Module 2 – The Metric System

The Importance of Units

The fastest and most effective way to solve problems in chemistry is to focus on the **units** used to measure quantities.

In science, measurements and calculations are done using the **metric system**.

Have you already mastered the metric system? Take the following *pretest* to be sure. If you get a perfect score, you may skip to Module 3. If not, go to Lesson 2A.

Pretest: Cover the answers at the bottom of the page, then write answers to these.

1. What is the mass, in kilograms, of 150 cc's of liquid water?
2. How many cm^3 are in a liter? How many dm^3 are in a liter?
3. 2.5 pascals is how many millipascals?
4. 3,500 centigrams is how many kilograms?
5. 1.4 picocuries would be how many curies?

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Pretest Answers: 1. 0.15 kg 2. 1,000 cm^3, 1 dm^3 3. 2,500 millipascals 4. 0.035 kg

5. 1.4×10^{-12} curies.

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Lesson 2A: Metric Fundamentals

Measurement systems begin with **standards** *defining* **distance**, **mass**, and **time**.

Distance

The metric distance unit is the **meter,** abbreviated **m**. It is about 39.3 inches, slightly longer than one yard. A meter stick is normally marked in **centimeters.**

|||||||||10|||||||||20|||||||||30|||||||||40|||||||||50|||||||||60|||||||||70|||||||||80|||||||||90|||||||||

Just as a dollar can be divided into 100 *cent*s, and a *cent*ury is 100 years, a meter is divided into 100 *centi*meters. The centimeter, abbreviated **cm**, is 1/100th of a meter.

1 meter = **100 centi**meters and 1 centimeter = 1/100 meters = 10^{-2} meters.

A centimeter can be divided into 10 *milli*meters (mm). Each **millimeter** is 1/1000th of a meter.

1 meter = **1,000 milli**meters and 1 millimeter = 1/1,000 meters = 10^{-3} meters.

A meter stick can also be divided into 10 **deci**meters (**dm**). In equations, we can write

1 meter = **10** *deci*meters and 1 *deci*meter = 1/10 meters = 10^{-1} meters.

A decimeter is equal to 10 centimeters.

Long distances can be measured in **kilo**meters (**km**). **1 kilometer = 1,000 meter sticks.**

There are other metric prefixes that we will learn in Lesson 2C, but the four prefixes above are those that are used *most* often in chemistry calculations.

What do you need to remember from the above? You need to be able to write from memory the *equalities* that define *deci-*, *centi-*, *milli-*, and *kilo-*. A convenient way to remember them is two memorize these two simple equalities

1. 1 METER = 10 **deci**METERS = 100 **centi**METERS = 1,000 **milli**METERS

2. 1,000 METERS = 1 **kilo**METER

To help in learning these relationships, visualize a meter stick. Use that image to help you to write the two "meter-stick" equalities above.

The metric-prefix definitions above are used to solve calculations in most textbooks. Some textbooks and courses prefer to use these equalities in a *1-prefix-* format. If that is the case in your course, be able to write from memory these definitions:

1a. 1 deciMETER = 10^{-1} METERS	1b. 1 centiMETER = 10^{-2} METERS
1c. 1 milliMETER = 10^{-3} METERS	2. 1 kiloMETER = 10^{3} METERS

The above two sets of equations are mathematically equivalent. In Lesson 2C, you will learn how to switch between the two formats.

Whichever set of rules above you use, the following rule always applies.

3. You may substitute *any word* for METER in any of the equalities above, and the new equalities that result will be true.

Rule 3 means that the prefix relationships that are true for meters are true for *any* units of measure. The three rules above allow us to write a wide range of equalities that we will use to solve problems, such as

1 *liter* = 1,000 milli*liters*   1 centi*gram* = 10^{-2} *grams* 10^3 *joules* = 1 kilo*joule*

To use *kilo-* or *milli-* or *centi-* with any units, you simply need to be able to write from memory the two meter-stick equalities.

Volume

Volume is three-dimensional space. Volume is termed a derived quantity, rather than a fundamental quantity, because it is derived from distance. Volume, by definition, is distance cubed. Volume units, by definition, are distance units cubed.

A cube that is 1 centimeter *wide* by 1 cm *high* by 1 cm *long* has a volume of one **cubic** centimeter (1 **cm^3**). Biologists often abbreviate this unit as 1 **cc**.

In chemistry, the unit one **milliliter** is defined as exactly one cubic centimeter. The milliliter is abbreviated as **mL**. Based on this definition, since

- 1,000 milliMETERs = 1 METER, and 1,000 milli*anythings* = 1 *anything*,
- 1,000 milliLITERS is defined as 1 **liter (1 L)**.

The mL is a convenient measure for smaller volumes, while the liter (about 1.1 quarts) is preferred when measuring larger volumes.

One liter is the same as **one cubic deci**meter (1 dm^3). Note how these units are related.

- The volume of a cube that is 10 cm x 10 cm x 10 cm = 1,000 cm^3 = 1,000 mL
- Since 10 cm = 1 dm, the volume of this *same* cube can be calculated as 1 dm x 1 dm x 1 dm = 1 cubic decimeter = 1 dm^3

Based on the above, all of the following terms are *equal*.

1,000 cm^3 = 1,000 mL = 1 L = 1 dm^3

What do you need to remember about volume? For now, just two more sets of equalities.

4. 1 cm^3 = 1 cc = 1 mL

5. 1,000 mL = 1 liter = 1 dm^3

Mass

Mass measures the amount of matter in a substance. If you have studied physics, you know that mass and weight are not the same. In chemistry, however, unless stated otherwise, we assume that mass is measured at the constant gravity of the earth's surface. In that case, mass and weight are directly proportional and can be measured with the same instruments.

The metric base-unit for mass is the gram. One **gram** (g) is *defined* as the mass of *one cubic centimeter* of *liquid water* at 4° Celsius, the temperature at which water has its highest density.

The mass of a given volume of water varies by a small amount with temperature. However, for most calculations in chemistry, the following rule may be used.

6. 1 **cm^3** $H_2O_{\text{(liquid)}}$ = 1 **mL** $H_2O_{\text{(liquid)}}$ = 1.00 **gram** $H_2O_{\text{(liquid)}}$

Temperature

Metric temperature scales are defined by the properties of water. The unit of the temperature scale is the **degree Celsius** (^{o}C), which is the same size as **one kelvin**.

0^{o}C = the freezing point of water.

100^{o}C = the boiling point of water at one atmosphere of pressure.

Time: The base unit for time in the metric system is the **second**.

Abbreviations

Unlike other abbreviations, metric abbreviations do *not* have periods at the end.

m = meter	L = liter = dm^3	cm = centimeter
mL = milliliter	mm = millimeter	cc = cubic centimeter = cm^3
km = kilometer	kg = kilogram	g = gram
s = second		

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SI Units

The modern metric system (*Le Système International d'Unités*) is based on **SI units**. The SI standard unit for mass is kilograms, for distance is meters, and for time is seconds.

However, chemistry calculations often use metric but non-standard-SI units, such as liters or milliliters in place of the SI standard cubic meters for volume, and grams instead of kilograms to measure mass. In Modules 4 and 5, you will learn to convert between the metric units usually used in chemistry and the standard SI units.

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Memorizing the Metric Fundamentals

A strategy that can help in problem-solving is to start each homework paper, quiz, or test by writing *recently* memorized rules at the top of your paper. By writing the rules at the beginning, you will not need to remember them under time pressure at the end of a test.

For the metric system, write →

Metric System

1. 1 METER = 10 deciMETERS
   = 100 centiMETERS
   = 1000 milliMETERS
2. 1000 METERS = 1 kiloMETER
3. Any word can be substituted for METER above.
4. 1 cm^3 = 1 mL = 1 cc
5. 1 liter = 1000 milliliters = 1 dm^3
6. 1 cm^3 $H_2O_{(liquid)}$ = 1 mL $H_2O_{(l)}$
   = 1.00 gram $H_2O_{(l)}$

If your course uses the *1 prefix-* format for Rule 1, substitute those rules.

A Note on Memorization

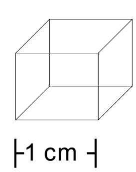
A goal of these lessons is to minimize what you must memorize. However, it is not possible to eliminate memorization from science courses.

When there are facts which you must memorize in order to solve problems, these lessons will tell you. This is one of those times. *Memorize* the metric equalities. You will need to write them from memory for the majority of assignments in chemistry.

Memorization Tips

When you memorize, use as many *senses* as you can. It helps to

- *say* the rules out loud, over and over, as you would learn lines for a play;
- *write* the equations several times, in the same way and order each time;
- *organize* the rules into patterns, rhymes, or mnemonics;
- *number* the rules so you know which rule you forgot, and when to stop;
- *picture* real objects.
  - For the first three equalities, sketch the meter stick. Then write the three meter-stick equalities and compare to your sketch.
  - Write METER in ALL CAPS for the three meter-stick equalities, to remind you that you can substitute ANYTHING for METER.
  - For volume, mentally picture a *1 cm* x 1 cm x 1 cm = ***1 cm³*** cube. Call it *one mL*. Fill it with water to make a *mass* of 1.00 *grams*.



After repetition, you will recall new rules *automatically*. That's the goal.

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Practice: Write the 6 fundamental metric rules in your problem notebook from memory. Repeat until you get them right, 100%. Then cement your knowledge by doing the following problems. When done, check your answers below.

1. Fill in the blanks in these equalities.

a. 1000 grams = 1 _____ e. 1000 millipascals = 1 ________

b. 1000 cm^3 = _______ mL f. _____ centigrams = 1 gram

c. 1 mole = 10^3 _____moles g. 100 cc $H_2O_{(l)}$ = _____ grams $H_2O_{(l)}$

d. 1 dm^3 = _______ L h. 1 centimeter = _____ meter

2. Which is larger, a kilometer or a millimeter?
3. Which is larger, a kilojoule or a millijoule?
4. Name four units that can be used to measure volume in the metric system.
5 . What does *kilo*- mean?
6. What does *centi*- mean?
7. How many centimeters are on a meter stick?
8. How large is a kiloliter?
9. What is the mass of 15 milliliters of liquid water?
10. A liter of liquid water has what mass?
11. What is the volume of one gram of ice?

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ANSWERS

1. a. 1000 grams = 1 **kilogram** b. 1000 cm^3 = **1000** mL c. 1 mole = 10^3 **milli**moles

d. 1 dm^3 = 1 L e. 1000 millipascals = 1 **pascal** f. **100** centigrams = 1 gram

g. 100 cc liquid water = **100** grams H_2O (liquid)

h. 1 centimeter = **1/100th (or 10^{-2})** meters

2. A kilometer 3. A kilojoule
4. Possible answers include cubic centimeters, milliliters, liters, cubic decimeters, cubic meters, and any metric distance unit cubed.
5 . 1,000 of something 6. 1/100th of something 7. 100 8. 1,000 liters
9. 15 grams 10. 1,000 grams, or one kilogram
11. These lessons have not supplied the answer. Water expands when it freezes. So far, we know the answer only for liquid water.

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Lesson 2B: Calculations With Units

Pretest: If you can do the following two problems, you may skip this lesson. Answers are at the end of the lesson.

1. What is the volume of a sphere that is 4.0 cm in diameter? ($V_{sphere} = 4/3\,\pi r^3$).
2. $2.0\ \frac{kg \bullet m}{s^2} \bullet 3.0\ m \bullet 6.0\ s =$

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Units In Calculations (Try doing this lesson with*out* a calculator.)

A measurement consists of a number and its units.

When doing calculations in chemistry, it is essential to write the *units* with the numbers. Why? The units are the best indication of what steps are needed to solve problems. Units also provide a check that you have done a calculation correctly.

In calculations, both the *number* math and the *unit* math must be completed, but usually the unit math can be done in your head.

Do this example of unit math, then check your answer below. cm x cm = ________ .

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cm x cm = $\mathbf{cm^2}$ The units obey the rules of algebra. Try: $\frac{cm^5}{cm^2} =$ ____________

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$\frac{cm^5}{cm^2}$ = can be solved as $\frac{cm \bullet cm \bullet cm \bullet \cancel{cm} \bullet \cancel{cm}}{\cancel{cm} \bullet \cancel{cm}} = cm^3$

or by using the rules for exponential terms:

$\frac{cm^5}{cm^2} = cm^{5-2} = cm^3$ Both methods arrive at the same answer (as they must).

In most chemistry calculations include both numbers and units. In these cases, there are three important rules. Rule 1:

> When *adding* or *subtracting*, the *units must* be the *same* in the numbers being added and subtracted, and the units will be the *same* in the answer.

This rule is logical. Try these two examples.

A. 5 apples + 2 apples = ________ B. 5 apples + 2 oranges = _________

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A is easy. B cannot be done. It makes sense that you *can* add two numbers that refer to apples, but you *can't* add apples and oranges. By Rule 1, you can add numbers that have the same units, but you can*not* add numbers directly that do *not* have the same units.

Use Rule 1 on this problem:

$$\begin{array}{r} 14.0\ \text{grams} \\ -\ \underline{7.5\ \text{grams}} \end{array}$$

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$$\begin{array}{r} 14.0 \text{ grams} \\ -\ \underline{7.5 \text{ grams}} \\ \mathbf{6.5}\ \textbf{\textit{grams}} \end{array}$$

If the unit is the same, you can add or subtract.

Rule 2, for *multiplying* and *dividing* with units is different, but Rule 2, too, is logical:

When multiplying and dividing units, the units multiply and divide.

For example, try this problem. A postage stamp has the dimensions 2.0 cm x 4.0 cm. The surface area of the stamp = ____________

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Area of a rectangle = $l \times w$ = 2.0 cm x 4.0 cm = **8.0 cm²** = 8.0 *square* centimeters

The units, by Rule 2, must obey the rules of multiplication. Both units and numbers follow the laws of multiplication and division, but the units are calculated *separately* from the numbers.. The correct unit is an *essential* part of a correct answer.

Use Rule 2 on these problems: a. $\frac{8.0\ km^6}{2.0\ km^2}$ = __________ b. $\frac{9.0\ km^6}{3.0\ km^6}$ = _________

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a. $\frac{8.0\ km^6}{2.0\ km^2} = \frac{8.0}{2.0} \bullet \frac{km^6}{km^2} = 4.0\ \mathbf{km^4}$

b. $\frac{9.0\ \cancel{km^6}}{3.0\ \cancel{km^6}} = \mathbf{3.0}$ (with no unit.)

Do the math for the numbers and units separately, just as was done in Module 1 when numbers and exponential terms were mixed.

The units follow the familiar laws of multiplication and division and powers, including "like units cancel."

Let us summarize the above as Rule 3:

To calculate with numbers, exponential terms, *and* units, *separate* then *group* the numbers, exponents, and units, solve the math for each of the three parts separately, then recombine the terms.

Use the rules for exponential notation and units: $\frac{12 \times 10^{-3}\ mm^3}{3.0 \times 10^2\ mm^2}$ = ____________

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$$\frac{12 \times 10^{-3}\ mm^4}{3.0 \times 10^2\ mm^2} = \frac{12}{3.0} \bullet \frac{10^{-3}}{10^2} \bullet \frac{mm^4}{mm^2} = 4.0 \times 10^{-5}\ \mathbf{mm^2}$$

With practice, you will soon be able to apply Rule 3 automatically, and you will not need to write out the middle step shown above.

In calculations, often some units will cancel and some will not. Apply the rules to:

$$4.0\ \frac{kg \bullet m}{s^2} \bullet 3.0\ m \bullet \frac{6.0\ \ s}{9.0\ m^2} =$$

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$$4.0 \frac{kg \cdot m}{s^2} \cdot 3.0\ m \cdot \frac{6.0\ s}{9.0\ m^2} = \frac{72}{9} \cdot \frac{kg \cdot \cancel{m}}{s \cdot \cancel{s}} \cdot \cancel{m} \cdot \frac{\cancel{s}}{\cancel{m^2}} = \mathbf{8.0} \frac{\mathbf{kg}}{\mathbf{s}}$$

This math will become automatic -- with practice.

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Practice: Do *not* use a calculator except as noted. If you need just a few reminders, do just a few problems. If you need more practice, do more. Check your answer below after each problem. If you miss a question, review the rules to figure out why before continuing.

1. 16 cm — 2 cm =
2. 12 cm • 2 cm =
3. $(mm^4)(mm)$ =
4. mm^4 / mm =
5. $\frac{10^5}{10^{-2}}$ =
6. $\frac{km^{-5}}{km^2}$ =
7. 3.0 meters • 9.0 meters =
8. 3.0 g / 9.0 g =
9. $\frac{24\ dm^5}{3.0\ dm^{-2}}$ =
10. $\frac{18 \times 10^{-3}\ m^5}{3.0 \times 10^1\ m^2}$ =
11. $12 \frac{L \cdot g}{s} \cdot 2.0\ m \cdot \frac{4.0\ s^3}{6.0\ L^2}$ =
12. A rectangular box has dimensions of 2.0 cm x 4.0 cm x 6.0 cm. Calculate its volume.
13. Do pretest problem 1 at the beginning of this lesson (use a calculator).
14. Do pretest problem 2 (without a calculator).

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ANSWERS

The number and the ***unit*** must be written and correct.

Pretest: See answers to Problems 13 and 14 below.

1. 16 cm — 2 cm = **14 cm**
2. 12 cm • 2 cm = $\mathbf{24\ cm^2}$
3. $(mm^4)(mm) = mm^{(4+1)} = \mathbf{mm^5}$
4. $mm^4 / mm = mm^{(4-1)} = \mathbf{mm^3}$
5. $\frac{10^5}{10^{-2}} = \mathbf{10^7}$
6. $\frac{km^{-5}}{km^2} = \mathbf{km^{-7}}$
7. 3.0 meters • 9.0 meters = $\mathbf{27\ meters^2}$
8. 3.0 g / 9.0 g = **0.33 (*no* unit)**
9. $\frac{24\ dm^5}{3.0\ dm^{-2}} = \mathbf{8.0\ dm^7}$
10. $\frac{18 \times 10^{-3}\ m^5}{3.0 \times 10^1\ m^2} = \mathbf{6.0 \times 10^{-4}\ m^3}$
11. $12 \frac{L \cdot g}{s} \cdot 2.0\ m \cdot \frac{4.0\ s^3}{6.0\ L^2} = \mathbf{16 \frac{g \cdot m \cdot s^2}{L}}$
12. The formula for the volume of a rectangular solid is length *times* width *times* height.

    2.0 cm x 4.0 cm x 6.0 cm. = $\mathbf{48\ cm^3}$

13. The diameter is 4.0 cm, so the radius is 2.0 cm.

$V_{sphere} = 4/3\ \pi\ r^3 = 4/3\ \pi\ (2.0\ cm)^3 = 4/3\ \pi\ (8.0\ cm^3) = \mathbf{(32/3)\ \pi\ cm^3} = \mathbf{34\ cm^3}$

14. $2.0\ \frac{kg \cdot m}{s^2} \cdot 3.0\ m \cdot 6.0\ s = \mathbf{36\ \frac{kg \cdot m^2}{s}}$

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Lesson 2C: Metric Prefix Formats

Timing: Do this lesson when you are assigned problems using *giga, mega-*, *deci-*, *micro-*, *nano-* , or *pico-* prefixes.

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Additional Prefixes

Chemistry problems most often involve the *milli-*, *centi-*, and *kilo-* prefixes, but some topics, will deal with *very* large or *very* small quantities, and additional metric prefixes will be used. The nine prefixes you will encounter most often are shown in the following table.

Prefix	Symbol	Means	Relationship	
			Based on **1 prefix-**	Based on 1 **base unit**
giga-	G	10^9	1 gigaX = 10^9 X	1 X = 10^{-9} gigaX
mega-	M	10^6	1 megaX = 10^6 X	1 X = 10^{-6} megaX
kilo-	k	10^3	**1 kiloX = 10^3 X**	1 X = 10^{-3} kiloX
deci-	d	10^{-1}	1 deciX = 10^{-1} X	1 X = 10 dX
centi-	c	10^{-2}	1 centiX = 10^{-2} X	**1 X = 100 cX**
milli-	m	10^{-3}	1 milliX = 10^{-3} X	**1 X = 1000 mX**
micro-	µ	10^{-6}	1 microX = 10^{-6} X	1 X = 10^6 µX
nano-	n	10^{-9}	1 nanoX = 10^{-9} X	1 X = 10^9 nX
pico-	p	10^{-12}	1 picoX = 10^{-12} X	1 X = 10^{12} pX

Note that in columns 4 and 5, the difference is where the 1 is.

- Column 4 defines each prefix using 1 *prefix*-base unit. Column 5 uses 1 base unit.
- Columns 4 and 5 are mathematically equivalent; simply different ways of writing the *same* prefix relationships.

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Practice A: You may consult the table above. Answers are at the end of the lesson.

1. 1 centijoule = ____ joules
2. 1 watt = ___ milliwatts
3. 10^6 volts = 1 _____volt
4. 1000 grams = 1 _________
5. 1 meter = _____ nanometers

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Converting Between Prefix Formats

Be able to write the first 4 columns of the 9 rows from memory. However, you need not memorize column 5, since it is derived from column 4. To write column 5, multiply both sides of the column 4 equality by the *reciprocal* of the column 4 power.

Example: Knowing **1** *micro*gram = 10^{-6} grams , **1** gram = **?** *micrograms*

To get a *one* in front of gram, multiply both sides of the first equation by 10^6.

$10^{-6} \times 10^{6} = 10^{0} = \mathbf{1}$; so **1 gram = 10^6 micro**grams

To write column 5, remember: when the prefix changes sides, the exponent changes sign.

Most textbooks, in their examples and problem solving, use relationships from both columns 4 and 5, such as *1 kilo*gram = 1000 grams, and 1 liter = *1000 milli*liters. You will need to know the prefix definitions in both the column 4 and 5 formats. In writing metric equalities, if you get confused over where the **1** should be,

- write the 5 columns with their headings, then the first column of prefixes.
- Fill in *familiar* meter-stick equalities, such as: 1 m = 100 cm and 1 km = 1,000 m
- Fill in the remaining blanks in a consistent fashion, based on the pattern seen in the familiar equalities.

Memorizing tables is helpful when there are patterns to relationships.

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Other Prefix Formats

Computer science, which calculates based on powers of 2, uses slightly different definitions for metric prefixes, such as *kilo-* = 2^{10} = *1,024* instead of 1,000.

However, in chemistry and all other sciences, for all base units, the prefix to power relationships in the metric-prefix table are true and *exact* definitions.

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Practice B: *Memorize* the table of nine metric prefixes, *then* do this problem.

1. Fill in this table, from memory, for the nine most common metric prefixes.

Prefix	Symbol	Means	Relationship	
			Based on **1 prefix-**	Based on 1 **base unit**

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ANSWERS

Practice A

1. 1 centijoule = **10^{-2}** joules 2. 1 watt = **10^{3}** milliwatts 3. 10^{6} volts = 1 **mega**volt

4. 1000 grams = 1 **kilogram** 5. 1 meter = **10^{9}** nanometers

Practice B

See table in text.

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Lesson 2D: Cognitive Science – and Flashcards

Cognitive science is the field that studies how the mind works and how it learns. The following principles of cognitive science will be helpful to keep in mind in learning chemistry – and other subjects as well.

1. **Learning is cumulative.** Experts in a field can learn new information quickly because they already have in memory a storehouse of knowledge about the context surrounding new information. That storehouse must be developed over time, with practice.
2. **Learning is incremental** (done in small pieces)**.** Especially for an unfamiliar subject, there is a limit to how much new information you can store in memory in a short amount of time and then apply to solving problems. Knowledge is extended and refined gradually. In learning, steady wins the race.
3. **The working memory in your brain is limited.** Working memory is where you think. Try dividing 11,556 by 12 in your head. Now try it with a pencil, a paper, and your head. Keeping track of the middle-step answers "in your head" while performing successive steps can be challenging!
4. **"Automaticity in the fundamentals"** is a key to overcoming limitations in working memory. When facts can be recalled automatically due to practice, they require little space in working memory, and more memory is available for higher level thinking.
5. **"You can always look it up" is a poor strategy for problem-solving.** The more information you must stop to look up, the less likely you will be able to follow your train of thought to solve a complex problem.

How can you promote the learning and retention of needed fundamentals? It takes practice, but some forms of practice are more effective than others.

1. **The spacing effect.** To *retain* learned material, 20 minutes of study spaced over 3 days is more effective than one hour of study in one day. More will be recalled in the future if you distribute your practice over time.

   Studies show that when the initial learning of facts and vocabulary is spread over 3-4 days, then re-visited weekly for 2-3 weeks, then monthly for 3-4 months, it can often be recalled for decades thereafter.
2. **Overlearning.** Practice until you are perfect, and you will only be perfect briefly. To be able to retain new skills and apply those skills to problems, *sustained* long-term practice to perfection is necessary.

Get that flashcard right three days in a row, then 3 weeks in a row, then 3 months in a row, and you are more likely to *retain* what you learn.

3. **Effort.** Experts in a field less often attribute their success to "talent" than to "hard work over an extended period of time."
4. **Core skills.** The facts and processes you should practice most often are those used most often in the discipline.

[For additional science that relates to learning, see Willingham, Daniel [2007] *Cognition: The Thinking Animal.* Prentice Hall, and Bruer, John T. [1994] *Schools for Thought*. MIT Press.]

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Learning and Retaining Needed Facts

What is more important in learning: Knowing the facts or the process? Cognitive studies show the answer is: both.

"Fragmented facts" are often best learned using flashcards. Flashcards can be divided into two types:

- "One-way cards" for questions that make sense in *one* direction; and
- "Two-way" cards for facts that need to be recalled in both directions.

In these lessons, we will recommend flashcards that will help you recall needed facts and improve your success in chemistry. Try the following steps.

1. You can get started now if you have access to about 30 3 x 5 index cards. For this first batch of flashcards, use *one* color of card if possible.

   (Plan to buy tomorrow about 100-200 3x5 index cards, lined or unlined. Different colors are not essential, but are helpful.)

2. On 12-15 of your 30 cards, cut a triangle off the top-right corner, making cards like this:

These cards will be used for questions that go in *one* direction.

Keeping the notch at the *top right* will identify the *front* side.

3. Using the following table, cover the *answers* in the right column with a cover sheet or sticky note, then put a check beside questions in the left column that you can answer accurately and without hesitation. When done, write the *others* onto the notched flashcards.

Front-side of cards (with notch at top right):	**Back Side -- Answers**
Define one gram.	The mass of 1 cm^3 of liquid water.
If you make the signifcand larger	Make the exponent smaller
42^0	Any number to the zero power = 1
Simplify $1/10^x$	10^{-x}
Simplify $1/10^{-x}$	10^x
To *add* or *subtract* in exponential notation	Make all the exponents the same

To multiply exponential terms	Add the exponents
To divide exponentials	Subtract the exponents.
To bring an exponential term from the bottom of a fraction to the top	Change its sign
1 meter = ? cm	100 cm
1 mm = ? m	10^{-3} m
The metric prefix abbreviation d- means	d- = deci = 10^{-1}
Symbol for *micro*- prefix	μ
8 x 7	56
84/12	7

Yes, any multiplication or division up to 12's that you cannot answer *instantly*, add to your list of one-sided cards. If you need a calculator to do easy multiplication and division, easy parts of chemistry such as "balancing an equation" will be frustrating. With flashcard practice, you will quickly learn what you need.

4. To make "two-way" cards, use the cards as they are, with*out* the notch cut.

   On the following questions, first cover the *right* column, then put a check on the left if you can answer the left column question quickly and with certainty. Then cover the *left* column and check the right side if you can answer the right-side *automatically*.

   Then, for any row that does not have *two* checks, make the flashcard.

Two-way cards (with*out* a notch):

1,000 g = 1 __g	1 kg = ____ g
1 nanometer = ___ m	10^{-9} meters = 1 ____meter
1 GHz	10^{9} Hz
1 picoliter	10^{-12} liters
2/3 = 0.?	0.666… = ? / ?
3/4 = 0.?	0.75 = ? / ?
1/8 = 0.?	0.1250 = ? / ?
1/80 = 0.?	0.**0**1250 = ? / ?
1 μm = ? m	10^{-6} m = 1 __m
1 Mg = ? g	10^{6} g = 1 __g
x^{-1}	1/x
1 cm^3 = 1 ___	1 mL = 1 __
1 dm^3 = 1 ___	1 L = 1 __
1,000 mL = 1 ___	1 Liter = ____ mL
Freezing temperature of water	0 degrees Celsius
Boiling temperature of water	100 degrees Celsius if 1 atm. pressure

Which cards you need will depend on your prior knowledge, but when in doubt, make a card. On the fundamentals, you need quick, automatic, confident, accurate recall, every time.

5. **Practice**. Use *one* type of card at a time.

   - **For front-sided cards**, if you get a card right quickly and automatically, set it aside. If you miss a card, say it. Close your eyes. Say it again. And again. If needed, write it several times. Return that card to the bottom of the "do-it" deck. Practice until every card is in the "got-it" pile.
   - **For two-sided cards,** do the same steps as above in one direction, then again in the *other* direction.

   For 3 days in a row, repeat the above steps. Repeat again before you do assigned problems in your current textbook chapter, then before the next quiz, then before your next test, that includes this material.

6. Master the cards once, *then* try them on problems. Problems will reinforce your practice.
7. Make cards for new topics early: before lectures and before homework. Mastering the fundamentals and vocabulary first will help in understanding lectures and in problem-solving.
8. Rubber band and carry new cards. Practice during "down times."
9. After a few modules, or for a new textbook chapter, change card colors.

This system requires an initial investment of time, but in the long run, it will *save* time and improve achievement substantially.

The above two tables of flashcards are examples. You are encouraged to add your own cards as needed. Try, then modify, this flashcard system to meet your needs.

<u>Flashcards, Charts, or Lists?</u>

What is the best strategy for learning new information? Use *multiple* strategies.

To develop automaticity in fundamentals, you may use numbered lists, mnemonics, phrases that rhyme, flashcards, reciting, and writing what must be remembered. Do so repeatedly, spaced over periods of time.

For more complex information, automatic visual and verbal recall may be less important than being able to methodically write out on paper what is needed, such as a list of equations or relationships to use to solve problems. Learning a *chart* is especially helpful when you need to be able to write from memory a large amount of information that falls into *patterns*.

To learn the metric-prefix relationships, learning the flashcards *and* the chart of prefixes *and* picturing the meter stick relationships, all help to fix in memory the fundamentals needed for chemistry calculations.

* * * * *

Practice: Make the two kinds of flashcards above. Run both sets until all cards are in the "got it" pile. *Then* try these problems. Write the answers in your notebook, then check your answers below. If needed to do answer these questions, make additional cards. Run the cards *and* this practice again in a day or two.

1. Fill in the blanks.

Format: 1 prefix-	1-base unit
1 μMETER = ______ METERS	1 METER = _______ μMETERS
1 gigawatt = ______ watts	1 watt = ________ gigawatts
1 nanogram = ______ grams	_______ nanograms = 1 gram

2. Use prefixes and powers of 10 to fill in the blanks in the following.

a. 10^{-6} farads = 1 ___________farad

b. 1 megawatt = ___________watts

c. 1 mole = ___________ millimoles

d. 1 nm = ___________ meters

e. 1 watt = ___________ gigawatts

f. 1 picocurie = ___________ curies

g. 1 μg = ____________ grams

h. 1 dL = ____________ liters

i. 1 g = ____________ cg

j. 1 kPa = ____________ Pa

3. a. $10^{-6} / 10^{-8}$ b. 2^{-1} c. 1/20 = 0.??

* * * * *

ANSWERS

1.

1 μMETER = **10^{-6}** METERS	1 METER = **10^{6}** μMETERS
1 gigawatt = **10^{9}** watts	1 watt = **10^{-9}** gigawatts
1 nanogram = **10^{-9}** grams	**10^{9}** nanograms = 1 gram

2. a. 10^{-6} farads = 1 **micro**farad

b. 1 megawatt = **10^{6}** watts

c. 1 mole = **10^{3}** millimole

d. 1 nm = **10^{-9}** meters

e. 1 watt = **10^{-9}** gigawatts

f. 1 picocurie = **10^{-12}** curies

g. 1 μg = **10^{-6}** grams

h. 1 dL = **10^{-1}** liters

i. 1 g = **10^{2}** cg

j. 1 kPa = **10^{3}** Pa

3. a. $10^{-6} / 10^{-8} = 10^{-6+8}$ = **10^{2}** b. 2^{-1} = 1/**2** = **0.5** c. 1/20 = 0.**0**5

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