Chapter 1. Measurement

Section 1.1. Measuring Things, Including Lengths

Note. Measurements of physical quantities are a basic part of physics. Quantities measured in physics include length, time, mass, speed, temperature, force, pressure, work, energy, electrical current, resistance, and capacitance. The *unit* is a unique name we assign to measures of a particular physical quantity. For example, we use the meter as the unit for measuring length. Now, we need to determine exactly how long a meter is; that is, we need a *standard* which determines the length of a meter. Some physical quantities act as *base quantities* (such as length and time), and other physical quantities are measured in terms of base quantities (for example, speed is measured in units of length/time or, if you like, distance/time).

Note. In 1971, the 14th General Conference on Weights and Measures picked seven quantities as base quantities. These seven units make up the *International System of Units*, or *SI* units. These units are given in Table 1-1A.

Table 1-1A. Units for the Seven SI Base Quantities

Quantity	Unit Name	Unit Symbol
Length	meter	m
Time	second	s
Mass	kilogram	kg
Temperature	Kelvin	$^\circ$K
Electrical Current	ampere	A
Intensity of Light	candela	cd
Amount of Substance	mole	mol

An SI *derived unit* is defined in terms of base units. For example, speed is measured in units of m/s, and power is measured in watts where 1 watt equals $1 \text{ kg} \cdot \text{m}^2/\text{s}^3$.

Note. We assume a working knowledge of *scientific notation*. For example,

$$3\,560\,000\,000 \text{ m} = 3.56 \times 10^9 \text{ m and } 0.000\,000\,492 \text{ s} = 4.92 \times 10^{-7} \text{ s}.$$

(Notice that we use small spaces instead of commas to block off digits.) When dealing with very large or very small measurements, we use the prefixes listed in Table 1-2, which are based on powers of 10. Notice that we have the familiar situation where 1 km = 1000 m.

Table 1-2 Prefixes for SI Units

Factor	Prefix[a]	Symbol
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

[a]The most frequently used prefixes are shown in bold type.

Note 1.1.A. Since we may measure quantities in units other than basic units (or even standard units), then there is a need to convert from one unit of measure to another; Halliday and Resnick call this process *chain-link conversion*. For example, we could measure time in minutes ("min") instead of seconds. We know that 1 min = 60 s. We use this equation to create *conversion factors* as follows:

$$\frac{1\text{ min}}{60\text{ s}} = 1 \text{ and } \frac{60\text{ s}}{1\text{ min}} = 1.$$

We treat the units as if they were numbers and cancel them when they appear in quotients. If we want to convert 2 min to seconds, we multiply by the appropriate conversion factor (the one on the right above, in this case) to eliminate the units of minutes and introduce the units of seconds:

$$2\text{ min} = (2\text{ min})(1) = (2\text{ min})\left(\frac{60\text{ s}}{1\text{ min}}\right) = 120\text{ s}.$$

Appendix D of Halliday and Resnick give equations that can be used to produce a number of conversion factors, including those that allow us to convert metric units to U.S. units. It is common to see U.S. units used in engineering classes.

Note. In 1792, the Republic of France gave a definition of a meter as one ten-millionth of the distance from the north pole to the equator. This lacks practical use, but it represents a big step in the direction of standardization. This definition was replaced with the distance between to lines engraved on a platinum-iridium bar, the *standard meter bar*, kept at the International Bureau of Weights and Standards near Paris. Copies of the bar, called "secondary standards," were made and distributed worldwide. In 1960, a new more mobile standard meter was defined as 1 650 763.73 wavelengths of light emitted by atoms of krypton-86. The gas could stored in a tube and excited to produce the light in various labs around the world without the need for access to a standard metal bar. This definition was revised in 1983 based on the extremely accurately known speed of light. A meter was defined as the distance light travels in $1/299\,792\,458$ of a second.

Note 1.1.B. We now discuss *significant figures*. Since experimental physical quantities result from actually measuring something with some type of device (a ruler, stopwatch, scale, etc.) then these numerical values have only a certain level of accuracy. In scientific notation, a number such as 3.15×10^3 has three significant digits (given by the 3, 1, and 5). The number 0.00356 also has three significant digits because $0.00356 = 3.56 \times 10^{-3}$. It should make sense that we consider this approach to discuss levels of accuracy, instead of the number of digits (because we could jump around between meters, kilometers, or millimeters and that has an effect on the number of digits, but should not affect the accuracy of the measurements). When we perform computations, we round final results to match the least number of significant figures in the given data. When rounding to a certain number of significant figures, we look to the next figure and discard it (and the digits to the right of it) if it is less than 5, and round up the last significant figure if this next figure is 5 or more. For example, 11.3516 rounds up to three significant figures as 11.4, and 11.3279 rounds down to three significant figures as 11.3. In the book, equal signs are used instead of $\approx$, even though rounding has occurred. **In this book,** when a measurement such as 3000 is given then it is interpreted as having four significant figures (so we are interpreting it as 3.000×10^3). This is not a universal standard!

Section 1.2. Time

Note. An atomic clock at the National Institute of Standards and Technology in Boulder, Colorado, is the standard for "Coordinated Universal Time" in the U.S. In 1967, the 13th General Conference on Weights and Measures in 1967 defined a standard second as 9 192 631 770 oscillations of the light emitted by a cesium-133 atom.

Section 1.3. Mass

Note. The SI standard of mass is a cylinder of platinum and iridium kept at the International Bureau of Weights and Measures near Paris which is defined as having a mass of 1 kilogram. Another approach is to define the mass of a carbon-12 atom as having 12 *atomic mass units* (u), and then relate atomic units to kilograms as $1\ \mathrm{u} = 1.660\,538\,86 \times 10^{-27}$ kg (with an uncertainty of ± 10 in the last two decimal places).

Note. Density of an object is defined as the mass per unit volume and denoted by ρ (rho). We then have for an object of mass m and volume V is $\rho = \mathrm{m/V}$. The density of water is 1.00 gram per cubic centimeter.

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