Practical Guide to the

International System of Units (SI)

Table 1 Prefixes

	Symbol	Prefix	Factor
	Y	yotta	10^{24}
	Z	zetta	10^{21}
	E	exa	10^{18}
	P	peta	10^{15}
	T	tera	10^{12}
	G	giga	10^{9}
	M	mega	10^{6}
	k	kilo	10^{3}
	h	hecto	10^{2}
*	da	deka	10^{1}
			$10^{0} = 1$
	d	deci	10^{-1}
*	c	centi	10^{-2}
	m	milli	10^{-3}
	μ	micro	10^{-6}
	n	nano	10^{-9}
	p	pico	10^{-12}
	f	femto	10^{-15}
	a	atto	10^{-18}
	z	zepto	10^{-21}
	y	yocto	10^{-24}

* The four shaded prefixes (hecto, deka, deci, and centi) are irregular in that they are not powers of 1000. They are generally limited to cm, m², and m³. See sections 4, 5, 7, 8.

Powers of two—the binary numbers used in computers—have their own corresponding system of prefixes, modeled on SI although they're not SI:

Ei	exbi	$= 2^{60}$	≈ 1.15 E
Pi	pebi	$= 2^{50}$	≈ 1.13 P
Ti	tebi	$= 2^{40}$	≈ 1.09 T
Gi	gibi	$= 2^{30}$	≈ 1.07 G
Mi	mebi	$= 2^{20}$	≈ 1.05 M
Ki	kibi	$= 2^{10}$	≈ 1.02 k

Table 2 SI Units

Symbol	Unit Name	Quantity (*general symbol*)	Definition
		General Purpose	
m	meter	length (l)	BASE UNIT
kg	kilogram	mass (m)	BASE UNIT
s	second	time (t)	BASE UNIT
K	kelvin	temperature (T)	BASE UNIT
m²	square meter	area (A)	m²
m³	cubic meter	volume (V)	m³
N	newton	force (F)	kg·m/s²
J	joule	energy (E)	N·m
W	watt	power (P)	J/s
Pa	pascal	pressure (p)	N/m²
Hz	hertz	frequency	1/s
		Electromagnetic	
C	coulomb	charge (Q)	A·s ≈ 6.24×10^{18} *e*
A	ampere	current (I)	BASE UNIT = C/s
V	volt	voltage (V)	J/C = W/A
Ω	ohm	resistance (R)	V/A
S	siemens	conductance (G)	1/Ω = A/V
F	farad	capacitance (C)	C/V
Wb	weber	magnetic flux	V·s
T	tesla	magnetic flux density	Wb/m^2
H	henry	inductance (L)	Wb/A
		Dimensionless	
mol	mole	amount of substance (n) (number of particles)	BASE UNIT = g/Da = g/u ≈ 6.02×10^{23}
rad	radian	plane angle	1/2π of a circle
sr	steradian	solid angle	1/4π of a sphere
		Visible Light	
lm	lumen	Luminous flux	cd·sr = 1/683 W @ 540 THz
cd	candela	luminous intensity (I)	BASE UNIT = lm/sr
lx	lux	illuminance (E)	lm/m^2
		Radiology & Biochemistry	
Bq	becquerel	radioactivity	1/s (*decays per second*)
Gy	gray	absorbed dose (D)	J/kg (*of body mass*)
Sv	sievert	dose equivalent (H)	Gy·Q (*Q = quality factor*)
kat	katal	catalytic activity	mol/s

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Understanding measurement and SI

1. Advantages and history

The International System of Units, abbreviated **SI**, is the simplified modern version of the various metric systems. Most metric units are not part of SI, so don't call it "the metric system." SI has many advantages:

- **No conversions.** Only one unit for each quantity.
- **No numbers to memorize.** Derived units are defined without numerical factors.
- **No fractions.** Decimals only.
- **No long rows of zeroes**. Prefixes replace them.
- **Complete.** SI can measure any physical quantity.
- **Coherent.** Units follow natural laws and can be manipulated algebraically.
- **Only 30 units.** Compared to hundreds of non-SI units.
- **Clear symbols.** Unique, unambiguous letter symbols.
- **World standard.** Virtually all measurements are based on SI, even if expressed in other units.

Non-SI units. Any unit not on Table 2 (page 1) is a **non-SI** unit. Hundreds of them are in use, especially in the USA. They include a chaotic hodgepodge of old metric, Babylonian, and European units, plus units invented for various industries and scientific fields. None of them are really necessary, since all physical quantities can be measured in SI.

History. SI was introduced in 1960. However, its roots go back a century earlier when British scientists developed the first coherent measurement system, based on physical laws and metric base units. SI is governed by the General Conference of Weights and Measures (CGPM), an international treaty organization founded in 1875. The United States is a charter member. The names of most SI units (those with capitalized symbols) honor the scientists who discovered the laws for the corresponding quantity. It is truly an international system. Only two of the 30 SI units (meter and kilogram) were part of the original metric system introduced in France in the 1790s.

SI in the United States. Americans were intimately involved in developing SI. For example, the energy and electrical units (joule, watt, volt, ampere, etc.) were established at conferences in Chicago in the 1880s. But paradoxically, the United States is virtually the only nation where antiquated non-SI units still predominate in everyday life. The U.S. Constitution (Article I, section 8) gives Congress the job of establishing a measuring system. After detailed studies, Congress legalized metric units in 1866. Since 1893, all American measuring units have been based on SI standards. In 1975 and 1988, after still more studies, Congress adopted SI as the preferred U.S. system, but failed to pass effective laws enforcing it. Nevertheless, a growing fraction of the American economy is now largely SI, including automobiles, heavy equipment, farm machinery, medicine, science, electronics, computers, cameras, bicycles, the military, and several sports.

Rules. For clarity and simplicity, there are international rules for expressing measurements, summarized in Table 7 (pages 12 & 13) with correct examples and common mistakes. Study them carefully. You will encounter errors, even in textbooks. Follow this guide, not the textbooks.

2. Base & derived units (Table 2)

A **quantity** is a physical measurement, such as length, time, volume, area, energy, temperature, and mass. Hundreds of different quantities are used in science, technology, and everyday life. Quantities are represented with *italic* letter symbols. A specific quantity consists of a number times a unit. A **unit** is a standard of measurement. Units are represented with normal (upright) letter symbols. For simplicity, we usually write units with symbols rather than spelling them out. For example, 5 m is a quantity (length) consisting of the number 5 times the unit meter (m). Write symbols exactly as they appear in the tables. They are symbols, not abbreviations, and are case sensitive. Always leave a space between the number and unit. (See Rules 2 through 11, pages 12 & 13.)

SI is built on seven fundamental standards called **base units**, included in Table 2 (page 1) and defined in Table 9 (page 14). All other SI units are **derived** by multiplying, dividing, or powering these base units in various combinations. No numerical factors are involved (except for the sievert). SI is a **coherent** system, which means that derived units are defined by the same laws or equations as the quantities they measure. For example, the quantity called *speed* (v) is defined as *distance per time*. **Per** means "divided by." Distance is a kind of length. In symbols,

$$v = d/t \qquad \text{(definition of speed)}$$

The SI unit of speed is therefore **meter per second**—the unit of length divided by the unit of time. In symbols, you can show division three different ways: a slash, horizontal bar, or negative exponent. For example, you may write "8 meters per second" as

$$8\ \mathrm{m/s} \qquad \frac{8\ \mathrm{m}}{\mathrm{s}} \qquad 8\ \mathrm{m{\cdot}s^{-1}}$$

The slash and negative-exponent styles keep everything neatly on one line, while the horizontal-bar style is useful in calculations, for ease in canceling.

To multiply unit symbols, use a middle dot (·), Unicode character 00B7. Don't pronounce or spell it out. Example:

15 N·m (pronounced "15 newton meters")

See Rules 13 and 14, page 13.

3. Characters not on the keyboard

SI requires four characters not shown on a computer keyboard. In any application, you can insert them by holding down the Alt key while you type a four-digit code on the number pad (fourth column of Table 3 below). Num Lock must be on. However, in Microsoft Word™ it's much easier to use shortcut keys, which are easily to set up. Click Insert, Symbol, enter the Unicode character number, click Shortcut Key, press the desired shortcut keys, Assign, Close. Thereafter, you can insert the symbol by just pressing the shortcut key. The key assignments in the right hand column of Table 3 are recommended, so you won't disable any of Word's default shortcuts. For combinations you use frequently, the AutoCorrect feature is even easier (Tools, AutoCorrect Options...). For example, set m3 to autocorrect to m³. This works in other Microsoft applications as well, such as Excel and Publisher.

Table 3 Special Characters

Symbol	Name	Unicode (hex)	Alt+ code	Recommended Word™ shortcut
µ	micro	00B5	Alt+0181	**Alt+M**
·	middle dot	00B7	Alt+0183	**Alt+8**
²	squared	00B2	Alt+0178	**Alt+9**
³	cubed	00B3	Alt+0179	**Alt+0**

4. Prefixes (Table 1)

Prefixes are short names and letter symbols for numbers (powers of ten). A prefix may be attached to the front of a unit to form a **multiple** of the unit. It does not form a separate unit. For example, the prefix kilo (k) means 1000, so kilometer (km) means 1000 meters. To preserve the sound of a prefix, stress the first syllable. For example, pronounce kilometer as *KILL-oh-meter* (not *kuhl-OM-uh-ter*). Prefixes are easier to write and pronounce than powers of ten, long rows of zeroes, and the old *-illion* and *-illionth* names. Here is the same quantity written four different ways. Which is easiest?

2 GW (pronounced "2 gigawatts")
2×10^9 W
2 000 000 000 watts
2 billion watts

Prefixes also eliminate the confusion of the old number names. For example, "billion" means 10^9 (giga) in North America but 10^{12} (tera) in most of Europe. This ambiguity continues for number-names larger than a million and smaller than a millionth. Another advantage of prefixes is that they help clarify the precision of a measurement (the number of significant digits). See section 6.

Learning the prefixes. Learn the prefixes as you learned other number names, by counting up and down the scale. Note on Table 1 that the larger prefixes (mega and up) have capital symbols and end in "a." The smaller prefixes (kilo and down) have lowercase symbols and mostly end in "o." The symbol is the first letter of the name, except for µ (micro) and da (deka). The letter µ is the Greek "m," called mu, which is Unicode character 00B5. Be sure to write letters carefully. There is a big difference between M (mega = 10^6) and m (milli = 10^{-3}), and an even bigger difference between P and p, Z and z, and Y and y.

Regular prefixes. Choose a prefix that minimizes placeholding, non-significant zeroes (Rule 12, page 13). Most of the prefixes are multiples of a thousand, or 10^3 (10^3, 10^6, 10^9, 10^{12}, etc.) These regular prefixes, shown without shading on Table 1, may be used with any SI unit. Think of them as a ladder. Going up the ladder multiplies a unit in steps of 1000 or 10^3. Include 10^0 (=1) as a step, although it has no prefix name. Using meter (m) as an example,

1000 m = km (kilometer)
1000 km = Mm (megameter)
1000 Mm = Gm (gigameter)

and so on. Going down the ladder *divides* a unit in steps of 1000, which is the same as multiplying it in steps of 0.001 or 10^{-3}. For example, a millimeter (mm) is a thousandth of a meter, a micrometer (µm) is a thousandth of a millimeter, and a nanometer (nm) is a thousandth of a micrometer:

0.001 m = mm (millimeter)
0.001 mm = µm (micrometer)
0.001 µm = nm (nanometer)

Changing prefixes manually. We often need to change prefixes to simplify an expression and get rid of unnecessary, placeholding zeroes. Don't call this "converting units." SI has only one coherent unit for each quantity (kind of measurement), so there are no conversions. To change a prefix on paper, just move the decimal point. To simplify large numbers and get rid of ending zeroes, jump the decimal point three places *left* and switch to the next *larger* regular prefix (up the table), as shown by the arrows below. Remember: **L**eft for **L**arger.

7 000 m = 7 km (7 kilometers)

40 000 kg = 40 Mg (40 megagrams)

To simplify decimals (numbers <1) and get rid of awkward leading zeroes, jump the decimal point three places *right* and switch to the next *smaller* regular prefix (down the table).

0.003 s = 3 ms (3 milliseconds)

0.2 kg = 0.200 kg = 200 g (200 grams)

Irregular prefixes. Four of the 20 prefixes (hecto, deka, deci, and centi—shaded on Table 1) are not the usual multiples of a thousand. We'll call them *irregular* prefixes. To avoid needless complexity, these prefixes are generally limited to three special cases:

- The centimeter (cm) is most common case. See below.
- Areas (square centimeter and square hectometer). See

section 8.

- Volumes (cubic centimeter, cubic decimeter, cubic dekameter, and cubic hectometer). See section 7.

In the case of the centimeter and square meter, you don't jump the decimal point the normal three places, so you must be careful. See section 8 for details on square meter.

Centimeter. Although it has an irregular prefix, the centimeter is convenient for everyday purposes. The numbers on most SI rulers are centimeters. A meter is 100 cm and a centimeter is 10 mm. To change between centimeters and meters, you therefore move the decimal point two places (instead of the usual three). To change between centimeters and millimeters, move it one place. Examples:

352 cm = 3.52 m

0.65 m = 65 cm

2.4 cm = 24 mm

760 mm = 76 cm

5. Prefixes on a calculator

A scientific calculator handles prefixes and moves the decimal point for you, if you keep the display set to ENG (engineering) notation. Do this with a key that may be labeled MODE, DISP, or SETUP. On most calculators, answers then display in the form

n **E** *a*

where

- *n* is a number with 1, 2, or 3 digits left of the decimal point;
- **E** is shorthand for "times 10 to the…power;" and
- *a* is the exponent of ten, which is always a multiple of 3 like the regular prefixes.

There are three ways of handling prefixes on calculators:

1. Ignore. In simple problems where all the prefixes and units are the same, you can ignore them when entering data. The answer will have the same prefix. For example, when adding lengths in millimeters, you don't need to enter the prefix milli. Your answer will be in millimeters. However, you may need to simplify the answer by changing prefixes (as in section 4).

2. Change. If the data have different prefixes, you can't ignore them. For example, you can't multiply millimeters times meters or add grams and kilograms. Before entering the numbers in your calculator, you must move decimal point(s) so that all the prefixes the same. In simple problems, you can do this mentally:

1.20 m + 35 cm = 1.20 m + 0.35 m = 1.55 m

3. Enter. In complex problems with different units and prefixes, it's best to enter all the prefixes in your calculator. Do this with the exponent key (usually labeled **EE**, **E**, or **EXP**) which means "times ten to the…power." The **E** symbol will display, if your calculator is set to ENG notation. For example, to enter 25 MW (megawatts), key in

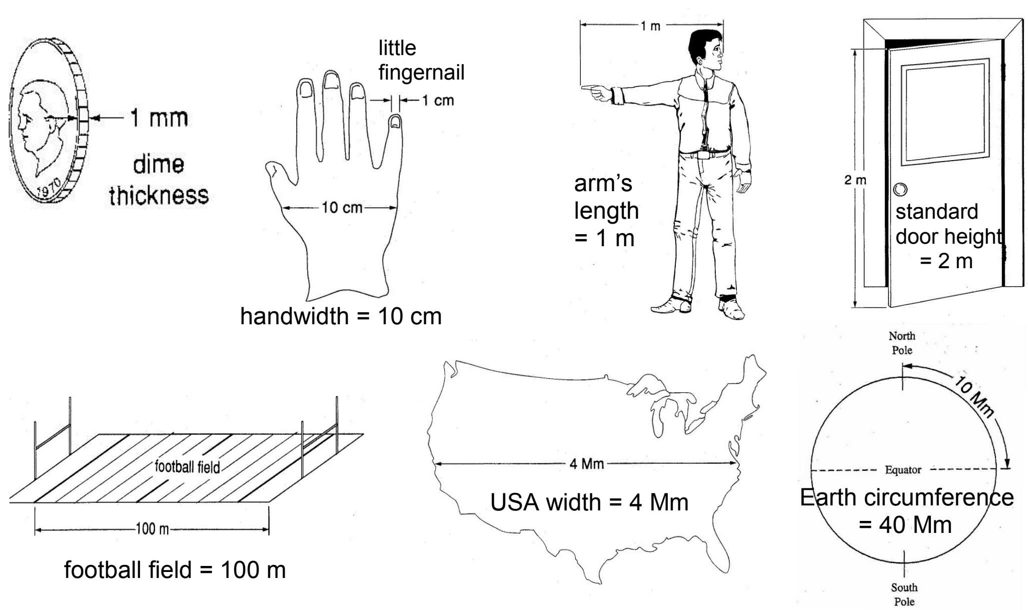
25 **EE** 6

because M means 10^6. Be sure to enter negative exponents with the negative key, not the minus key. The negative key is usually labeled **(–)** or +/–. Be sure to enter powers of ten with the exponent key (**EE**). Do not use the powering key (labeled **^**, a^b, or y^x) or the 10^x key for this purpose.

Recording answers. If you enter prefixes with the exponent key, you will need to assign a prefix when recording the answer. In most cases, you just substitute the prefix letter symbol for the displayed exponent (power of ten). For example, suppose you are calculating a length, entering all

Figure 1. Length examples: multiples of meter

Ym	the universe
Zm	galaxies
Em	farther stars
Pm	nearer stars
Tm	solar system
Gm	star diameters
Mm	planets
km	cities
m	arm's length
cm	little fingernail width
mm	dime thickness
μm	bacteria
nm	viruses
pm	atoms
fm	protons, neutrons



prefixes, and the answer displays as

25E3

This means 25×10^3 meters, or 25 km. Just substitute the prefix "kilo," meaning 10^3, for the exponent 3. Don't write down the **E** symbol, which is calculator shorthand. (In SI, the symbol E means exa or 10^{18}.)

Centimeters. You can enter centimeters with the exponent key, but it's usually easier to mentally move the decimal point and enter the data in meters. A calculator set to ENG notation will not display centimeters. It will display either millimeters (E–3) or meters without a prefix (E0).

Caution! There are three prefix complications you must carefully watch out for: **volume** and **area** (mentioned in section 4), and **mass**. Unfortunately, these are common quantities. See sections 7, 8, and 9 below.

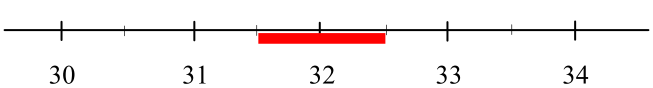
6. Precision and Rounding

Significant digits. No quantity can be measured exactly. All measurements are approximations. A digit that was actually measured is called a **significant digit**. Significant digits may be shown on measuring devices (rulers, meters, dials, etc.) as tick marks or displayed digits, although you can't always be sure. The number of significant digits is called **precision**. It tells us how precise a measurement is—how close to exact. If a quantity is written properly, all the digits are significant except **placeholding zeroes**.

Leading zeroes are always placeholders (never significant). For example, the three zeroes in the quantity 0.002 m are just placeholders to show where the decimal point goes. They were not measured. We could write this length as 2 mm and the zeroes would disappear.

Ending zeroes entirely to the left of the decimal point are usually not significant, but one or two of them might be significant. You can't be sure without other information. For example, the last two or three zeroes in the quantity 8000 meters are probably not significant. They are probably just placeholders to show where the decimal point goes. (We understand there is a decimal point at the end of a whole number, although we don't write it.) The precise length might be anything from 7500 m to 8499 m. You don't know without more information.

Note that other zeroes are always significant, including ending zeroes to the *right* of the decimal point and zeroes surrounded by non-zero digits. To help you understand precision, imagine a quantity as if plotted on a number line. For example, 32 meters (two significant digits) would look like this:



The 32 really means "closer to 32 than to either 31 or 33," or "somewhere between 31.5 and 32.5" (shaded above). Anywhere in the shaded area, rounded to two significant digits, is 32. Study the following examples:

Quantity	Significant digits
351.2 kg	4
0.04 m	1
0.040 m	2
140 K	? (2 or 3)
104 K	3
83 000 s	? (2, 3, 4, or 5)
5.02 W	3
5.020 W	4

Prefixes. An advantage of prefixes is that they help clarify the precision. For example, writing 8000 m as 8.0 km makes it clear that there are two significant digits. However, it is possible to have one or two ending zeroes to the left of the decimal point (for example, 50 km or 500 km). In that case, the precision could be 1, 2, or 3 significant digits. You can't be sure without other information.

Rounding rules. Failure to round off answers is a common but serious error. A calculated answer cannot be more precise than the data you started with. It can be less precise, if you have no need for greater precision. There are five general rules for rounding. (See Rule 1, page 12):

1. If the next digit (the first to be discarded) is 4 or less, "round down" (leave the significant digits as they are and discard all the following digits, or change them to placeholding zeroes if necessary). Example:

5.3278 rounded to two significant digits is 5.3

2. If the next digit (the first to be discarded) is 5 or greater, "round up" (add 1 to the last significant digit and discard all the following digits, or change them to placeholding zeroes if necessary). Example:

137 rounded to two significant digits is 140

3. If the problem contains multiplication or division, round answers to the same number of significant digits as the least precise measurement or original data. Example:

$5.247 \times 3.0 = 16$ (round answer to two digits)

4. When adding or subtracting only, round answers to the same place value as the least precise measurement or original data. Example:

$8.821 + 4 = 13$ (round answer to nearest integer)

5. Don't round off until you're finished, to avoid accumulating rounding errors.

The above rounding rules don't guarantee that your answer will always have the same precision as the original data. You may need to apply some judgment.

Rounding with a calculator. Your calculator will display many useless, non-significant digits if you let it. You can set a scientific calculator to display answers rounded to a specified number of decimal places. Do this with a key that may be labeled FIX or TAB. On the best calculators, you can specify the number of significant digits. In any case, you do not need to key in significant ending zeroes to the right of the decimal point. For example, enter 6.000 as 6.

Reasons for rounding. The fundamental reason measurements are always approximate (never exact) is that all quantities become "fuzzy" when you examine them too closely. For example, it is impossible to determine the exact length of an object because its edge is never exactly defined. Its atoms are jiggling about, and atoms themselves are fuzzy things. But precision is usually limited for other reasons as well. We may not need a very precise number. Or it may be too much work to get it, or too expensive, or require equipment we don't have. The best measurements today have about 14 significant digits, but such extreme precision is rare. In science and everyday life, we usually measure to 2, 3, or 4 significant digits.

Accuracy. Don't confuse precision ("how close to exact") with **accuracy** ("how close to true"). Accuracy is often hard to determine. Inaccuracy results from a systematic error, such as a broken or poorly designed measuring device. A quantity may be very precise but inaccurate, or completely accurate but imprecise, or both, or neither.

Labels. Product labels rarely show correct significant digits. For example, a bottle of soda labeled "2 L" probably contains 2.00 L, but not 2.000 L. Some products have nominal dimensions that are not precise measurements. For example, "2 by 4" lumber actually measures about 1.5 by 3.5 inches. The diameter of "one inch" pipe varies with the type of pipe and is never precisely 1 inch.

Scientific notation. Scientific notation (called SCI on calculators) is similar to the engineering notation (ENG) described in section 5. However, it has only one digit left of the decimal point (never a zero), and the exponent can be any number, not just a multiple of 3. Scientific notation was useful in the days of slide rules, but prefixes are more convenient. The only advantage of scientific notation is that the precision is always clear, because there are no zeroes left of the decimal point. However, this is outweighed by the ease in writing, pronouncing, and remembering quantities with prefixes. Quantities too large or small for a prefix may be expressed in either ENG or SCI notation.

Exact numbers. An **exact** number has an infinite number of significant digits—infinite precision. Measured quantities can never be exact. However, pure numbers, definitions, and counts *may* be exact. Even so, you must use good judgment and round off when appropriate. A **pure number** is a number alone, without a unit. If not derived from measurements, it *may* be exact, but you need other information.

Definitions may also be exact, even if they contain a unit. For example, a foot is defined as exactly 0.3048 meters.

A **count** is the number of individual things. It is not a measurement. Objects may be counted in exact whole numbers. You cannot have 1.3 chairs or 0.5 dog! But you still must round off when appropriate. It would be incorrect, for example, to say that the population of a city is 876 645 people. Population constantly changes and we can't count such a large number of people exactly. We would probably round this number to 880 000 when reporting it.

7. Volume: cubic meter (Table 4)

Volume (V) is the quantity of three-dimensional space. The SI unit of volume is the **cubic meter** (m^3). Don't mispronounce it "meter cubed." Prefixes on cubic meter are a bit tricky because the prefix is cubed along with the unit (Rule 15, page 13). For example, a cubic kilometer (km^3) is the volume of a cube 1 km on each side. Its volume is therefore

$$1000 \text{ m} \times 1000 \text{ m} \times 1000 \text{ m} = 10^9 \text{ m}^3$$

or a billion cubic meters. Although kilo means thousand, a cubic kilometer (km^3) is *not* a thousand cubic meters (1000 m^3). This is easier to understand using powers of ten. Contrary to the normal rules of algebra, the prefix and unit are understood to be enclosed in unwritten parentheses:

$$\text{km}^3 = (\text{km})^3 = (10^3 \text{ m})^3 = 10^9 \text{ m}^3$$

If we used only the regular prefixes (multiples of 10^3), the cubic meter would step by a billion (10^9) per prefix. This would be very awkward because numbers could have up to 8 non-significant, placeholding zeroes (instead of the usual maximum of 2). So we use the irregular prefixes hecto (100), deka (10), deci (0.1) and centi (0.01) to fill in the gap between kilo (1000) and milli (0.001). These extra prefixes, *when cubed*, make the cubic meter step by the usual three places per prefix (10^3, 10^6, 10^9, and 10^{-3}, 10^{-6}, 10^{-9}). They cover all ordinary volume measurements. Study Table 4 and Figure 2 (page 7).

Liter. A further complication of cubic meter is that some of the common multiples have "nicknames" and symbols left over from an old version of the metric system, shown in parentheses on Table 4: liter (L), milliliter (mL), and microliter (µL). They survive because they are easier to write and pronounce than the formal names, although they are not SI and make volume calculations more complex. *Caution:* Don't use other prefixes with liter. For example, don't call a cubic meter a "kiloliter" and don't use the incorrect abbreviation "cc" for cubic centimeter (cm^3 = mL). A quarter-liter (250 mL) is popularly called a "cup" or "glass;" a "tablespoon" is 15 mL; and a "teaspoon" is 5 mL. Of course, actual cups, glasses, and spoons vary considerably.

Changing prefixes. Jump the decimal point three places per prefix, as usual, but include the irregular prefixes or "nicknames" as well. Use Table 4 as a guide. Example:

$$0.056 \text{ m}^3 = 56 \text{ dm}^3 = 56 \text{ L}$$

On a calculator, you can't just substitute the prefix name for its exponent, as you normally do. For example, you

Multiples of the cubic meter form nesting cubes (below). As the sides increase 10 times, the volume increases 1000 times.

Table 4 Volume: common multiples of cubic meter

Symbol	Name	Equals	Example
km^3	cubic kilometer	10^9 m^3	mountain
hm^3	cubic hectometer	10^6 m^3	large building
dam^3	cubic dekameter	10^3 m^3	large house
m^3	**cubic meter**	10^0 m^3	desk
dm^3 (L)	cubic decimeter (liter)	10^{-3} m^3	bottle
cm^3 (mL)	cubic centimeter (milliliter)	10^{-6} m^3	bean
mm^3 (μL)	cubic millimeter (microliter)	10^{-9} m^3	sand grain

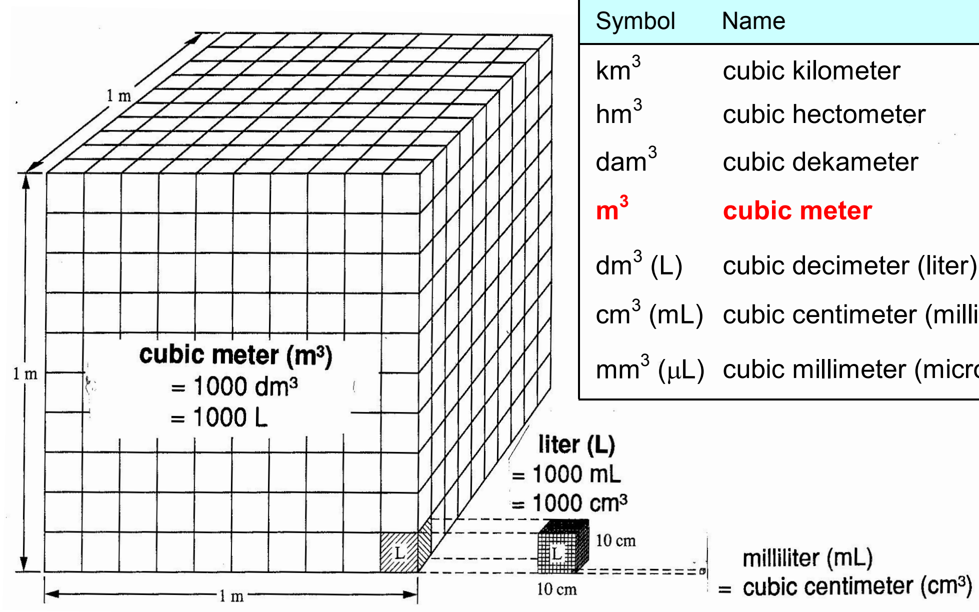


Figure 2. Volume: multiples of cubic meter

must enter 78 hm^3 as

78 **EE** 6 (cubic meters)

even though hecto means 10^2. Either consult Table 4 or mentally cube the prefix by multiplying its exponent by 3. When recording a displayed answer, take the cube *root* of the power by *dividing* its exponent by 3. For example, record a display of 55**E**9 cubic meters as 55 km^3 (not 55 Gm^3)

Prefixes larger than kilo or smaller than milli are usually impractical with cubic meter, because of their huge billion steps and long rows of zeroes. Use powers of ten instead.

8. Area: square meter (Table 5)

Area (A) is the quantity of surface, including imaginary surfaces. The SI unit of area is the **square meter** (m^2). Don't mispronounce it "meter squared." Any prefix on square meter is squared too (Rule 15, page 13). For example, a square kilometer (km^2) is the area of a square 1 km on each side (Figure 3, page 8). Its area is therefore

$$1000 \text{ m} \times 1000 \text{ m} = 1\,000\,000 \text{ m}^2$$

or a million square meters. Even though kilo means 1000, a square kilometer is not 1000 m^2. This is easier to understand using powers of ten. As with cubic meter, parentheses are understood:

$$\text{km}^2 = (\text{km})^2 = (10^3 \text{ m})^2 = 10^6 \text{ m}^2$$

To avoid huge million-steps with square meter, we also use the irregular prefixes hecto (100) and centi (0.01). (Deka and deci are needlessly complex and rarely used with square meter.) Unfortunately, we can't get the usual steps of 1000 because the square root of 1000 isn't a multiple of 10. Prefixes are trickier on square meter than on any other unit. Learn Table 5 (page 8).

Hectare. A further complication is that a square hectometer (hm^2) is commonly known by its old metric name **hectare** (ha), a non-SI unit. A hectare equals a square 100 m × 100 m, which is 10 000 m^2. That's about the area of two football fields. There are 100 ha or 100 hm^2 in a square kilometer (km^2). See Figure 3 for more area examples.

Changing prefixes. When changing prefixes on square meter, you move the decimal point 2, 4, or 6 places instead of the usual 3. Refer to Table 5, using the exponents in the $\mathbf{m^2}$ column to determine how many places to move the decimal point. For example, there is a difference of 4 exponents (4 – 0) between square meter and square hectometer (hectare), so you move the decimal point 4 places when switching between these units. Examples:

500 ha = 5 km^2

0.03 km^2 = 3 ha

65 000 m^2 = 6.5 ha

0.45 ha = 4 500 m^2

Caution: Don't jump the decimal point into a digit-separating space, as you normally do.

Calculators. You can't just substitute the prefix name for its power of ten, as you normally do. For example, even

Table 5 Area: common multiples of square meter

Symbol	Name	m^2	Equals
Mm^2	square megameter	$= 10^{12}\ m^2$	$= 1\ 000\ 000\ km^2$
km^2	square kilometer	$= 10^{6}\ m^2$	$= 100\ hm^2 = 100$ ha
hm^2 (ha)	square hectometer (hectare)	$= 10^{4}\ m^2$	$= 10\ 000\ m^2$
m^2	**square meter**	$= 10^{0}\ m^2$	$= 10\ 000\ cm^2$
cm^2	square centimeter	$= 10^{-4}\ m^2$	$= 100\ mm^2$
mm^2	square millimeter	$= 10^{-6}\ m^2$	

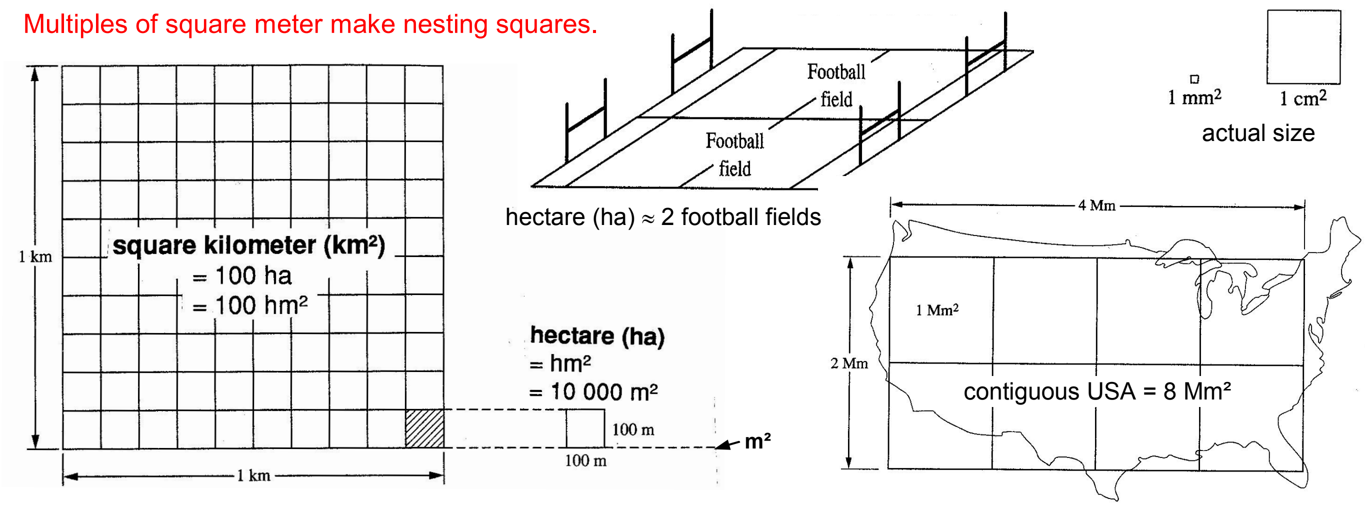


Figure 3. Area examples: multiples of square meter

though centi means 10^{-2}, you must enter 85 cm² as

85 EE (–) 4

Either consult Table 5 or mentally square the prefix by multiplying its exponent by 2. When recording a displayed answer, take the square *root* of the power by *dividing* the exponent by 2. For example, record 24E6 square meters as 24 km² (not 24 Mm²). Unfortunately, your calculator may display an exponent such as 3 that is not on Table 5. Then you have to juggle the decimal point and exponent manually to get a suitable exponent (4, 6, or 12). This is a bother.

Prefixes larger than mega or smaller than milli step by a million (10^6) and are usually impractical with square meter. Use a power of ten instead.

Confused? The prefixes on cubic and square meter are awkward and confuse many people. However, they're much easier than the dozens of non-SI volume and area units used in the United States. The CGPM—the international organization that governs SI—could fix the problem by giving the cubic meter and square meter special short names and symbols, as it did for many other derived units. Then prefixes would work just like any other unit. The irregular prefixes would no longer be necessary and units would be easier to pronounce and write. SI is occasionally revised, but it would be difficult for people to give up common names they have used for two centuries.

9. Mass and density (Table 6)

Mass (m) is the quantity of matter, measured in **kilograms** (kg). In everyday language, mass is usually called "weight" as in "my weight is 75 kg" or "I weigh 75 kg." One should say, "my mass is 75 kg" or "I mass 75 kg." In correct scientific language, weight is the force of gravity, not mass. Like all forces, it is measured in newtons (section 11, page 10).

The kilogram was originally defined as the mass of a cubic decimeter (liter) of water. It is still very close. Each multiple of the kilogram corresponds to the mass of water contained in some multiple of the cubic meter (Table 6). This is a very handy relationship to remember.

Changing prefixes. Jump the decimal point three places per prefix, as usual. Don't use the irregular prefixes (hecto, deka, deci, or centi). For historical reasons, the kilogram is the only base unit that includes a prefix (kilo). Other prefixes are attached to the word gram in the usual way. This can be confusing. Most equations require the base unit (kilogram, not gram), in which case prefixes are offset by 1000 or 10^3. When entering a mass in a calculator, you must therefore step down one prefix. Do this by mentally subtracting 3 from the prefix's exponent. Examples:

Enter 25 kg as 25 (ignore the kilo)

Table 6 Mass: some multiples of kilogram

Symbol	Name	Equals	Closely equals mass of
Pg	petagram	= 10^{12} kg	≈ 1 km³ of water
Tg	teragram	= 10^{9} kg	≈ 1 hm³ of water
Gg	gigagram	= 10^{6} kg	≈ 1 dam³ of water
Mg	megagram	= 10^{3} kg	≈ 1 m³ of water
kg	**kilogram**	BASE UNIT	≈ 1 L (dm³) of water
g	gram	= 10^{-3} kg	≈ 1 mL (cm³) of water
mg	milligram	= 10^{-6} kg	≈ 1 µL (mm³) of water

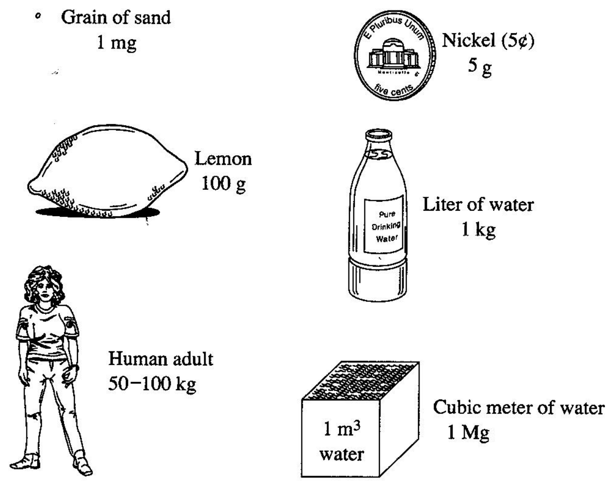


Fig. 4. Mass examples: multiples of kilogram

Enter 48 g as 48 **E** –3 (think: 0 – 3 = –3)

Enter 30 mg as 30 **E** –6 (think: –3 – 3 = –6)

Enter 7 Mg as 7 **E** 3 (think: 6 – 3 = 3)

The answer will display in kilograms (not grams). To use a different prefix, you must mentally *add* 3 to the exponent and record the resulting prefix. Examples:

Record 65**E**0 as 65 kg (ignore the kilo)

Record 250**E**–3 as 250 g (think: –3 + 3 = 0)

Record 74**E**–6 as 74 mg (think: –6 + 3 = –3)

Record 98**E**3 as 98 Mg (think: 3 + 3 = 6)

The CGPM, the international organization that governs SI, could fix this problem by introducing a special short name for the kilogram. Then prefixes would work in the usual way, without complications. But the kilogram is so well established around the world that it would be difficult for people to change.

Metric ton or **tonne.** A megagram (Mg = 1000 kg) is traditionally known as a **metric ton** or **tonne**. Avoid these non-SI units, since there are many other confusing kinds of tons. A thousand metric tons, or kilotonne, is correctly called a gigagram (Gg). A million metric tons, or megatonne, is correctly called a teragram (Tg). A billon (10^9) metric tons is a petagram (Pg).

Density. Density is mass per volume. Its symbol is ρ, the Greek letter rho.

$\rho = m/V$ (definition of density)

The density of water is very close to 1 kilogram per liter, which equals 1 megagram per cubic meter, or 1 gram per cubic centimeter or milliliter. In symbols,

ρ_{water} = 1 kg/L = 1 Mg/m³ = 1 g/mL = 1 g/cm³

As noted earlier, this is very useful to remember, because water is such a common and important substance. Objects denser than water (>1 kg/L) sink in water, while objects less dense (<1 kg/L) float in water.

10. Time and frequency

Time (t) is also called period. In the original metric system of the 1790s, the day was to be subdivided decimally. This failed to catch on, in part because people thought it would make their expensive clocks obsolete. As a result, we still use awkward hours, minutes, and seconds, which were rooted in the duodecimal-sexagesimal number system of ancient Babylonia. If you don't think they're awkward, try adding

13 h 48 min 33 s + 17 h 52 min 46 s = ?

By default, the **second** (s) became the universal base unit of time. It is the only SI unit that predates the metric system. Most SI units incorporate the second, so it is essential in calculations. But clocks record hours (h) and minutes (min), and the day (d) and year (a) are vital natural units. So we often have to convert between time units. It is helpful to memorize the following definitions (from Table 8, page 14):

1 h = 3600 s
1 d = 86 400 s
1 a ≈ 31.6 Ms

Frequency (f) is the inverse or reciprocal of time:

$f = 1/t$ (definition of frequency)

The SI unit of frequency is therefore one per second, which has the short name **hertz**, after Heinrich Hertz, the discoverer of radio waves.

Hz = 1/s (definition of hertz)

11. Force, acceleration, weight

Force (F) is the quantity of push or pull. A force applied to an object (mass) accelerates it, obeying Isaac Newton's second law of motion:

Force = mass × acceleration ($F = ma$)

Acceleration (a) is the change in velocity per time. **Velocity** is speed in a straight direction, so the SI unit of velocity is meter per second (section 2, page 2). The unit of acceleration is therefore meter per second, per second. We express this simply as **meter per second squared** (m/s^2).

The SI unit of force is derived from Newton's second law. It is therefore the unit of mass times the unit of acceleration: a kilogram meter per second squared ($kg{\cdot}m/s^2$). For convenience, this derived unit has the short name **newton** (N).

$N = kg{\cdot}m/s^2$ (definition of newton)

Weight. There are four kinds of force in the universe: gravitation, weak [nuclear], electromagnetic, and strong [nuclear]. All are measured in newtons. The downward force of gravity (F_G) is correctly called **weight**. It obeys Newton's second law. On Earth, the acceleration in this case is $g \approx 9.8$ m/s^2, the rate bodies fall freely. In symbols,

$F_G = mg \approx m\,(9.8)$ (weight on Earth)

If you know the mass of an object in kilograms, you can mentally approximate its weight on Earth by moving the decimal point one place right (multiplying by 10 rather than 9.8). For example, a 70 kg person weighs close to 700 N on Earth. A 0.1 kg or 100 g object, such as a lemon, weighs about 1 N on Earth.

Weight varies with location, but mass does not. A 70 kg person is 70 kg everywhere, but on the Moon weighs only 113 N. Three centuries ago, Isaac Newton explained the difference between mass and weight, but our everyday language still hasn't caught up.

12. Pressure

Pressure (p), also called stress, is force per area.

$p = F/A$ (definition of pressure)

The SI unit of pressure is therefore a newton per square meter (the unit of force per the unit of area). For convenience, this unit has the short name **pascal** (Pa).

$Pa = N/m^2$ (definition of pascal)

Blaise Pascal first explained the laws of pressure in fluids. At sea level, atmospheric pressure averages about 101 kPa (kilopascals, pronounced *KILL-oh-pass-kuhls*). Atop Mt. Everest (elevation 9 km) it is only 30 kPa. Human blood pressure ranges from about 7 kPa to 20 kPa (above atmospheric). The air pressure in car tires is typically 200 kPa to 300 kPa.

13. Energy and power

Energy (E) goes by many names, such as work (mechanical energy), motion (kinetic energy), stored (potential) energy, heat, sound, waves, electromagnetic radiation (light, radio waves, infrared, ultraviolet, X rays, gamma rays), gravitational energy, electrical energy, chemical energy, and nuclear energy. But they are all fundamentally the same. We can measure them all with the same unit. Energy is defined as the ability to do work. Work is force times distance: the force applied to an object times the distance it moves as a result. In symbols,

$E = Fd$ (definition of energy)

The SI unit of energy is therefore a newton meter (N·m)—the unit of force times the unit of distance. For convenience, this derived unit has the short name **joule** (J).

$J = N{\cdot}m$ (definition of joule)

James Joule was the British scientist who demonstrated in the 1840s that different kinds of energy are related.

Power (P) is energy per time—the "flow rate" of energy.

$P = E/t$ (definition of power)

The SI unit of power is therefore a joule per second. For convenience, this derived unit has the short name **watt** (W).

$W = J/s$ (definition of watt)

James Watt was the Scottish inventor who developed the steam engine, our first artificial power source, in the late 18th century. The typical U.S. household uses several kilowatts (kW) of commercial power in various forms (primarily electricity, natural gas, and gasoline). The entire human population currently consumes about 15 TW (terawatts) of commercial power. The Earth intercepts about 170 PW (petawatts) from the Sun.

14. Heat and temperature

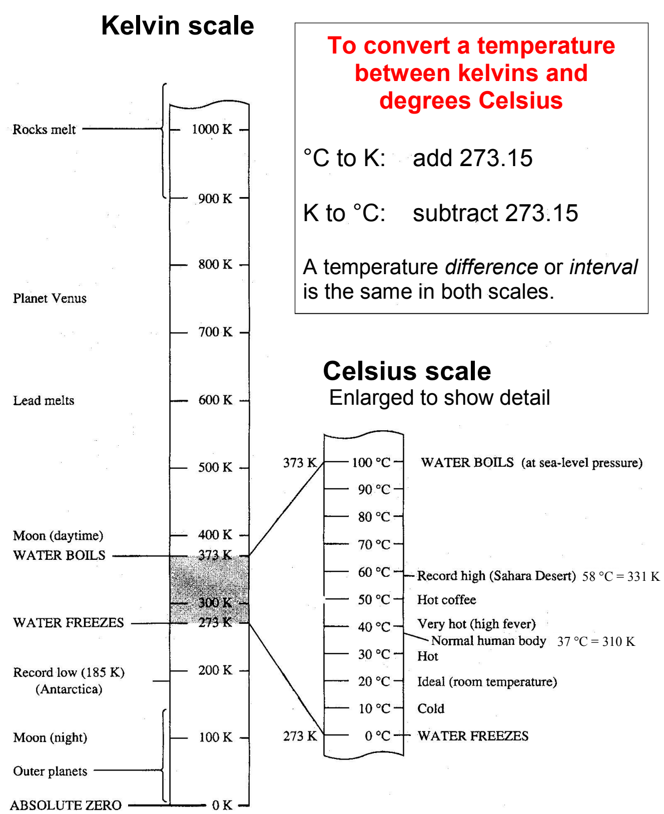
Heat is the random kinetic energy of the tiny particles that make up matter (atoms, molecules, ions, etc.). Like all kinds of energy, heat is measured in joules (J) (section 13). **Temperature** (T), by contrast, is the *average* heat energy *per particle.* Because this is difficult to measure, the SI temperature unit is the **kelvin** (K), a base unit. Don't call it "degrees kelvin."

Zero kelvins (0 K) is the coldest theoretical temperature, called **absolute zero**. Nothing can get quite that cold. The advantage of the kelvin scale is that it has no negative numbers. The kelvin is essential in most energy equations.

Water freezes at 273 K and boils (at sea level) at 373 K. The ideal temperature for unclothed humans is about 300 K. Not surprisingly, that's the average annual temperature in the tropics, where we evolved. Our normal internal body temperature is 310 K. The sun's surface is about 6 kK (kilokelvins) while its core is 15 MK (megakelvins). Outer space is about 3 K. See Figure 5 for more examples.

Degrees Celsius. For everyday purposes such as the weather, you may also use the old metric temperature scale, degrees Celsius (°C). However, it's harder to write and pronounce than kelvins and doesn't work in most energy equations. Celsius degrees are the same size as kelvins but the zero is shifted to the freezing point of water. The exact conversion is 0 °C = 273.15 K. Temperatures below freezing water are negative numbers on the Celsius scale. That doesn't make much sense, but the Celsius scale was invented in the 18th century before people understood temperature. At sea level, water boils at 100 °C = 373 K. Normal human body temperature is 37 °C = 310 K. A high fever is about 40 °C = 313 K. To get a feel for degrees Celsius, learn this rhyme: "30 is hot, 20 is nice, 10 is cold, zero is ice."

Figure 5. Temperature: kelvin and Celsius scales



15. The mole

The **mole** (mol), an SI base unit, is an historical accident. If we designed SI from scratch today, we wouldn't need it. But it is important in chemistry and physics, where it is used to count bulk numbers of atoms, molecules, ions, protons, neutrons, electrons, and other tiny particles that make up matter, or groups of such particles (called formula units). Only pure substances of known composition can be measured in moles. You can't measure mixtures or unknown substances—such as rocks, wood, or people—in moles.

Dalton (atomic mass unit). In the 19th century, chemists learned how to measure the *relative* masses of different kinds of atoms (elements), but had no idea of their actual mass in kilograms. For example, they discovered that an oxygen atom is about 16 times more massive than a hydrogen atom. So they invented a second mass unit, now called a dalton (Da) or atomic mass unit (u). It is arbitrarily defined as 1/12 the mass of a carbon-12 atom. Today, we know the value of this unit very precisely.

$$1 \text{ Da} = 1 \text{ u} \approx 1.660\,539 \text{ yg} \qquad \text{(yoctograms)}$$

The dalton, or atomic mass unit, is not SI. We could abandon it and measure atomic particles in yoctograms. But we continue to use it partly out of tradition and partly because it's a convenient standard that gives hydrogen (the simplest element), or a nucleon (a proton or neutron), a mass of about 1 Da or 1 u.

So what is a mole? It is simply the conversion factor between grams and daltons (or atomic mass units):

$$\text{mol} = \frac{\text{g}}{\text{Da}} = \frac{\text{g}}{\text{u}} \approx \frac{\text{g}}{1.66 \text{ yg}} \qquad \text{(definition of mole)}$$

$$\approx 6.02 \times 10^{23}$$

Since the grams cancel, the mole is a pure number or "dimensionless unit," unlike most SI units. Rearranging the equation above we get:

$$\text{Da} = \text{u} = \text{g/mol}$$

This expression, grams per mole (g/mol), is used routinely to convert between daltons (listed in reference books and the Periodic Table of Elements) and grams (which you can measure on a laboratory balance or massmeter).

16. References

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Taylor, Barry N. 1995. *Guide for the use of the International System of Units (SI).* Special Publication 811. Washington: U.S. Dept. of Commerce. National Institute of Standards and Technology (NIST). 74 pp. Download pdf version from http://physics.nist.gov/cuu/Units/index.html.

Table 7. Rules for expressing quantities

Excerpted from the authoritative U.S. and international standards (BIPM, ISO, NIST, ANSI, IEEE, ASTM)

Rule	Correct examples	Common mistakes
1. Rounding. No measurement is exact. All expressed digits should be significant *except* placeholding zeroes. Leading zeroes are always placeholders (as in 0.02). Ending zeroes entirely to the *left* of the decimal point are often placeholders (as in 500), but *may* be significant. When multiplying or dividing quantities, round the final answer to the same number of significant digits as the least precise original data. When adding or subtracting quantities, round the final answer to the same *place value* as the least precise original data.	(5.24 m) (3.0 m) = 16 m² (3 m) (2.14 m) = 6 m² 25 m / 0.04 s = 600 m/s 8.82 m + 4 m = 13 m	(5.24 m) (3.0 m) ≠ 15.7 m² (3 m) (2.14 m) ≠ 6.42 m² 25 m / 0.04 s ≠ 625 m/s 8.82 m + 4 m ≠ 12.82 m
2. Letter symbols. Write symbols *exactly* as shown in the Tables. Don't use abbreviations. Don't change lowercase to capital or vice versa. Don't add an "s" for the plural. Don't write a period after a symbol (unless it ends a sentence). The prefixes kilo (k) and smaller have lowercase symbols. The prefixes mega (M) and larger have capital symbols. Units named for a person have capitalized symbols (W for watt, N for newton, etc.). The symbol for liter (L) is also capitalized because a lowercase el (l) would be confused with the numeral one (1). All other units have lowercase symbols, even when the surrounding text is capitalized.	kg (kilograms) cm (centimeters) mm (millimeters) Mm (megameters) s (seconds) cm³ (cubic centimeters) mL (milliliters) h (hours) K (kelvins) µm (micrometer)	kgs. kg. Kg KG KGS. cms. cm. CM CMS Cm mm. MM Mm M/M MM Mm. sec secs. Sec. S s. cc cu. cm. ML ml. ML. mℓ Ml hr hrs. °K um
3. Type style. Use normal (upright) fonts for numbers, unit and prefix symbols, and chemical element symbols—even if the surrounding text is italicized. Use *italic (slanted)* letters for quantity symbols, algebraic variables, constants, and vectors. Press **Ctrl+I** to turn italics on and off. Don't use script (*cursive*) letters for symbols.	5 L (liters) 10 L 25 m 30 s	5 l 5 *l* [*l* = length] 10 ℓ 25 *m* [*m* = mass] 30 *s*
4. Spacing. For legibility, always leave a space between the number and unit symbol. Never use a hyphen, which could be mistaken for the minus sign. If there is danger that the space will break and wrap to the next line, use a non-breaking "hard space." (In Microsoft Word™, press **Ctrl+Shift+Space**.)	35 mm 20 °C 0 g 5 lm (lumens)	35mm 35-mm 20°C 20° C 0g 5lm
5. Digit separators. When writing long numbers, use spaces (not commas) to separate digits into groups of three, counting both left and right from the decimal point. The space is usually omitted if there are only four digits left or right. Many countries use a comma as the decimal point, so the old U.S. habit of using commas as digit separators can cause great confusion. To prevent the space from breaking and wrapping to the next line, use a non-breaking "hard space." (In Word™, press **Ctrl+Shift+Space**).	65 238 3.023 586 2470 2 470 1.3524 1.352 4 6.023 27 25 000 000	65,238 3.023586 2,470 1.352,4 6.02327 25,000,000
6. Leading zeroes. Always write a zero in front of a leading decimal point, so it isn't "lost" or overlooked.	0.5 m	.5 m

Rule	Correct examples	Common mistakes
7. Spelled-out units. Units are common nouns, not proper nouns. Don't capitalize a spelled-out name, even if its symbol *is* capitalized (unless all words are capitalized, as in a title, or the word begins a sentence). However, Celsius is capitalized because it is a proper adjective, not the name of the unit.	100 watts 50 megawatts 8 newtons 20 degrees Celsius	100 Watts 50 Megawatts 8 Newtons 20 degrees celsius
8. Pronunciation. Stress the first syllable to preserve the sound of the prefix. There are two exceptions: candela (*can-DELL-uh*) and steradian (*ste-RAID-ee-an*).	(km) *KILL-oh-meter* (kPa) *KILL-oh-pass-kuhl*	*kuhl-OM-uh-ter* *kill-oh-pass-CALL*
9. No mixing of symbols and names. Don't mix symbols with spelled-out names in the same expression. In general, use numerals, not spelled-out numbers. But never begin a sentence with a numeral.	5 kg/L 5 kilograms per liter	5 kilograms/liter 5 kg per L five kilograms/liter
10. No attachments. Don't attach extraneous information or subscripts to a unit. Clearly separate such information with a space.	120 V (ac) 5 g/L of Mg (magnesium)	120 Vac 120 V(ac) 5 g Mg/L
11. No fractions. Use decimals, not fractions or mixed numbers, with SI units.	8.5 kg 0.5 km	8½ kg ½ km
12. Prefix choice. For simplicity, use a prefix that gives a number between 0.1 and 1000. Never use more than one prefix with a unit. Avoid the prefixes hecto, deka, deci, and centi, except with meter, square meter, and cubic meter. See sections 4, 7, and 8 for details.	5 km 500 g 0.5 kg 20 nm 3.15 m	5000 m 5 hg 5 dkg 50dag 20 mμm 3 m 15 cm
13. Compound units. To multiply unit symbols, use a middle dot (·), but don't pronounce or spell it out. (A middle dot is Unicode character 00B7.) To divide unit symbols, use a slash (/), horizontal bar, or negative exponent. Use full-size letters, not miniature fraction-style letters. To divide spelled-out units, use the word "per." So that quantities will be easy to compare, attach a prefix only to the left-hand or numerator unit. *Exception*: because kilogram (not gram) is the base unit, it is usually preferable to use kilogram (not gram) in the denominator.	m·K (meter kelvin) mK (millikelvin) 8 m/s $\frac{8\ \text{m}}{\text{s}}$ 8 m·s^{-1} 8 meters per second mN·m kW/m² kJ/kg	 8 mps 8 $\frac{\text{m}}{\text{s}}$ 8 m÷s 8 meters/second N·mm W/cm² J/g
14. Use only one slash or per. Don't use more than one slash (/) or "per" in a compound unit. To prevent ambiguity, insert parentheses or use negative exponents.	J/(kg·K) J·kg^{-1}·K^{-1} joule per kilogram kelvin	J/kg/K J/kg·K joule per kilogram per kelvin *The expressions above are unclear. They could mean either* J/(kg/K) *or* (J/kg)/K
15. Power a prefix with its unit. If a unit is raised to a power, any attached prefix is powered as well. Parentheses are understood. For example, in multiples of square meter or cubic meter, a prefix is squared or cubed along with the meter. In these cases, you can't just substitute the prefix name for its equivalent power-of-ten in your calculator, as you do with other units.	km² = (km)² = 10^6 m² km³ = (km)³ = 10^9 m³ cm² = (cm)² = 10^{-4} m² cm³ = (cm)³ = 10^{-6} m³ ms^{-1} = (ms)$^{-1}$ = 1/ms	km² ≠ k(m²) ≠ 1000 m² km³ ≠ k(m³) ≠ 1000 m³ cm² ≠ c(m²) ≠ 0.01 m² cm³ ≠ c(m³) ≠ 0.01 m³ ms^{-1} ≠ m·s^{-1} ≠ m/s

Table 8 Common non-SI units approved for use with SI[1]

Symbol	Unit	Traditional Definition	SI Definition
Old metric units			
L	liter[2]	cubic decimeter (dm^3)	0.001 m^3
ha	hectare	square hectometer (hm^2)	10 000 m^2
°C	degrees Celsius[3]	kelvins above freezing point of water	$T_{°C} = T_K - 273.15$
Solar time			
min	minute	60 s	60 s
h	hour	60 min	3600 s
d	day	24 h = 1440 min	86 400 s
a	year (seasonal)[4]	≈ 365.24 d	≈ 31.557 Ms
Plane angle			
°	degree (arcdegree)	1/360 circle	π/180 radians
′	minute (arcminute)[5]	1/60° = 1/21 600 circle	π/10 800 radians
″, as	second (arcsecond)[5]	1/60′ = 1/1 296 000 circle	π/648 000 radians

[1] These units are used worldwide but are not SI. They are convenient in some applications, but make comparisons and calculations difficult, so avoid them when possible. A few other specialized units (not listed here) are also accepted for use with SI. Use the correct symbols shown. Don't use prefixes with the units above, except as noted in the footnotes below.

[2] The prefixes milli and micro are commonly used with liter (mL, µL). See section 7, pages 6–7, for details.

[3] When used to specify a temperature *interval* or *difference*, the degree Celsius is identical to the kelvin. However, the units are different when specifying *the temperature* of something, the usual case. See section 14 for details.

[4] The year (symbol a) is an essential natural unit but is not mentioned in the official standards. There are several slightly different kinds of year. The prefixes kilo, mega, and giga are used with year (ka, Ma, Ga), particularly in the geological sciences. The symbol, a, comes from the Latin word *annus* ("year").

[5] Decimal degrees are preferred over angular minutes (arcminutes) and angular seconds (arcseconds), which survive primarily in cartography, navigation, civil surveying, and astronomy. In astronomy, the prefixes milli, micro, nano, and pico are used with arcsecond (mas, µas, nas, pas).

Table 9 Definitions of the Base Units

BASE UNIT	**HISTORIC DEFINITION** Now approximate or unofficial	**EXACT CURRRENT DEFINITION** Simpler or more reproducible definitions are being developed for kg, K, A, mol
meter (m)	1/40 000 000 Earth's circumference	The distance light travels in vacuum in exactly 1/299 792 458 of a second.
kilogram (kg)	The mass of a liter of water	The mass of the International Prototype Kilogram (preserved in Sèvres, France).
second (s)	1/86 400 of a mean solar day in the year 1900	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 atom.
kelvin (K)	Celsius degrees above absolute zero	The fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
ampere (A)	Coulombs per second (C/s), where $C \approx 6.24 \times 10^{18}$ *e* and *e* is the charge on an electron or proton.	That constant current which, if maintained in two straight parallel conductors of infinite length and negligible circular cross section, and placed one meter apart in vacuum, would produce between those conductors a force of 200 nN per meter of length.
mole (mol)	Grams (g) per dalton (Da) or atomic mass unit (u): mol = g/Da = g/u	As many elementary entities as there are atoms in 12 grams of carbon-12. The entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles. (Objects of unknown composition cannot be measured in moles.)
candela (cd)	The brightness of a standard candle	The luminous intensity in a given direction of a source that emits 1/683 watt per steradian of monochromatic radiation at a frequency of 540 terahertz.