = (1.8 × 25) + 32 = 77 °F.

Conversion Factors

References [1] and [2] at the end of this chapter contain extensive conversion factors among SI units and other units. Some pocket calculators and websites also offer conversion factors. Table 1-5 provides conversion factors for most of the quantities discussed in this text.

In practice, it is helpful to use a consistent set of denominations for units. This reduces the likelihood of error from mixing two units of mass (e.g., g and kg) in a calculation. Two sets of metric units are commonly used:

- The meter–kilogram–second system, known as the "MKS" system. Lengths are expressed in meters (m), mass in kilograms (kg), and time in seconds (s).
- The "cgs" system. Lengths are expressed in centimeters (cm), mass in grams (g), and time in seconds (s).

Temperature units are the same (K and °C) in both systems.

MKS units are generally preferred, but the magnitude of the calculated quantity can guide the choice of system. For example, automobile velocity (tens of meters per second) might be expressed in MKS units, while the dimensions of a human finger are conveniently expressed in cm.

Table 1-5 Conversion Factors among Common Units. To convert Column A to Column B, *multiply* Column A by Column C. To convert Column B to Column A, *divide* Column B by Column C.

Column A		Column B		Column C
U.S. Unit	**Abbreviation**	**SI Unit**	**Abbreviation**	**Conversion Factor**
inch	in.	centimeter	cm	2.54
foot	ft	meter	m	0.305
mile	mi	kilometer	km	1.61
miles/hour	mi/h	meters per second	m/s	0.447
square feet	ft^2	square meter	m^2	0.0930
acre	acre	hectare	ha	0.405
cubic feet	ft^3	liter	L	28.3
gallon (U.S.)	gal (U.S.)	liter	L	3.785
pound (mass)	lb (mass)	kilogram	kg	0.454
ton	ton (U.S.)	metric ton	ton (metric)	0.907

Column A		Column B		Column C
U.S. Unit	**Abbreviation**	**SI Unit**	**Abbreviation**	**Conversion Factor**
pound per cubic inch	$lb/in.^3$	gram per cubic centimeter	g/cc	27.7
pound per cubic foot	lb/ft^3	gram per cubic centimeter	g/cc	0.0160
pound (force)	lb (force)	newton	N	4.45
pound per square inch	psi	kilopascal	kPa	6.90
pound per square inch	psi	atmosphere	atm	0.0689
atmosphere	atm	bar	bar	1.013
foot-pound	ft-lb	joule	J	1.356
British thermal unit	Btu	joule	J	1.055
calorie	cal	joule	J	4.187
Btu per second	Btu/s	kilowatt	kW	1.055
horsepower	hp	joule per gram	kW	0.746
Btu per pound	Btu/lb	joule per gram	J/g	2.33
Btu per pound-°F	Btu/lb-°F	joule per gram-°C	J/g-°C	4.18
Btu per pound-°F	Btu/lb-°F	calorie per gram-°C	cal/g-°C	1.000
Btu per square foot-second	Btu/ft^2-s	kilowatt per square meter	kW/m^2	11.35
calorie per square centimeter-second	cal/cm^2-s	kilowatt per square meter	kW/m^2	41.87
gallon (U.S.) per minute-square foot	gal/min-ft^2	millimeter depth/minute	mm/min	40.7

WRAP-UP

Chapter Summary

- The ability to quantify, or measure, is essential to understanding fire phenomena and to performing fire safety calculations.
- The basic measurements for fire phenomena are time, length, area, volume, mass, density, force, pressure, enthalpy and energy, power, and temperature.
- There are multiple units for each of these measurements. Metric units are most widely used worldwide; English units remain in use in the United States.
- Familiarity with these various units and their interconversion can minimize the chance of making a serious calculation error.

Key Terms

absolute zero The lowest possible temperature, at which all molecular motion has ceased. This temperature is 0 K, −273.15 °C, and −459.67 °F.

accuracy The degree of closeness of measurements of a quantity to that quantity's actual (true) value.

bar A unit of pressure equal to 10^5 Pa or 10^2 kPa.

Celsius scale (°C) A temperature scale in which 0 °C and 100 °C are the freezing point and boiling point of water, respectively.

concentration The quantity of a substance in a mixture per unit volume of the mixture.

density Usually, the mass of a substance per unit volume. However, when an extinguishing agent is applied to a surface, the term *density* is used to mean the mass rate of application of agent per unit of surface.

energy The capacity to do work or effect a change within a system at constant volume.

enthalpy The capacity to do work or effect a change for a system at constant pressure. The enthalpy released is equal to the energy released plus the change in the product of the temperature and pressure.

force The influence on a body that causes it to accelerate if it is free to move.

heat The enthalpy or energy that travels from a higher temperature source to a lower temperature sink.

heat of combustion (at constant pressure) The enthalpy released when 1 mole of a combustible item reacts completely with oxygen at atmospheric pressure and 298 K to form combustion products at 298 K.

joule (J) The basic SI unit of energy or enthalpy. It is equal to a force of 1 N acting through a distance of 1 m.

Kelvin scale (K) A temperature scale in which 0 K is absolute zero and 1 K equals 1 °C.

kilogram (kg) The basic unit of mass in the SI system. Its magnitude is defined as the mass of an object called the *international prototype kilogram*, made of an alloy (90 % platinum and 10 % iridium by mass), machined into a right-circular cylinder, 39.17 mm in both diameter and height.

mass The fundamental inertial property of an object.

mass fraction The mass of a substance in a mixture per unit mass of the mixture.

meter (m) The basic SI unit of length. It is defined as the length of the path traveled by light in 1/299,792,458 of 1 second.

newton (N) The basic SI unit of force. It is the force needed to accelerate a mass of 1 kg at the rate of 1 m/s^2.

pascal (Pa) The basic SI unit of pressure, or force per unit area. It is equal to a force of one N exerted over an area of one square meter.

power The rate at which enthalpy or energy is expended.

precision The degree to which the correctness of a quantity is expressed.

pressure Force per unit area.

SI units The units used in the metric system of measurement.

significant figures In a number, those digits that carry meaning contributing to its precision.

specific gravity The ratio of the density of a substance to the density of a reference substance at a specified temperature and pressure. For gases, the reference substance is generally taken to be dry air. For liquids, the reference substance is water.

volume fraction The volume of a gas in a mixture of gases per unit volume of the mixture.

watt (W) The fundamental SI unit of power. It is equal to the expenditure of one joule for one second.

Challenging Questions

1. Using the units presented in this chapter, list 10 quantities that might be useful in describing a fire.
2. Normal body temperature is 98.6 °F, and a 5 °F increase represents a serious fever. Convert these values to °C and then to *kelvins*.
3. A fire truck 12 m long is traveling at 90 km/h. Convert these values to English units.
4. A fire pump pressurizes water at 60 psi above atmospheric pressure and pumps it at the rate of 300 U.S. gal/min. Convert these values to SI units.
5. An electric motor self-heats to 15 °C above ambient temperature when operating steadily. If the ambient temperature is 70 °F, what is the operating temperature of the motor in °F?
6. An automatic sprinkler applies water at a "density" of 0.3 gal/min/ft^2. Convert this to SI units.
7. If the heat of combustion of benzene is 40 kJ/g, what is it in cal/g? In Btu/lb?
8. A 170 lb fire fighter is carrying 75 lb of equipment up (10 in.) stairs. There are 15 stairs per story in this building. How many dietary calories does the fire fighter burn in climbing 10 flights of stairs?
9. If the same fire fighter were part of a colony on Jupiter, where the force of gravity is 2.5 times that on Earth, what would the fire fighter's mass be? What would his weight be?

References

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2. Haynes, W. M., ed. *Handbook of Chemistry and Physics*, 92nd ed. Boca Raton, FL: CRC Press, 2011: Section 1.