2.5: The Metric System

Learning Objectives

- State the different measurement systems used in chemistry.
- Describe how prefixes are used in the metric system and identify how the prefixes milli-, centi-, and kilo- compare to the base unit.

How long is a yard? It depends on whom you ask and when the question was asked. Today, we have a standard definition of the yard, which one may see marked on every football field. The distance from goal line to goal line is 100 yards. It does not matter whether the field is in Minneapolis, Green Bay, or Detroit. However, at one time that yard was arbitrarily defined as the distance from the tip of the king's nose to the end of his outstretched hand. The problem with this is simple: new king, new distance, and then all those football fields would need to be re-marked.

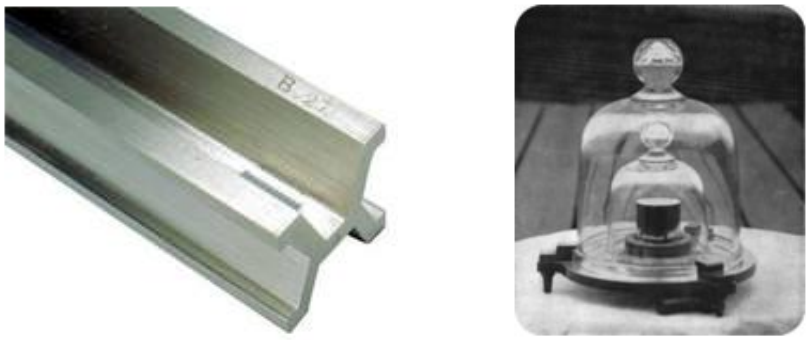

Figure 2.5.1: Meter standard (left) and Kilogram standard (right).

SI Base Units

All measurements depend on the use of units that are well known and understood. The **English system** of measurement units (inches, feet, ounces, etc.) are not used in science because of the difficulty in converting from one unit to another. The **metric system** is used because all metric units are based on multiples of 10, making conversions rather simple by comparison. The metric system was originally established in France in 1795. **The International System of Units** is a system of measurement based on the metric system. The acronym **SI** is commonly used to refer to this system and stands for the French term, *Le Système International d'Unités*. The SI was adopted by international agreement in 1960 and is composed of the seven base units in Table 2.5.1.

Table 2.5.1: SI Base Units of Measurement

Quantity	SI Base Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Temperature	kelvin	K
Time	second	s
Amount of a Substance	mole	mol
Electric Current	ampere	A
Luminous Intensity	candela	cd

The first five units are commonly used in chemistry. All other measured quantities, such as volume, force, and energy, may be derived from these seven base units and are referred to as *derived units*.

⚓ Unfortunately, the Metric System is Not Ubiquitous

The map below shows the adoption of the SI units in countries around the world. The United States has legally adopted the metric system for measurements, but does not use it in everyday practice. Great Britain and much of Canada use a combination of metric and imperial units.

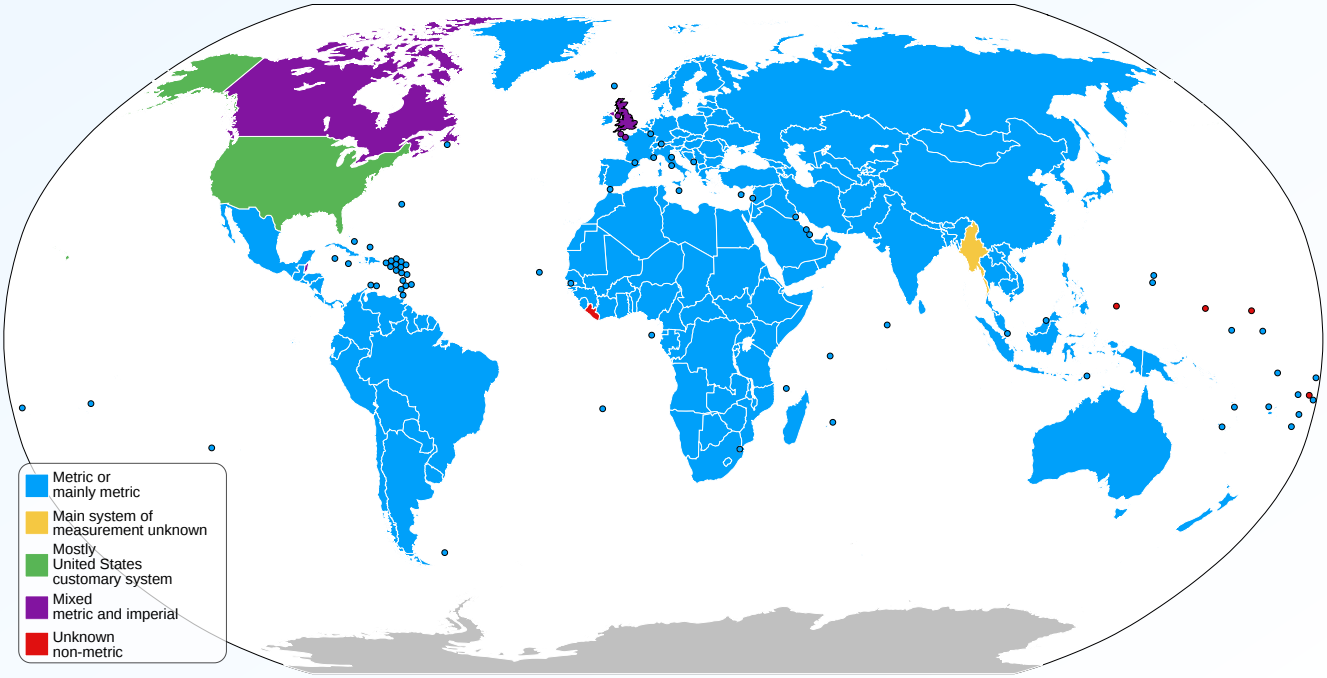

Figure 2.5.1: Areas of world using metric system. Only a few countries are slow or resistant to adoption, including the United States.

Prefix Multipliers

Conversions between metric system units are straightforward because the system is based on powers of ten. For example, meters, centimeters, and millimeters are all metric units of length. There are 10 millimeters in 1 centimeter and 100 centimeters in 1 meter. **Metric prefixes** are used to distinguish between units of different size. These prefixes all derive from either Latin or Greek terms. For example, *mega* comes from the Greek word $\mu\varepsilon\gamma\alpha\varsigma$, meaning "great". Table 2.5.2 lists the most common metric prefixes and their relationship to the central unit that has no prefix. Length is used as an example to demonstrate the relative size of each prefixed unit.

Table 2.5.2: SI Prefixes

Prefix	Unit Abbreviation	Meaning	Meaning	Example
tera-	T	1,000,000,000,000	10^{12}	1 terameter $(\mathrm{Tm}) = 10^{12}$ m
giga-	G	1,000,000,000	10^{9}	1 gigameter $(\mathrm{Gm}) = 10^{9}$ m
mega-	M	1,000,000	10^{6}	1 megameter $(\mathrm{Mm}) = 10^{6}$ m
kilo-	k	1000	10^{3}	1 kilometer $(\mathrm{km}) = 1000$ m
hecto-	h	100	10^{2}	1 hectometer $(\mathrm{hm}) = 100$ m
deka-	da	10	10^{1}	1 dekameter $(\mathrm{dam}) = 10$ m
		1		1 meter (m)

Prefix	Unit Abbreviation	Meaning	Meaning	Example
deci-	d	$\frac{1}{10}$	10^{-1}	1 decimeter $(\text{dm}) = 0.1\ \text{m}$
centi-	c	$\frac{1}{100}$	10^{-2}	1 centimeter $(\text{cm}) = 0.01\ \text{m}$
milli-	m	$\frac{1}{1000}$	10^{-3}	1 millimeter $(\text{mm}) = 0.001\ \text{m}$
micro-	μ	$\frac{1}{1,000,000}$	10^{-6}	1 micrometer $(\mu\text{m}) = 10^{-6}\ \text{m}$
nano-	n	$\frac{1}{1,000,000,000}$	10^{-9}	1 nanometer $(\text{nm}) = 10^{-9}\ \text{m}$
pico-	p	$\frac{1}{1,000,000,000,000}$	10^{-12}	1 picometer $(\text{pm}) = 10^{-12}\ \text{m}$

There are a couple of odd little practices with the use of metric abbreviations. Most abbreviations are lowercase. We use "m" for meter and not "M". However, when it comes to volume, the base unit "liter" is abbreviated as "L" and not "l". So we would write 3.5 milliliters as 3.5 mL.

As a practical matter, whenever possible you should express the units in a small and manageable number. If you are measuring the weight of a material that weighs 6.5 g, this is easier than saying it weighs 6500 mg or 0.0065 kg. All three are correct, but units of g in this case make for a small and easily managed number. However, if a specific problem needs milligrams instead of grams, go with the milligrams for consistency.

✅ Example 2.5.1

Give the abbreviation for each unit and define the abbreviation in terms of the base unit.

A. kiloliter
B. microsecond
C. decimeter
D. nanogram

Solutions

	Explanation	Answer
A	The prefix kilo- means 1000, so 1 kL equals 1000 L.	kL
B	The prefix micro- means $\frac{1}{1,000,000}$, so 1 µs equals 0.000001 s.	µs
C	The prefix deci- means $\frac{1}{10}$, so 1 dm equals 0.1 m.	dm
D	The prefix nano- means $\frac{1}{1,000,000,000}$, so 1 ng equals 0.000000001 g.	ng

✏️ Exercise 2.5.1

Give the abbreviation for each unit and define the abbreviation in terms of the base unit.

A. kilometer
B. milligram
C. nanosecond

D. centiliter

Answer A

km ⇒ 1 km = 10^3 m = 1000 m

Answer B

mg ⇒ 1 mg = $\frac{1}{1000}$ g = 0.001 g

Answer C

ns ⇒ 1 ns = $\frac{1}{1{,}000{,}000{,}000}$ s = 10^{-9} s

Answer D

cL ⇒ 1 cL = $\frac{1}{100}$ L = 0.01 L

Summary

- Metric prefixes derive from Latin or Greek terms. The prefixes are used to make the units manageable.
- The SI system is based on multiples of ten. There are seven basic units in the SI system. Five of these units are commonly used in chemistry.