1.3: Measurements

Measurements are an essential part of making observations needed to develop science. Several measurements are commonly done in everyday life, as illustrated in Fig. 1.3.1. The measured values have two components: a number and a unit.

Figure 1.3.1: Measurements of mass, length, time, and temperature are part of daily life. Source: https://www.hiclipart.com/free-trans...xnlrr/download

Numbers

The numbers are composed of digits. The digits are 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. The digits are written in a row in the number, e.g., 123, which means one hundred and twenty-three. The numbers include a decimal point. If the decimal point is not marked, it is assumed to be present at the right of the number. For example, 123 is 123. by conversion, with the decimal point shown in red font.

Place value of a number

The digits have place values. The place values are relative to the decimal point, i.e., the 1st digit to the left of the decimal point is ones, the 2nd is tens, 3rd is hundreds, and so on. The digit 1st to the right of the decimal point is tenth, 2nd is a hundredth, 3rd is thousandth, and so, as shown in Fig. 1.3.2. For example, in 231.45, the digit 2 is hundreds, i.e., 200, 3 is tens, i.e., thirty, 1 is ones, that is one, 4 is tenth, i.e., four divided by ten, and 5 is hundredth, that is five divided by hundred.

Billions	Hundred millions	Ten millions	Millions	Hundred thousands	Ten thousands	Thousands	Hundreds	Tens	Ones	Decimal place	Tenth	Hundredth	Thousandth	Ten thousandth	Hundred thousandth	Millionth	Ten millionth	Hundred millionth	Billionth	Ten billionth
1	2	3	4	5	6	7	8	9	1	.	1	2	3	4	5	6	8	9	0	1

Figure 1.3.2: Place values of numbers.

Sign of a number

Numbers have signs, either +ve or -ve, to the left of a number, e.g., -23.4 and +430. By conversion, no sign means +ve. The signs are relative to zero; the -ve sign means the number is less than zero, and the +ve sign means the number is more than zero.

The number and the sign in calculations

The rules for the sign in a calculated answer are the following.

1. When two positive numbers add, the answer has a +ve sign, e.g., 3+2 = 5.
2. When two negative numbers add, the answer has –ve sign, e.g., -4 + (-2) = -6.
3. When two numbers having opposite signs add, subtract the smaller number from the larger number, and the answer has the sign of the larger number. For example, -5 +3 = -2.
4. In subtraction, change the sign of the subtracted number and then follow the addition rules. For example, subtract 3 from 5: 5-(+3) = 5-3 = 2. Note that 3 is subtracted, and its sign changed before operating addition. Another example: subtract -6 from 2: 2-(-6) = 2+6 = 8
5. When two positive numbers multiply, the answer has a +ve sign, e.g., 2x3 = 6.
6. When two negative numbers multiply, the answer has a +ve sign, e.g., (-4) x (-3) = 12.
7. When the two numbers multiplied have opposite signs, the answer has a –ve sign, e.g., (-3) x 2 = -6 and 4 x (-4) = -16.
8. When a number is divided by another number, it follows multiplication rules for the sign. For example, $\frac{-4}{-2}=2, \quad \frac{4}{2}=2, \quad \frac{-4}{2}=-2, \text{ and } \frac{9}{-3}=-3$.

Figure 1.3.3: Battery % remaining.

Percentage calculations

The percentage (%) is the part out of a hundred, as illustrated in Fig. 1.3.3. The percentage is calculated as part divided by the total and then multiplied by a hundred, i.e.:

$$\text{percentage } \% = \frac{\text{Part amount}}{\text{Total amount}} \times 100$$

Example 1.3.1

Calculate the percentage of aspirin if there is 81 mg aspirin in a 325 mg tablet?

Solution

part = 81 mg aspirin, Total = 325 mg tablet

Formula:

$$\text{percentage } = \frac{\text{Part amount}}{\text{Total amount}} \times 100$$

Plug in values in the formula and calculate:

$$\text{Percentage } = \frac{81 \text{mg aspirin}}{325 \text{mg tablet}} \times 100 = 25\% \text{ aspirin}$$

Example 1.3.2

A piece of 18K green color gold jewelry has 7.5 g gold, 2.0 g silver, and 0.5 g copper. Calculate the percentage of gold in the jewelry?

Solution

Part = 7.5 g gold, Total = 7.5 g gold + 2.0 g silver + 0.5 g copper = 10 g jewelry.

Plug in values in the formula and calculate:

$$\text{percentage } = \frac{\text{Part amount}}{\text{Total amount}} \times 100 = \frac{7.5 \text{ggold}}{10 \text{ g}} \times 100 = 75\% \text{gold}$$

Writing numbers in scientific notation

Sometimes the given number is too large or too small to be easily written, read, and grasped. Scientific notation is one approach to changing a too large or a too-small number into an easily readable and writable number. The following steps convert a given number to scientific notation.

1. Move the decimal point to the right or the left side, one digit at a time, till the largest non-zero digit becomes one's place.

   For example, move the decimal in 12,700,000 seven times to the right 

   to obtain 1.27, and move the decimal in 0.000,006 six-time to the left 

   to get 6. The numbers 1.27 and 6 obtained are the coefficients of the scientific notation.
2. The coefficient is multiplied by 10^x, where x is a power of ten. The power of ten equals the number of times the decimal moved. The sign of the power is +ve if the decimal moved to the left and -ve if the decimal moved to the right. For example, 12,700,000 in scientific notation is 1.27 x 10^7, and 0.000,006 is 6 x 10^{-6}.

Units

Physical properties like mass, length, and temperature are measured. The measured value is a combination of a number and a unit, as illustrated in Fig. 1.3.4. For example, a person's height is 1.83 meters, where 1.83 is a number and a meter is a unit.

Units are quantities defined by the standard that peoples agree to use as a reference.

For example, the meter is defined as the distance light travels in a vacuum in $\frac{1}{299,792,458}$ of a second.

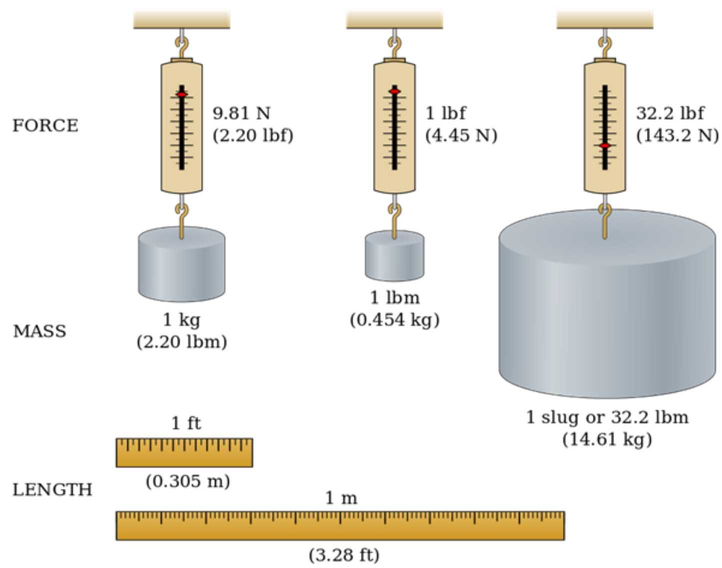

Figure 1.3.4: Measurement is a combination of a number and a unit. Source: https://www.hiclipart.com/free-trans...lzufr/download

Systems of units

There are different sets of units used in different systems of units. For example, 1.83 meters and 6.00 feet show the same length value but using a unit of ‘meter’ from the international system of units (SI) and ‘foot’ from the English system of units. The international system of units (SI) is universally used in scientific work. There are seven base units in SI, as listed in Table 1.

Table 1: Base units in the International System of Units (SI).

Measurement	Unit	Abbreviation
Time	second	s
Length	meter	m
Mass	kilogram	kg

Measurement	Unit	Abbreviation
Temperature	kelvin	K
Amount of substance	mole	mol
Electric current	ampere	A

Note

The following section is based on the 2019 redefinition of the SI base units: https://en.Wikipedia.org/wiki/2019_redefinition_of_the_SI_base_units#Kilogram, accessed on May 2nd, 2020

Time

Time is the progress of existence and events that occur in succession from the past through the present to the future.

In old times, the time measuring device was the hour sandglass shown in Fig. 1.3.5. The basic unit of time is second (s), a standard unit of time in all the measurements systems. Other units of time are minute (min) which is equal to 60 s, and hour which is equal to 60 min or 3600 s.

Definition: Second

The duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atoms at a temperature of 0 K.

Figure 1.3.5: German; Half-hour sandglass; Horology. Source: Metropolitan Museum of Art / CC0

Length

Length is a measure of distance, i.e., a numerical measurement of how far apart the objects or points are.

Fig. 1.3.6. illustrated the concept of length. The SI unit of length is a meter (m).

Meter

The meter is defined as the distance that light travels in a vacuum in $\frac{1}{299,792,458}$ of a second.

Figure 1.3.6: Measure of length. Source: https://www.hiclipart.com/free-trans...nhlxx/download

Mass

> The mass of an object is a measure of its inertia.

Inertia is the resistance of any physical object to any change in its velocity. Mass determines the strength of the gravitational attraction of an object to another object -a property commonly used in modern balances for mass measurements, as shown in Fig. 1.3.7. SI unit of mass is the kilogram (kg).

> **Kilogram**
>
> Earlier definition: The mass of one cubic decimeter of water at the melting point of ice.
>
> Current definition: Kilogram (kg) is defined by taking the fixed numerical value of the Planck constant h to be $6.62607015 \times 10^{-34}$ when expressed in the unit $kg \cdot m^2 \cdot s^{-1}$.

Figure 1.3.7: Laboratory Analytical balance. Source: https://www.hiclipart.com/free-trans...bbigu/download

Temperature

Temperature is a physical property of matter that expresses hotness or coldness, as illustrated in Fig. 1.3.8.

> Temperature is a manifestation of the thermal energy of the matter, which is a source of the flow of energy in the form of heat from a hot object to a cold object when they are in contact with each other.

The SI unit of temperature is Kelvin (K).

Kelvin

Kelvin (K) is defined by taking the fixed numerical value of the Boltzmann constant k to be 1.380649×10^{-23} when expressed in the unit $kg\cdot m^2\cdot s^{-2}\cdot K^{-1}$.

A 0 K, also called absolute zero, is the temperature of a matter at which no energy can be removed as heat from the matter. The freezing point of water is 273.15 K, and the boiling point of water is 373.15 K.

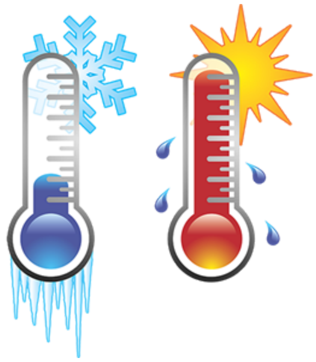

Figure 1.3.8: An illustration of temperature. Source: https://www.hiclipart.com/free-trans...txxww/download

Amount of substance

In chemistry, the amount of substance (n) measures the number of specified elementary entities. The elementary particles in chemistry are usually atoms in the case of elements and molecules or formula units in the case of compounds. SI unit of the amount of a substance is a mole (mol).

Mole (mol)

Mole is exactly 6.02214076×10^{23} elementary entities.

Fig. 1.3.9 illustrates one mole of aluminum, copper, and carbon. The molar mass is the mass in grams of one mole of that substance, i.e., the mass of 6.02214076×10^{23} atoms or molecules. Usually, the number of particles is shown with four significant figures, i.e., 6.022×10^{23} atoms or molecules in one mole of the substance.

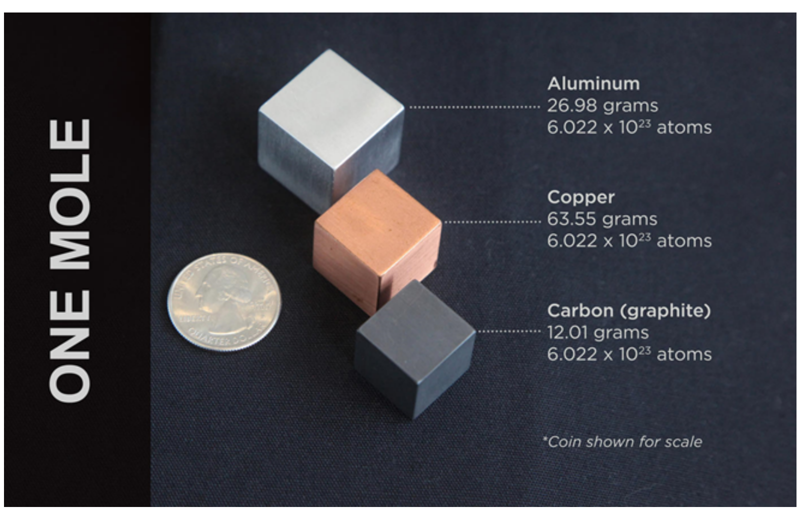

Figure 1.3.9: Amount in one mole of aluminum, copper, and carbon shown relative to US Quarter coin.

Source: Public information, photo: R. Press/NIST; graphic design: N. Hanacek/NIST

Electric current

> Electric current is the flow rate of electric charge past a point or a region.

It could be the flow of electrons in electric wires or the flow of cations and anions in opposite directions as in electrolytes, as illustrated in Fig. 1.3.10. The SI unit of current is ampere (A).

> **Definition: Ampere (A)**
>
> Ampere (A) is defined by taking charge of an electron (e) to be $1.602176634 \times 10^{-19}$ coulomb (C), where C is equivalent to ampere-second (A.s).

Figure 1.3.10: Illustration of the definition and direction of electric current, i.e, the current (I) is the rate of flow charges (Q) per unit time (t). Source: And1mu/ CC-BY-SA-4.0, https://commons.wikimedia.org/wiki/F...ricCurrent.gif

Luminous intensity

> Luminous intensity measures the wavelength-weighted power emitted by a light source in a particular direction per unit solid angle.

The solid angle is measured in steradian (sr), analogous to the radian. The radian is a planar angel that gives the length of the circumference of a circle, and the steradian is a 3D angle, like a cone, that gives an area on the surface of a sphere, as shown in Fig. 1.3.11.

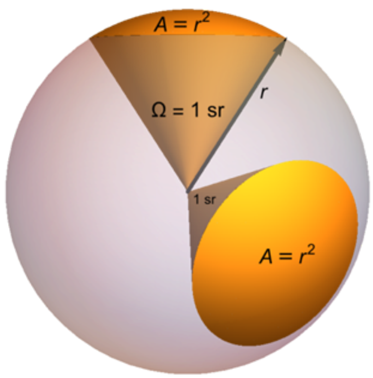

Figure 1.3.11: A solid angle is a three-dimensional analog of a circular angle that relates a portion of the volume of a sphere to the surface area it subtends. If that area equals the sphere's radius squared, the solid angle is one steradian. This diagram displays two solid angles of one steradian, viewed from different directions. Source: Andy Anderson / CC BY-SA (https://creativecommons.org/licenses/by-sa/4.0)

SI unit of luminous intensity in a given direction is Candela (cd).

> **Candela (cd)**
>
> Candela (cd) is defined by taking the fixed numerical value of the luminous efficacy of monochromatic radiation of frequency 540×10^{12} Hz, K_{cd}, to be 683 $cd \cdot sr \cdot W^{-1}$, or $cd \cdot sr \cdot kg^{-1} \cdot m^{-2} \cdot s^{3}$, where **W is watt** –a SI unit of power described by $kg.m^{2}.s^{-3}$.

Prefixes in SI

In several situations, the measured number with the base unit is either too large or too small. For example, a person's height is comfortable to represent in the meter as the height is usually in a 1 m to 2 m range. However, the diameter of the earth, i.e., 12,700,000 m, and the diameter of red blood cells, i.e., 0.000,006 m, are too large and too small, respectively. The unit needs to be revised so that the number with it is easy to read and write.

> Prefixes are used in SI to increase or decrease the base unit by order of tens.

For example, kilo (k) means a thousand times, i.e., 1 km means 1000 m and 1 kg means 1000 g. Similarly, micro (µ) means one-millionth time, i.e., 1 µm is 10^{-6} m, and 1 µg is 10^{-6} g. Table 2 lists commonly used prefixes in SI.

Table 2: Commonly used prefixes in SI (note: m means "meter" in SI units, but as a prefix, it means "mili")

Prefix	**Means**	**Abbreviation**
Gega	10^{9}	G
Mega	10^{6}	M
Kilo	10^{3}	k
Deci	10^{-1}	d
Centi	10^{-2}	c
Mili	10^{-3}	m
Micro	10^{-6}	µ
Nano	10^{-9}	n
Pico	10^{-12}	p

A new unit may be defined and used if there is no appropriate prefix available in SI for some specific type of measurement. For example, the diameter of atoms varies in the range of 1 x 10^{-10} m to 5 x 10^{-10} m, where the prefix pico (p, 10^{-12}) is too small, and the prefix nano (n, 10^{-9}) is large. A new unit called **angstrom** (Å) is defined as 1Å = 10^{-10} m for reporting atomic diameter and inter-atomic distances.

Derived units

> The units in SI other than the seven base units are Derived units obtained by combining the base units.

For example, The SI unit of volume is meter-cube (m^3), equal to the space occupied by a cube of 1m on each edge, as illustrated in Fig. 1.3.12.

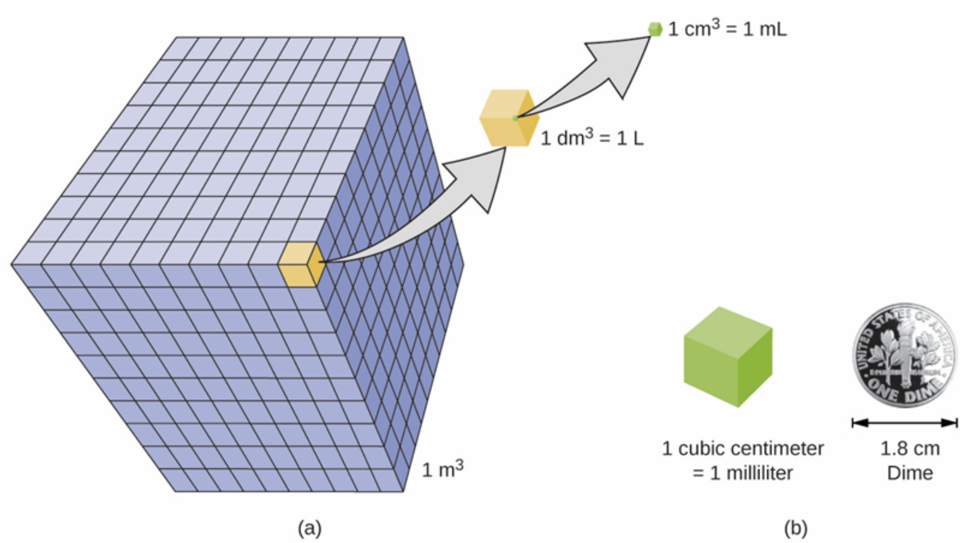

Figure 1.3.12: Relative volume in m^3, dm^3 and cm^3. Diagram of a 10x10x10 cubes. The small cubes represent one decimeter-cube (dm^3); the big cube represents one meter-cube (1 m^3). The purpose is to show that even though there is 10 dm in 1 m, there are 1000 dm^3 in 1 m^3. More generally, it shows that the conversion factor between units of volume is the cube of the conversion factor between corresponding length units. Source: Download for free at https://openstax.org/details/books/chemistry

Usually, the volume is reported in decimeter-cube (dm^3), commonly known as liter (L). One liter is a volume occupied by a cube that is one dm on each edge. Another commonly used unit of volume is the centimeter-cube (cm^3), which is also called cc or mL.

One mL is the volume occupied by a cube that is one cm on each edge. The dm^3 is a thousandth of m^3, and cm^3 is the thousandth of $dm^{3,}$ i.e., 1000 dm^3 = 1 m^3, and 1000 cm^3 = 1 dm^3, as illustrated in Fig. 1.3.11.

Relationship of SI units with metric and English system of units

SI was developed from the metric system. Some basic units are different, but both systems have much in common, using the same prefixes. The English system of units uses a different set of units except for the common unit of time. Table 3 compares the standard measuring units in the three systems of measurement.

Table 3: Common measurement units in three conventional systems of measurements

Quantity	**English unit**	**Metric unit**	**SI unit**	**Relationships**
Mass	Pound (lb)	Gram (g)	Kilogram (kg)	1 kg = 2.205 lb 1 kg = 1000 g
Length	Foot (ft)	Meter (m)	Meter (m)	1 m = 3.281 ft
Volume	Quart (qt)	Liter (L)	Cubic meter (m^3)	0.946 L = 1 qt 1 m^3 = 1000 L
Energy	calorie (cal)	calorie (cal)	Joule (J)	4.184 J = 1 cal
Temperature	Degree Fahrenheit (°F)	Degree Celsius (°C)	Kelvin (K)	°F = (1.8 × °C) + 32 K = °C + 273.15