The International System of Units

Unit: Mathematics

NGSS Standards/MA Curriculum Frameworks (2016): SP5

AP® Physics 1 Learning Objectives/Essential Knowledge (2024): N/A

Mastery Objective(s): (Students will be able to…)

- Use and convert between metric prefixes attached to units.

Success Criteria:

- Conversions between prefixes move the decimal point the correct number of places.
- Conversions between prefixes move the decimal point in the correct direction.
- The results of conversions have the correct answers with the correct units, including the prefixes.

Language Objectives:

- Set up and solve problems relating to the concepts described in this section.

Tier 2 Vocabulary: unit, prefix

Notes:

This section is intended to be a brief review. You learned to use the metric system and its prefixes in elementary school. Although you will learn many new S.I. units this year, ***you are expected to be able to fluently apply any metric prefix to any unit and be able to convert between prefixes in any problem you might encounter throughout the year****.*

A unit is a specifically defined measurement. Units describe both the type of measurement, and a base amount.

For example, 1 cm and 1 inch are both lengths. They are used to measure the same dimension, but the specific amounts are different. (In fact, 1 inch is exactly 2.54 cm.)

Every measurement is a number multiplied by its units. In algebra, the term "3x" means "3 times x". Similarly, the distance "75 m" means "75 times the distance 1 meter".

The number and the units are <u>*both*</u> *necessary to describe any measurement.* You *always* need to write the units. Saying that "12 is the same as 12 g" would be as ridiculous as saying "12 is the same as 12 × 3".

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The International System (often called the metric system) is a set of units of measurement that is based on natural quantities (on Earth) and powers of 10.

The metric system has 7 fundamental "base" units:

Unit	**Quantity**
meter (m)	length
kilogram (kg)	mass
second (s)	time
Kelvin (K)	temperature
mole (mol)	amount of substance
ampere (A)	electric current
candela (cd)	intensity of light

All other S.I. units are combinations of one or more of these seven base units.

For example:

Velocity (speed) is a change in distance over a period of time, which would have units of distance/time (m/s).

Force is a mass subjected to an acceleration. Acceleration has units of distance/time^2 (m/s^2), and force has units of mass × acceleration. In the metric system this combination of units (kg·m/s^2) is called a Newton, which means:
$1\text{ N} \equiv 1\text{ kg}\cdot\text{m/s}^2$

(The symbol "≡" means "is identical to," whereas the symbol "=" means "is equivalent to".)

The S.I. base units are calculated from these seven definitions, after converting the derived units (joule, coulomb, hertz, lumen and watt) into the seven base units (second, meter, kilogram, ampere, kelvin, mole and candela).

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Prefixes

The metric system uses prefixes to indicate multiplying a unit by a power of ten. Prefixes are defined for powers of ten from 10^{-30} to 10^{30}:

Factor		Prefix	Symbol
1 000 000 000 000 000 000 000 000 000 000	10^{30}	quetta	Q
1 000 000 000 000 000 000 000 000 000	10^{27}	ronna	R
1 000 000 000 000 000 000 000 000	10^{24}	yotta	Y
1 000 000 000 000 000 000 000	10^{21}	zeta	Z
1 000 000 000 000 000 000	10^{18}	exa	E
1 000 000 000 000 000	10^{15}	peta	P
1 000 000 000 000	10^{12}	tera	T
1 000 000 000	10^{9}	giga	G
1 000 000	10^{6}	mega	M
1 000	10^{3}	kilo	k
100	10^{2}	hecto	h
10	10^{1}	deca	da
1	10^{0}	—	—
0.1	10^{-1}	deci	d
0.01	10^{-2}	centi	c
0.001	10^{-3}	milli	m
0.000 001	10^{-6}	micro	µ
0.000 000 001	10^{-9}	nano	n
0.000 000 000 001	10^{-12}	pico	p
0.000 000 000 000 001	10^{-15}	femto	f
0.000 000 000 000 000 001	10^{-18}	atto	a
0.000 000 000 000 000 000 001	10^{-21}	zepto	z
0.000 000 000 000 000 000 000 001	10^{-24}	yocto	y
0.000 000 000 000 000 000 000 000 001	10^{-27}	ronto	r
0.000 000 000 000 000 000 000 000 000 001	10^{-30}	quecto	q

↑ Move Decimal Point to the Left ↓ Move Decimal Point to the Right

Note that some of the prefixes skip by a factor of 10 and others skip by a factor of 10^3. This means ***you can't just count the steps in the table—you have to actually look at the exponents***.

The most commonly used prefixes are:

- mega (M) = 10^6 = 1 000 000
- kilo (k) = 10^3 = 1000
- centi (c) = $10^{-2} = \frac{1}{100}$ = 0.01
- milli (m) = $10^{-3} = \frac{1}{1\,000}$ = 0.001
- micro (µ) = $10^{-6} = \frac{1}{1\,000\,000}$ = 0.000 001

Any metric prefix is allowed with any metric unit. For example, "35 cm" means "35 × c × m" or "(35)($\frac{1}{100}$)(m)". If you multiply this out, you get 0.35 m.

Note that some units have two-letter abbreviations. *E.g.,* the unit symbol for pascal (a unit of pressure) is (Pa). Standard atmospheric pressure is 101 325 Pa. This same number could be written as 101.325 kPa or 0.101 325 MPa.

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There is a popular geek joke based on the ancient Greek heroine Helen of Troy. She was said to have been the most beautiful woman in the world, and she was an inspiration to the entire Trojan fleet. She was described as having "the face that launched a thousand ships." Therefore a milliHelen must be the amount of beauty required to launch one ship.

Conversions

If you need to convert from one prefix to another, simply move the decimal point.

- Use the starting and ending powers of ten to determine the number of places to move the decimal point.
- When you convert, the actual measurement needs to stay the same. This means that if the prefix gets larger, the number needs to get smaller (move the decimal point to the left), and if the prefix gets smaller, the number needs to get larger (move the decimal point to the right).

Definitions

In order to have measurements be the same everywhere in the universe, any system of measurement needs to be based on some defined values. As of May 2019, instead of basing units on physical objects or laboratory measurements, all S.I. units are defined by specifying exact values for certain fundamental constants:

- The Planck constant, h, is exactly $6.626\,070\,15 \times 10^{-34}$ J·s
- The elementary charge, e, is exactly $1.602\,176\,634 \times 10^{-19}$ C
- The Boltzmann constant, k, is exactly $1.380\,649 \times 10^{-23}$ $J \cdot K^{-1}$
- The Avogadro constant, N_A, is exactly $6.022\,140\,76 \times 10^{23}$ mol^{-1}
- The speed of light, c, is exactly 299 792 458 $m \cdot s^{-1}$
- The ground state hyperfine splitting frequency of the caesium-133 atom, $\Delta\nu(^{133}Cs)_{hfs}$, is exactly 9 192 631 770 Hz
- The luminous efficacy, K_{cd}, of monochromatic radiation of frequency 540×10^{12} Hz is exactly 683 $lm \cdot W^{-1}$

The exact value of each of the base units is calculated from combinations of these fundamental constants, and every derived unit is calculated from combinations of base units.

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The MKS vs. cgs Systems

Because physics heavily involves units that are derived from other units, it is important to make sure that all quantities are expressed in the appropriate units before applying formulas. (This is how we get around having to do factor-label unit-cancelling conversions—like you learned in chemistry—for every single physics problem.)

There are two measurement systems commonly used in physics. In the MKS, or "meter-kilogram-second" system, units are derived from the S.I. units of meters, kilograms, seconds, moles, Kelvins, amperes, and candelas. In the cgs, or "centimeter-gram-second" system, units are derived from the units of centimeters, grams, seconds, moles, Kelvins, amperes, and candelas. The following table shows some examples:

Quantity	MKS Unit	Base Units Equivalent	cgs Unit	Base Units Equivalent
force	newton (N)	$\frac{kg \cdot m}{s^2}$	dyne (dyn)	$\frac{g \cdot cm}{s^2}$
energy	joule (J)	$\frac{kg \cdot m^2}{s^2}$	erg	$\frac{g \cdot cm^2}{s^2}$
magnetic flux density	tesla (T)	$\frac{N}{A}$, $\frac{kg \cdot m}{A \cdot s^2}$	gauss (G)	$\frac{0.1\,dyn}{A}$, $\frac{0.1\,g \cdot cm}{A \cdot s^2}$

In general, because 1 kg = 1 000 g and 1 m = 100 cm, each MKS unit is 100 000 times the value of its corresponding cgs unit.

In this class, we will use exclusively MKS units. This means you have to learn only one set of derived units. However, you can see the importance, when you solve physics problems, of making sure all of the quantities are in MKS units before you plug them into a formula!

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Formatting Rules for S.I. Units

- The value of a quantity is written as a number followed by a non-breaking space (representing multiplication) and a unit symbol; *e.g.,* 2.21 kg, 7.3×10^2 m^2, or 22 K. This rule explicitly includes the percent sign (*e.g.,* 10 %, not 10%) and the symbol for degrees of temperature (*e.g.,* 37 °C, not 37°C). (However, note that angle measurements in degrees are written next to the number without a space.)
- Units do not have a period at the end, except at the end of a sentence.
- A prefix is part of the unit and is attached to the beginning of a unit symbol without a space. Compound prefixes are not allowed.
- Symbols for derived units formed by multiplication are joined with a center dot (·) or a non-breaking space; *e.g.,* N·m or N m.
- Symbols for derived units formed by division are joined with a solidus (fraction line), or given as a negative exponent. *E.g.,* "meter per second" can be written $\frac{\text{m}}{\text{s}}$, m/s, m s^{-1}, or m·s^{-1}.
- The first letter of symbols for units derived from the name of a person is written in upper case; otherwise, they are written in lower case. *E.g.,* the unit of pressure is the pascal, which is named after Blaise Pascal, so its symbol is written "Pa" (note that "Pa" is a two-letter symbol). Conversely, the mole is not named after anyone, so the symbol for mole is written "mol". Note, however, that the symbol for liter is "L" rather than "l", because a lower case "l" is too easy to confuse with the number "1".
- A plural of a symbol must not be used; *e.g.,* 25 kg, not 25 kgs.
- Units and prefixes are case-sensitive. *E.g.,* the quantities 1 mW and 1 MW represent two different quantities (milliwatt and megawatt, respectively).
- The symbol for the decimal marker is either a point or comma on the line. In practice, the decimal point is used in most English-speaking countries and most of Asia, and the comma is used in most of Latin America and in continental European countries.
- Spaces should be used as a thousands separator (1 000 000) instead of commas (1,000,000) or periods (1.000.000), to reduce confusion resulting from the variation between these forms in different countries.
- Any line break inside a number, inside a compound unit, or between a number and its unit should be avoided.

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Homework Problems

Perform the following conversions.

1. **(M)** 2.5 m = __________ cm

2. **(M)** 18mL = __________ L

3. **(M)** 68 kJ = __________ J

4. **(M)** 6 500 mg = __________ kg

5. **(M)** 101 kPa = __________ Pa

6. **(M)** 325 ms = __________ s

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