Free Chem Download

For instructors and students, these pages may be viewed, or downloaded, or printed.

This packet includes:

For pages where "writing on the page" is suggested, printing the page will speed your work.

The pages are the first two chapters of *Calculations In Chemistry – An Introduction* (2nd edition) from W. W. Norton. Additional information on the book is here.

A note to **instructors** on cognitive science and chemistry is here.

CALCULATIONS IN CHEMISTRY

An Introduction

SECOND EDITION

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Brief Contents

Note to Students

The goal of these lessons is to help you solve *calculations* in first-year chemistry. This is only one part of a course in chemistry, but it can be the most challenging.

We suggest purchasing a *spiral notebook* as a place to write your work when solving problems in these lessons. You will also need

- Two packs of 100 3 × 5-inch index cards (two or more colors are preferred) plus a small assortment of rubber bands, and
- A pack of long sticky notes (4 × 6-inch notes are recommended) for use as cover sheets

It is important that *you* use the *same* calculator to solve homework problems that you will be allowed to use during tests, in order to learn and practice the rules for that calculator before tests.

Many courses will not allow the use of a graphing calculator or other calculators with extensive memory during tests. If no type of calculator is specified for your course, any inexpensive calculator with a [1/x] *or* [x^{-1}], [y^x] or [^], [log] *or* [10^x], *and* [ln] functions will be sufficient for most calculations in first-year chemistry.

How to Use These Lessons

1. ***Read* the lesson and *work* the Try It questions.** Use this method:
   - As you start a new page, *if* you see a *stop* sign on the page, *cover* the text *below* the *stop sign*. As a cover sheet, use either a sticky note or a folded sheet of paper.
   - In the space provided in the text or in your problem notebook, write your answer to the question (**Q.**) that is above the stop sign. Then move your cover sheet down to the next stop sign and check your answer. If you need a hint, read a *part* of the answer, then re-cover the answer and try the problem again.
2. ***First* learn the rules, *then* do the Practice.** The goal of learning is to move rules and concepts into *memory*. To begin, when working Try It questions, you may look back at the rules, but make an effort to commit the rules to memory before starting the Practice sets.

   Answers to the Practice problems are at the end of each chapter. If you need a hint, read a part of the answer and try again.

3. **How many Practice problems should you do?** It depends on your background. These lessons are intended to
   - Refresh your memory on topics you once knew, and
   - Fill in the gaps for topics that are less familiar

   If a topic is familiar, read the lesson for reminders and review, then do a *few* problems in each Practice set. Be sure to do the last problem (usually the most challenging).

   If a topic is unfamiliar, do more problems.
4. **Work Practice problems at least three days a week.** Chemistry is cumulative. What you learn in initial topics you will need in memory later. To retain what you learn, *space* your study of a topic out over several days.

   Begin lessons on new topics early, preferably before the topic is covered in a lecture.
5. **Memorize what must be memorized.** Use flashcards and other memory aids.

The key to success in chemistry is to *study* rules and concepts and *practice* solving problems at a *steady* pace.

1

Numbers in Scientific Calculations

Lesson 1.1 Learning Chemistry

What does science tell us about the most effective ways to study?

1. **In the sciences, the goal of learning is to solve problems.** Your brain solves problems using information from your environment and from your memory. The brain contains different types of memory, including
   - **working memory (WM)**, where you think by processing information; and
   - **long-term memory (LTM)**, where the brain stores information you have learned.
2. **Problem solving depends on well-memorized information.** A key discovery of recent research in cognitive science is that working memory can hold and process essentially *unlimited* knowledge that one is able to recall quickly from long-term memory but can hold and process only a few small elements that have *not* previously been memorized. During initial learning, a primary goal is to move new knowledge into LTM so that it can then be linked to other knowledge.

3. **Reliably moving knowledge into LTM** requires *repeated thought* about the meaning of new information, *effort* at recalling new facts, and *practice* in applying new skills.
4. **"Automaticity" in recall of fundamentals** is the central strategy to overcome limitations in working memory. When knowledge can be recalled quickly and accurately, more space in WM is available both for processing and for noting the associations within knowledge that build conceptual understanding.
5. **Memorizing standard algorithms** (stepwise procedures) is another way around the "processing bottleneck" in WM.
6. **Concepts are crucial.** Your brain constructs "conceptual frameworks" to judge when information should be recalled. Frameworks are built by practice in applying new knowledge to a variety of problems.
7. **"You can always look it up" is a poor strategy for problem solving.** The more information you must stop to look up, the more difficult it is for WM to manage the steps needed to solve a complex problem.

Moving Knowledge into Memory

How can you promote the retention of needed fundamentals in LTM? The following strategies are recommended by cognitive scientists:

1. **Learn incrementally** (in small pieces). The brain is limited in how much new memory it can construct in a short amount of time. In learning, *steady* wins the race.
2. **Overlearn.** If you practice recalling new information only one time, it will tend to remain in memory for only a few days. *Repeated* practice to perfection (called *overlearning*) builds reliable recall.
3. **Space your learning.** To *retain* what you learn, 20 minutes of study spaced over 3 days ("distributed practice") is more effective than 1 hour of study for 1 day. Study by "massed practice" (cramming) tends not to "stick" in LTM.
4. **Focus on core skills.** The facts and processes you should practice most often are those needed most often in a discipline.
5. **Effort counts.** Experts in a field usually attribute their success to "hard work over an extended period of time" rather than talent.
6. **Self-testing builds memory.** Practicing recall (such as by use of flashcards) and *then* solving problems is more effective than highlighting or re-reading notes or texts.
7. **Use parallel processing.** To remember new knowledge, listen, observe, recite, write, and practice recall. Your brain stores multiple *types* of memory. Multiple cues help you to recall steps and facts needed to solve a problem.
8. **Get a good night's sleep.** While you sleep, your brain reviews the experience of your day to decide what to store in LTM. Sleep promotes retention of what you learn.

For more on the science of learning, see *Cognition: The Thinking Animal* by Daniel Willingham (Prentice Hall, 2007) and *Make It Stick: The Science of Successful*

Learning by Peter C. Brown, Henry L. Roediger III, and Mark A. McDaniel (Harvard University Press, 2014).

PRACTICE

Answer these questions in your notebook:

1. What is "overlearning"?
2. When is "working memory" limited?
3. Which better promotes long-term learning: "massed" or "distributed" practice?

Lesson 1.2 Numeracy

Before you begin this lesson, read "Note to Students" on page 000.

Mental Arithmetic

Research has found that one of the best predictors of success in first-year college chemistry is the ability to solve simple mathematical calculations without a calculator. In part, this is because if you can recall "math facts" quickly from memory, the many relationships in science that are based on simple whole-number ratios make sense. In addition, speed matters in working memory. Fast recall of fundamentals leaves space for attention to the "science side" of demonstrations and calculations.

PRACTICE A

Find a device that measures how long it takes to complete a task in seconds (such as a stopwatch or digital timer on a phone or computer). To learn to use the device, *practice* until you can reliably time "counting to 30 in your head." Then:

1. Time how long it takes, in seconds, to write answers to these eight **addition** problems. Go as *fast* as you can with accuracy.

$7 + 4 =$	$5 + 9 =$	$3 + 7 =$	$9 + 7 =$
$5 + 8 =$	$7 + 5 =$	$8 + 7 =$	$11 + 6 =$

   Record your time: _____ seconds

2. Time how long it takes to write answers to these **subtraction** problems as fast as you can.

$9 - 4 =$	$12 - 9 =$	$11 - 5 =$	$10 - 3 =$
$12 - 7 =$	$9 - 5 =$	$12 - 3 =$	$15 - 4 =$

   Record your time: _____ seconds

(continued)

3. Time answering these **multiplication** problems as fast as you can.

$8 \times 4 =$	$8 \times 9 =$	$3 \times 9 =$	$9 \times 5 =$
$6 \times 6 =$	$4 \times 3 =$	$8 \times 3 =$	$5 \times 8 =$

Record your time: _____ seconds

4. Time answering these **division** problems as fast as you can.

24/4 =	36/9 =	56/8 =	45/9 =
42/6 =	49/7 =	60/12 =	40/5 =

Record your time: _____ seconds

Analysis

Check your answers. Reading from left to right across the top row, then the bottom:

Addition: 11, 14, 10, 16, 13, 12, 15, 17

Subtraction: 5, 3, 6, 7, 5, 4, 9, 11

Multiplication: 32, 72, 27, 45, 36, 12, 24, 40

Division: 6, 4, 7, 5, 7, 7, 5, 8

With fast and accurate recall, you should be able to complete each numbered question above with 100% accuracy in 24 seconds. If you did so for all four questions, great!

If you missed that goal for one or more questions, search online for a "mental arithmetic flashcard" application for your smartphone or computer. Practice each "rusty" skill for 5–10 minutes a day until you can accurately solve at "3 seconds per problem" (20 correct in 1 minute).

In your head, by *quick recall* not calculation, without a calculator or pencil, you must

- be able to add and subtract numbers from 1 through 20, and
- know your times tables (and corresponding division facts) through 12.

With practice, you will achieve the "automaticity" in math facts that is an essential foundation for work in the sciences.

Staying in Practice

The goal of study is learning that lasts, but we know that some of what we study is forgotten. What study practices build *long-term* memory?

Science has found that when we first learn something new, we best remember what we *practice recalling* for several days in a week, then again practice recalling about a week later, about a month later, and occasionally thereafter. This schedule for study seems to convey to the brain which new knowledge it especially needs to remember.

In these lessons, to keep your "math facts" sharp, we will ask you to occasionally perform simple multiplication and division without a calculator. There are several "standard algorithms" that can be used for multiplication and division, but to avoid confusion, research recommends that you learn one, then practice until its application becomes "automatic."

The multiplication algorithm usually taught in the United States includes these steps:

For 76 × 42 = ?

Step 1:

$$\begin{array}{r} {}^{1}76 \\ \times\ 42 \\ \hline 152 \end{array}$$

Steps 2 and 3:

$$\begin{array}{rl} {}^{2}76 & \\ \times\ 42 & \\ \hline 152 & \\ 304 & \leftarrow \text{(a } \mathbf{0} \text{ after the 4 is an option)} \\ \hline \mathbf{3192} & \end{array}$$

The "long division" algorithm usually taught in the United States includes these steps:

For 2048 ÷ 8 = ?

$$\begin{array}{r} 2 \\ 8\overline{)20\mathbf{4}8} \\ -16 \\ \hline 4\mathbf{4} \end{array} \qquad \begin{array}{r} 256 \\ 8\overline{)204\mathbf{8}} \\ -16 \\ \hline 44 \\ -40 \\ \hline 4\mathbf{8} \\ -48 \\ \hline \end{array} \quad = \mathbf{256}$$

> In these lessons, using pencil and paper, you will be required to
> - multiply two digits by two digits, and
> - solve "long division" of an evenly divisible four-digit number by a single digit.

PRACTICE B

Complete the problems that follow using a standard algorithm you have practiced. If no standard algorithm is familiar, use the procedures given earlier. For additional help, search online for a "multiplication algorithm" or "long division algorithm" video.

Do one part of each problem if this is easy review but more if you need practice. Check answers as you go at the end of this chapter.

1. *Without* a calculator, working in your problem notebook, multiply these:

a. $\begin{array}{r} 93 \\ \times\ 75 \\ \hline \end{array}$ b. $\begin{array}{r} 64 \\ \times\ 82 \\ \hline \end{array}$ c. $\begin{array}{r} 49 \\ \times\ 38 \\ \hline \end{array}$

(continued)

2. *Without* a calculator, in your notebook, solve these "evenly divisible" problems (answers will be a multidigit whole number—no decimals or remainders):

a. $6\overline{)252}$ b. $9\overline{)801}$ c. $8\overline{)448}$

Decimal Equivalents

To divide 492 by 7.36, a calculator is useful, but when working in science, health care, or engineering, every calculation must be checked because every effort must be made to avoid errors.

One way to check your calculator use is estimation using mental math. Fast recall of the following **decimal equivalents** will help.

1/2 = 0.50	1/3 ≈ 0.33	1/4 = 0.25	1/5 = 0.20
2/3 ≈ 0.67	3/4 = 0.75	1/8 = 0.125	3/2 = 1.5

The squiggly ≈ sign means "approximately equals."

PRACTICE C

To practice conversion of fractions to decimal equivalents, try the following.

- On a sheet of paper, draw five columns and eight rows. List the fractions down the middle column.

		1/2		
		1/3		
		1/4		
		1/5		
		2/3		
		3/4		
		1/8		
		3/2		

- From memory, try writing the decimal equivalents of the fractions in the far right column. Then check your answers.
- Fold over those answers and repeat at the far left. Fold over those and repeat.

Using Mental Math to Simplify Fractions

Scientific calculations often involve fractions with several numbers. During estimation, these fractions can be simplified "on paper, with pencil," as a check on calculator use. Follow the steps across in this example, as "pencil arithmetic" is used to simplify the fraction.

$$\frac{8 \times 21 \times 3}{72} \quad \frac{\cancel{8} \times 21 \times 3}{\cancel{72}\ \mathbf{9}} \quad \frac{\cancel{8} \times 21 \times \cancel{3}}{\cancel{72}\ \cancel{\mathbf{9}}\ \mathbf{3}} = \frac{\mathbf{21}}{\mathbf{3}} = \mathbf{7}$$

Other steps to simplify the arithmetic would be equally valid. In a problem with several cancellations, you may want to rewrite the fraction to summarize your progress, as in the "next to last" step above, to keep your work clear.

PRACTICE D

Without a calculator, use your mental math skills to reduce these fractions. Show your work on this paper. Hint: It usually helps to try to reduce larger numbers first.

1. Simplify each of the following to a one- or two-digit whole number:

   a. $\frac{56 \times 2 \times 3}{4 \times 7} =$ b. $\frac{20 \times 4 \times 45}{8 \times 9} =$

   c. $\frac{42 \times 24 \times 5}{2 \times 6 \times 7} =$ d. $\frac{16 \times 12 \times 7}{2 \times 96} =$

2. Convert each of the following to a decimal equivalent in the form **0**.XXX:

   a. $\frac{27 \times 4 \times 7}{6 \times 42 \times 9} =$ b. $\frac{5 \times 3 \times 16}{8 \times 2 \times 30} =$

   c. $\frac{3 \times 2 \times 11}{22 \times 24} =$ d. $\frac{8 \times 3 \times 63}{9 \times 7 \times 96} =$

Fixed Decimal Notation and Exponential Notation

In science, we often deal with very large and very small numbers. For example:

- A drop of water contains about **1,500,000,000,000,000,000,000** molecules.
- An atom of gold has a mass of **0.000 000 000 000 000 000 000 327** gram.

Values expressed as "regular numbers," such as 153 or 0.0024 or the two numbers above, are said to be in **fixed decimal notation** (also called **fixed notation**).

In science, very large and very small numbers are most often expressed in **base 10 exponential notation:** as a *number* multiplied by **10** to an *integer* (positive or negative whole number) power. In chemistry, unless otherwise noted, you should assume that "exponential notation" means *base 10* exponential notation.

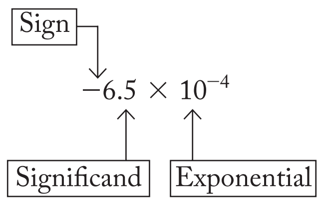
For the measurements above, in exponential notation we can write:

- A drop of water contains about $\mathbf{1.5 \times 10^{21}}$ molecules.
- An atom of gold has a mass of $\mathbf{3.27 \times 10^{-22}}$ gram.

Values expressed in exponential notation can be described as having three parts.

Example: In -6.5×10^{-4}

- The $-$ in front is the **sign**.
- The **6.5** is a fixed decimal number that has a variety of names. In this text, we will call it the **significand**.
- The $\mathbf{10^{-4}}$ is the **exponential** term: the **base** is **10** and the **exponent** (also called the **power**) is **−4**.



You will need to be able to label the parts of values in exponential notation using those six terms.

PRACTICE E

1. Express the value of the fraction **1/4** in fixed decimal notation. ________
2. Circle the significand in $\mathbf{6.02 \times 10^{23}}$

Lesson 1.3 Moving the Decimal

Powers of 10

Below are the numbers that correspond to powers of 10. Note the relationship between the exponent, the number of zeros, and the position of the decimal point in the fixed decimal numbers as you go down this sequence.

$10^6 = 1{,}000{,}000 = 10 \times 10 \times 10 \times 10 \times 10 \times 10$

$10^3 = 1000 = 10 \times 10 \times 10$

$10^2 = 100 = 10 \times 10$

$10^1 = 10$

$10^0 = \mathbf{1}$ *Any* number to the *zero* power equals *one*.

$10^{-1} = 0.1$

$10^{-2} = 0.01 = 1/10^2 = 1/100$

$10^{-3} = 0.001$

When converting from powers of 10 to fixed decimal numbers, use these steps:

1. To convert a *positive* power of 10 to a fixed decimal number, write 1, then move the decimal point to the *right* by the number of places in the exponent.

   Example: $10^2 = \mathbf{100}$

2. To convert a *negative* power of 10 to a fixed decimal number, write 1, then move the decimal to the *left* by the number of places equal to the number after the negative sign in the exponent.

TRY IT

(See "How to Use These Lessons," point 1, p. 000.)

STOP

Q. Convert to fixed decimal notation: $10^{-2} =$

Answer:

$$10^{-2} = \mathbf{0.01}$$

PRACTICE A

Convert these values to fixed decimal notation. Write your answers in the spaces below. Check answers at the end of this chapter.

1. $10^4 =$
2. $10^{-4} =$
3. $10^7 =$
4. $10^{-5} =$
5. $10^0 =$

Multiplying and Dividing by 10, 100, and 1000

To multiply or divide by fixed decimal numbers that are positive whole-number powers of 10 (such as 100 or 10,000), use these rules:

1. When *multiplying* a fixed decimal number by 10, 100, 1000, and so forth, move the number's decimal to the *right* by the number of zeros in the 10, 100, or 1000.

   Examples: $72 \times 100 = \mathbf{7{,}200}$ $\quad -0.0624 \times 1000 = \mathbf{-62.4}$

2. When *dividing* a number by 10, 100, 1000, and so forth, move the number's decimal to the *left* by the number of zeros in the 10, 100, or 1000.

TRY IT

Q. Write answers to these operations as fixed decimal numbers:

a. 34.6/1000 =

b. −0.47/100 =

Answers:

a. 34.6/1000 = **0.0346**

b. −0.47/100 = **−0.0047**

3. When writing a fixed decimal number between −1 and 1 (a number that "begins with a decimal point"), always place a *zero* in front of the decimal point.

   Example: Do not write .42 or −.74; do write 0.42 or −0.74.

During your written calculations, the zero in front helps in seeing your decimals.

PRACTICE B

1. When dividing by 1000, move the decimal to the ________ by ________ places.
2. Write answers to these operations in fixed decimal notation:

   a. 0.42 × 1000 =

   b. 63/100 =

   c. −74.6/10,000 =

Converting Exponential Notation to Fixed Decimal Notation

When working with numbers in science, we often need to convert between fixed decimal and exponential notation or to move the decimal in the significand of exponential notation.

A rule applies in all of these conversions: The sign in *front* never changes. The sign identifies whether the *value* is positive or negative. When moving the decimal, the sign of the *exponential* term *may* change, but positive values remain positive and negative values remain negative.

To convert from exponential notation (such as -4×10^3) to fixed decimal notation (−4,000), use these rules:

1. The sign in front never changes.
2. If the significand is multiplied by a *positive* power of 10, move the decimal point in the significand to the *right* by the number of places equal to the value of the exponent.

   Examples: $2 \times 10^2 =$ **200**; $-0.0033 \times 10^3 =$ **−3.3**

3. If the significand is multiplied by a *negative* power of 10, move the decimal point in the significand to the *left* by the number of places equal to the number *after* the negative sign in the exponent.

   Examples: 2×10^{-2} = **0.02**; $-7{,}653.8 \times 10^{-3}$ = **−7.6538**

PRACTICE C

Convert these values to fixed decimal numbers:

1. $3 \times 10^{3} =$
2. $5.5 \times 10^{-4} =$
3. $0.77 \times 10^{6} =$
4. $-95 \times 10^{-4} =$

Converting Exponential Notation to Scientific Notation

In chemistry, when we work with very large or very small numbers, it is preferable to write the numbers in **scientific notation**, which is a special form of exponential notation that makes values easier to compare. There are many equivalent ways to write a value in exponential notation, but there is only one correct way to write a value in scientific notation.

The general rule is:

To convert a value from exponential notation to *scientific* notation, move the decimal so that the significand is a single number from 1 to 9, then adjust the power of 10 to keep the value the same.

Another way to say this is:

To convert from exponential notation to *scientific* notation,

- move the decimal point in the significand to be *after* the first digit that is *not* a zero, then
- adjust the exponent to keep the same numeric value.

To apply these rules, the specific steps are:

1. Do not change the + or − *sign* in *front* of the significand.
2. When moving the decimal n times to make the significand *larger*, make the power of 10 *smaller* by a count of n.

Example: Convert from exponential notation to scientific notation:

$$0.045 \times 10^5 = 4.5 \times 10^3$$

The decimal must be after the 4. Move the decimal two places to the right. This makes the significand 100 times larger. To keep the same numeric value, lower the exponent by 2, making the 10^x value 100 times smaller.

TRY IT

Q. Convert this value to scientific notation:

$$-0.0057 \times 10^{-2} =$$

STOP

Answer:

The value *must* be written as -5.7×10^{-5}

To convert to scientific notation, the decimal must be moved to be after the first number that is not a zero: the 5. That move of three places makes the significand 1000 times larger. To keep the same value, make the exponential term 1000 times smaller.

The logic of the math is:

$$-0.0057 \times 10^{-2} = -[(5.7 \times 10^{-3}) \times 10^{-2}] = \mathbf{-5.7 \times 10^{-5}}$$

3. When moving the decimal n times to make the significand *smaller*, make the power of 10 *larger* by a count of n.

TRY IT

Q. Convert this value to scientific notation:

$$-8{,}544 \times 10^{-7} =$$

STOP

Answer:

$$-8{,}544 \times 10^{-7} = \mathbf{-8.544 \times 10^{-4}}$$

In scientific notation, the decimal must be after the 8, so you must move the decimal three places to the left. This makes the significand 1000 times smaller. To keep the same numeric value, increase the exponent by 3, making the 10^x value 1000 times larger.

Remember, 10^{-4} is 1000 times larger than 10^{-7}.

The general rule is:

If you move the decimal n places, change the exponent by a count of n.

When you move a decimal, it is helpful to *recite*, for the significand and the exponential term *after* the sign in front:

If one gets *smaller*, the other gets *larger*. If one gets *larger*, the other gets *smaller*.

The Role of Practice

In the **Practice** sets, do as many problems as you need to feel "quiz ready."

- If the material in a lesson is easy review, do the *last* problem in each series of similar problems (which is usually the most challenging).
- If the lesson is not as easy, put a check mark (✓) by every other problem, then work that half of the problem set. If you miss one, do additional problems in the set.
- Save a *few* problems for your next study session or for later review.

During **Examples** and **Try Its**, you *may* look back at the rules, but write and practice recalling new rules from memory *before* starting the Practice set.

If you use Practice sets to learn the rules, it will be difficult to find time for all of the problems you will need to do. If you use Practice sets to *apply* rules that are in memory, you will need to solve fewer problems to be "quiz ready."

PRACTICE D

Convert these values to scientific notation:

1. $5{,}423 \times 10^3 =$
2. $0.0067 \times 10^{-4} =$
3. $0.024 \times 10^3 =$
4. $-877 \times 10^{-4} =$
5. $0.00492 \times 10^{-12} =$
6. $-602 \times 10^{21} =$

Converting Fixed Decimal Notation to Scientific Notation

To convert fixed decimal numbers (that is, regular numbers) to *exponential* notation or *scientific* notation, we apply the following math rules:

- Any number to the zero power equals one: $\mathbf{2^0 = 1; 42^0 = 1}$.
  Exponential notation most often uses $\mathbf{10^0 = 1}$.
- Because any number can be multiplied by 1 without changing its value, any number can be multiplied by 10^0 without changing its value.

Example:

$$42 = 42 \times 1 = 42 \times \mathbf{10^0} \text{ in } \textit{exponential} \text{ notation}$$
$$= \mathbf{4.2} \times 10^{\mathbf{1}} \text{ in } \textit{scientific} \text{ notation}$$

To convert fixed notation to *scientific* notation, the steps are:

1. Add "**$\times 10^0$**" after the number.
2. Apply the steps that convert exponential notation to scientific notation:
   - Do not change the sign in *front*.
   - Move the decimal in the significand to be *after* the *first* digit that is not a zero.
   - Adjust the power of 10 to compensate for moving the decimal.

TRY IT

Q. Convert these fixed decimal numbers to scientific notation:

a. $943 =$ b. $-0.00036 =$

STOP

Answers:

a. $943 = 943 \times 10^0 = \mathbf{9.43 \times 10^2}$ b. $-0.00036 = -0.00036 \times 10^0 = \mathbf{-3.6 \times 10^{-4}}$

When converting between fixed notation and scientific notation, the sign in front never changes. For the terms *after* the sign in front:

- When converted to scientific notation, a fixed decimal number with a value *larger than one* will have a *positive* whole-number power of 10 (a power zero or greater).
- When converted to scientific notation, a fixed decimal number with a value *between zero and one* (such as 0.25) will have a *negative* whole-number power of 10.
- Comparing the position of the decimal in a fixed decimal number and in the significand of the value written in scientific notation, the number of *places* that the decimal in a number moves is the *number after* the sign of the scientific notation *exponent*.

Note how these rules apply to the two parts of the Try It above.

Note that in both exponential notation and scientific notation, whether the sign in *front* is positive or negative has no relation to the sign of the *exponential* term. The sign in front states whether the value is positive or negative. The sign of the exponential term indicates how many places the decimal moved in converting from fixed notation to exponential or scientific notation.

PRACTICE E

1. Which of these values is written in scientific notation? _____

   a. 74 b. -14.7×10^{-24} c. -9.6×10^{14} d. 77×10^{0}

2. Which lettered parts in problem 3 below must have a negative power of 10 when written in scientific notation?
3. Convert these values to scientific notation:

   a. 6,280 = b. 0.0093 =

   c. 0.741 = d. −1,280,000 =

To summarize this lesson in your problem notebook:

- In your own words, list the shaded rules that were unfamiliar or that you found helpful.
- Then, write and recite your rules until you can write them from memory.

PRACTICE F

Check (✓) and do every *other* letter. If you miss one, do another letter for that set.

1. Write answers in fixed decimal notation for these operations:

   a. 924/10,000 = b. 24.3×1000 =

   c. −0.024/10 =

2. Convert these values to scientific notation:

   a. 0.55×10^{5} = b. 0.0092×100 =

   c. -943×10^{-6} = d. 0.00032×10^{1} =

3. Convert these fixed decimal numbers to scientific notation:

   a. 7,700 = b. 160,000,000 =

   c. 0.023 = d. −0.00067 =

Lesson 1.4 Calculations Using Exponential Notation

PRETEST If you can answer these two questions correctly, you may skip to Lesson 1.5. Otherwise, complete Lesson 1.4. Answers are at the end of this chapter. Do *not* use a calculator. Convert final answers to scientific notation.

1. $(2.0 \times 10^{-4})\ (6.0 \times 10^{23}) =$

2. $\dfrac{10^{23}}{(100)\ (3.0 \times 10^{-8})} =$

Multiplying and Dividing Powers of 10

The following rules should be recited until they can be recalled from memory. Rules that apply to exponential terms include:

1. When you *multiply* exponentials, you *add* the exponents.

   Examples: $10^3 \times 10^2 = 10^5$ $10^{-5} \times 10^{-2} = 10^{-7}$ $10^{-3} \times 10^5 = 10^2$

2. When you *divide* exponentials, you *subtract* the exponents.

   Examples: $10^3/10^2 = 10^1$ $10^{-5}/10^2 = 10^{-7}$ $10^{-5}/10^{-2} = 10^{-3}$

   When subtracting, remember: Minus a minus is a plus.

   Example: $10^{6-(-3)} = 10^{6+3} = 10^9$

3. When you take the reciprocal of an exponential, change the exponent's sign.

   This rule is often remembered as:

   When you take an exponential term from the bottom to the top, change the exponent's sign.

   Example:

$$\frac{1}{\mathbf{10^3}} = \mathbf{10^{-3}};\ 1/\mathbf{10^{-5}} = \mathbf{10^5}$$

   Why does this work? By rule 2:

$$\frac{1}{\mathbf{10^3}} = \frac{10^0}{\mathbf{10^3}} = \mathbf{10^{0-3}} = \mathbf{10^{-3}}$$

In later lessons, we will practice additional rules for exponential notation.

Finally, when simplifying a fraction that includes two or more exponential terms, it generally helps if you simplify the top and bottom exponential terms *separately* in the first step, then divide the terms in the next step.

Example:

$$\frac{10^{-2} \times 10^{7}}{10^{2} \times 10^{-5}} = \frac{10^{5}}{10^{-3}} = 10^{5-(-3)} = 10^{5+3} = \mathbf{10^{8}}$$

TRY IT

Q. Without using a calculator, write the simplified top, then the simplified bottom, and then divide:

$$\frac{10^{-3} \times 10^{-4}}{10^{5} \times 10^{-8}} = \_\_\_\_\_\_\_\_\_\_ =$$

STOP

Answer:

$$\frac{10^{-3} \times 10^{-4}}{10^{5} \times 10^{-8}} = \frac{\mathbf{10^{-7}}}{\mathbf{10^{-3}}} = 10^{-7-(-3)} = 10^{-7+3} = \mathbf{10^{-4}}$$

PRACTICE A

Write these answers as 10 to a power. Work on this page if possible. Do *not* use a calculator.

1. $10^{6} \times 10^{2} =$
2. $10^{-5} \times 10^{-6} =$
3. $\frac{10^{-5}}{10^{-4}} =$
4. $\frac{10^{-3}}{10^{5}} =$
5. $\frac{1}{1/10^{4}} =$
6. $1/10^{23} =$
7. $\frac{10^{3} \times 10^{-5}}{10^{-2} \times 10^{-4}} =$
8. $\frac{10^{5} \times 10^{23}}{10^{-1} \times 10^{-6}} =$
9. $\frac{100 \times 10^{-2}}{1000 \times 10^{6}} =$
10. $\frac{10^{-3} \times 10^{23}}{10 \times 1000} =$

Multiplying and Dividing in Exponential Notation

To check calculator results, we need to be able to estimate answers (without using a calculator) for calculations that include exponential notation. In doing so, the following is the rule we use most often.

When multiplying and dividing in calculations that include exponential notation:

> Handle the math of fixed decimals and exponential terms separately.

To do so:

- Do the math for the fixed decimal numbers (including significands) using number rules.
- Then, separately simplify the exponential terms using exponential rules.
- Finally, combine the two parts.

TRY IT

Apply the rule to the following three problems.

Q1. Do not use a calculator: $(2 \times 10^3)\ (4 \times 10^{23}) =$

STOP

Answer:

For significands, use number rules: 2 multiplied by 4 is **8**

For exponentials, use exponential rules: $10^3 \times 10^{23} = 10^{3+23} = \mathbf{10^{26}}$

Then, combine the two parts: $(2 \times 10^3)\ (4 \times 10^{23}) = \mathbf{8 \times 10^{26}}$

Q2. Do the significand math on a calculator but the exponential math in your head for:

$$(2.4 \times 10^{-3})\ (3.5 \times 10^{23}) =$$

(We will review *how much* to round answers in Chapter 3. Until then, in your answers, round numbers and significands to *two* digits unless otherwise noted.)

STOP

Answer:

Handle significands and exponents separately.

Use a calculator for: $2.4 \times 3.5 = \mathbf{8.4}$

Do the exponentials in your head: $10^{-3} \times 10^{23} = \mathbf{10^{20}}$

Then, combine: $(2.4 \times 10^{-3})\ (3.5 \times 10^{23}) = \mathbf{8.4 \times 10^{20}}$

Q3. Do the significand math on a calculator but the exponential math without a calculator.

$$\frac{6.5 \times 10^{23}}{4.1 \times 10^{-8}} =$$

STOP

Answer:

$$\frac{6.5 \times 10^{23}}{4.1 \times 10^{-8}} = \frac{6.5}{4.1} \times \frac{10^{23}}{10^{-8}} = 1.585 \times [10^{23-(-8)}] = \mathbf{1.6 \times 10^{31}}$$

Here's one more rule that will help with problem solving:

When dividing, if an exponential term on top does not have a significand, place a "1×" in front of the exponential so that the number–number division is clear.

TRY IT

Q. Apply the rule to the following problem, then write the final answer in scientific notation. Do not use a calculator.

$$\frac{10^{-14}}{2.0 \times 10^{-8}} =$$

STOP

Answer:

$$\frac{10^{-14}}{2.0 \times 10^{-8}} = \frac{\mathbf{1} \times 10^{-14}}{2.0 \times 10^{-8}} = 0.50 \times 10^{-6} = \mathbf{5.0 \times 10^{-7}}$$

PRACTICE B

In your own words, summarize any unfamiliar rules in this lesson, then apply them from memory to these problems. If more room is needed for careful work, solve in your notebook. Do the odd-numbered problems first, then the evens if you need more practice. Try these *first* without a calculator, then check your mental arithmetic with a calculator if needed. Write final answers in scientific notation, rounding significands to two digits.

1. $(2.0 \times 10^{1})\,(6.0 \times 10^{23}) =$
2. $(4.0 \times 10^{-3})\,(1.5 \times 10^{15}) =$
3. $\dfrac{3.0 \times 10^{-21}}{-2.0 \times 10^{3}} =$
4. $\dfrac{6.0 \times 10^{-23}}{2.0 \times 10^{-4}} =$
5. $\dfrac{10^{-14}}{-5.0 \times 10^{-3}} =$
6. $\dfrac{10^{14}}{4.0 \times 10^{-4}} =$
7. Complete the two problems in the Pretest at the beginning of this lesson.

In your problem notebook, write a list of rules in Lesson 1.4 that were unfamiliar, need reinforcement, or were helpful to you. Write and recite your list until you can write all of the points from memory. Then, do the problems in Practice C.

PRACTICE C

Start by doing every *other* letter. If you get those right, go to the next number. If not, do a few more of that number. Save a few parts for your next study session.

1. Try these *without* a calculator. Convert your final answers to scientific notation.

   a. $3 \times (6.0 \times 10^{23}) =$

   b. $1/2 \times (6.0 \times 10^{23}) =$

   c. $0.70 \times (6.0 \times 10^{23}) =$

   d. $10^{3} \times (6.0 \times 10^{23}) =$

   e. $(-0.5 \times 10^{-2})\,(6.0 \times 10^{23}) =$

(continued)

f. $\frac{1}{10^{12}} =$

g. $1/(1/10^{-9}) =$

h. $\frac{2.0 \times 10^{18}}{6.0 \times 10^{23}} =$

i. $\frac{10^{-14}}{4.0 \times 10^{-5}} =$

2. Use a calculator for the fixed decimal math but not for the exponents. Write final answers in scientific notation.

a. $\frac{2.46 \times 10^{19}}{6.0 \times 10^{23}} =$

b. $\frac{10^{-14}}{0.0072} =$

3. Try these *without* a calculator. Write answers as a power of 10.

a. $\frac{10^{7} \times 10^{-2}}{10 \times 10^{-5}} =$

b. $\frac{10^{-23} \times 10^{-5}}{10^{-5} \times 100} =$

Lesson 1.5 Estimation and Exponential Calculations

PRETEST If you can solve *both* of the following problems correctly, skip this lesson. Convert your final answers to scientific notation. Check answers at the end of this chapter.

1. Solve this problem *without* a calculator:

$$\frac{(10^{-9})(10^{15})}{(4 \times 10^{-4})(2 \times 10^{-2})} =$$

2. For this problem, use a calculator as needed:

$$\frac{(3.15 \times 10^{3})\,(4.0 \times 10^{-24})}{(2.6 \times 10^{-2})\,(5.5 \times 10^{-5})} =$$

Choosing a Calculator

If you have not already done so, please read "Note to Students" on page 000.

Complex Calculations

The prior lessons covered the fundamental rules for exponential notation. For longer calculations, the rules are the same. The challenges are keeping track of the numbers and using the calculator correctly. The steps below will help you to simplify complex calculations and quickly *check* your answers.

TRY IT

Q. Let's try the following calculation two ways.

$$\frac{(7.4 \times 10^{-2})(6.02 \times 10^{23})}{(2.6 \times 10^{3})(5.5 \times 10^{-5})} =$$

Method 1: Do Numbers and Exponents Separately Work the calculation using the following steps:

1. **Do the numbers on the calculator.** Ignoring the exponentials, use the calculator to multiply all of the *significands* on top. Write the result. Then, multiply all the significands on the bottom, and write the result. Divide, write your answer, round to two digits for your final answer, then check below.

STOP

$$\frac{7.4 \times 6.02}{2.6 \times 5.5} = \frac{44.55}{14.3} = 3.1152 = \mathbf{3.1}$$

2. **Then handle the exponents.** Starting from the original problem, look only at the powers of 10. Solve the exponential math using pencil and paper as needed, but *without* a calculator. Simplify the top, then the bottom, then divide, and write a single exponential term as your answer.

STOP

$$\frac{10^{-2} \times 10^{23}}{10^{3} \times 10^{-5}} = \frac{10^{21}}{10^{-2}} = 10^{21-(-2)} = \mathbf{10^{23}}$$

3. **Now combine** the significand and exponential, and write the final answer.

STOP

Answer:

$$\mathbf{3.1 \times 10^{23}}$$

Note that by handling the numbers and exponents separately, you did *not* need to enter the exponents into your calculator. To multiply and divide the powers of 10, you simply add and subtract whole numbers.

TRY IT

Q. Method 1 above is a simple way to solve exponential notation without having to enter lots of numbers into the calculator. A second option is to enter *all* of the numbers and operations into the calculator. If you want to try that approach, try method 2.

Method 2: All on the Calculator Starting from the original Try It problem, enter *all* of the numbers and exponents into your calculator. Different calculators use different forms of data entry, but your calculator manual (usually available online) can help. Write your final answer in scientific notation. Round the significand to two digits.

On most calculators, you will need to use an [E] or [EE] or [EXP] or [^] key, rather than the *multiplication* key, to enter a "10 to a power" term.

STOP

Answer:

Your calculator answer, rounded, should be the same as with method 1:

$$\mathbf{3.1 \times 10^{23}}$$

Note how your calculator *displays* the *exponential* term in answers. The exponent may be set apart at the right, sometimes with an **E** in front.

Which way was easier: "Numbers on the calculator, exponents on paper" or "all on the calculator"? "Doing the exponents in your head" is often easier—and helps to keep your mental math sharp.

During calculations, try to use mental arithmetic to solve the exponential math, but always convert final answers that have exponential terms to scientific notation.

Answers in Fixed Notation or Scientific Notation?

In chemistry, as a very general rule, numeric values ranging from 0.01 to 9,999 are expressed as fixed decimals, whereas values outside that range are reported in scientific notation. When writing final answers to problems, a "rule of thumb" is: If a fixed decimal answer has more than two zeros at the beginning or end, convert it to scientific notation.

Checking Calculator Results

Whenever a complex calculation is solved on a calculator, to check your calculator use you *must* do the calculation a *second* time using different steps.

In these lessons, you will learn "mental arithmetic estimation" as a quick way to check that an answer "makes sense."

TRY IT

Q. Let's start with the calculation that we used in the first Try It section of this lesson:

$$\frac{(7.4 \times 10^{-2})\ (6.02\ \times 10^{23})}{(2.6 \times 10^{3})\ (5.5 \times 10^{-5})} =$$

Apply the following steps to the numbers above:

1. ***Estimate* the numbers answer first.** Ignoring the exponentials and using a pencil, write a *rounded* whole-number substitute for each significand on top. Then multiply all of the top significands, and write the result. *Round* the bottom significands to whole numbers, multiply them, and write the result. Then write a *rounded estimate* of the answer when you divide the top and bottom numbers.

STOP

Answer:

Your rounding might be

$$\frac{7 \times \cancel{6}}{3 \times \cancel{6}} = \frac{7}{3} \approx \mathbf{2} \text{ (The } \approx \text{ sign means "approximately equals.")}$$

Your "pencil and paper" estimate needs to be fast but does not need to be exact. With practice, your skill will improve in doing these estimates "in your head."

2. **Simplify the exponents.** Use pencil and paper to simplify the top exponential terms, then the bottom, then divide.

$$\frac{10^{-2} \times 10^{23}}{10^{3} \times 10^{-5}} = \frac{10^{21}}{10^{-2}} = 10^{21-(-2)} = \mathbf{10^{23}}$$

3. **Combine** the two parts. Compare this estimate to the answer found in the earlier Try It section. Are they close?

STOP

Answer:

The estimate is $\mathbf{2 \times 10^{23}}$. The answer with the calculator was $\mathbf{3.1 \times 10^{23}}$. Allowing for rounding, the two results are close.

If your fast, rounded, pencil-and-paper answer is *close* to the answer where all or part was done on the calculator, it is probable that your more precise calculator answer is correct. If the two answers are far apart, check your work.

On timed tests, you may want to do the more precise answer with the help of the calculator first, and then go back at the end, if time is available, and use rounded numbers and mental arithmetic as a check. When doing a calculation the second time, try not to look back at the first answer until after you write the estimate. If you look back, by the power of suggestion you will often arrive at the first answer whether it is correct or not.

For complex operations on a calculator, check the answer by estimation using rounded numbers and mental arithmetic.

PRACTICE

Do problems 1–4 without a calculator. Convert final answers to scientific notation. Round the significand in the answer to two digits.

1. $\dfrac{4 \times 10^{3}}{(2.00)(3.0 \times 10^{7})} =$

2. $\dfrac{1}{(4.0 \times 10^{9})(2.0 \times 10^{3})} =$

(continued)

3. $\dfrac{(3 \times 10^{-3})(8.0 \times 10^{-5})}{(6.0 \times 10^{11})(2.0 \times 10^{-3})} =$

4. $\dfrac{(3 \times 10^{-3})(3.0 \times 10^{-2})}{(9.0 \times 10^{-6})(2.0 \times 10^{1})} =$

Complete problems 5–8 below in your notebook as follows:

- First, write an *estimate.* Use mental math to solve exponents and rounded significands.
- Then, calculate a more precise answer. You may
  - use the "significands on calculator, exponents on paper" method; or
  - plug the entire calculation into the calculator; or
  - experiment to see which approach is best for you.

Convert both the estimate and the final answer to *scientific notation*. Round the significand in the answer to two digits. Use the calculator that you will be allowed to use on quizzes and tests.

To start, complete the even-numbered problems. If you need more practice, do the odds.

5. $\dfrac{(3.62 \times 10^{4})(6.3 \times 10^{-10})}{(4.2 \times 10^{-4})(9.8 \times 10^{-5})} =$

6. $\dfrac{10^{-2}}{(750)(2.8 \times 10^{-15})} =$

7. $\dfrac{(1.6 \times 10^{-3})(4.49 \times 10^{-5})}{(2.1 \times 10^{3})(8.2 \times 10^{6})} =$

8. $\dfrac{1}{(4.9 \times 10^{-2})(7.2 \times 10^{-5})} =$

9. For additional practice, do the two Pretest problems at the beginning of this lesson.

SUMMARY

To prepare for a quiz that includes the topics in this chapter:

1. Be able to summarize in your own words any shaded facts, relationships, and rules that are unfamiliar.
2. In your head, by *quick recall*, you need to be able to add and subtract numbers from 1 through 20 and to know your times tables through 12. If your mental math is at all rusty, try different math flashcard apps (or paper flashcards) for a 10-minute workout for several days a week.
3. Be able to solve the problems in the Review Quiz and the chapter.

REVIEW QUIZ

Solve the problems that follow. Do not use a calculator.

1. 87 multiplied by 94 (Solve in your notebook.)
2. 2,601 divided by 9
3. Simplify. Answer in fixed decimal numbers that have two non-zero digits.

   a. $\frac{42 \times 6 \times 8}{3 \times 7} =$ b. $\frac{7 \times 12}{4 \times 28} =$

4. Convert these to scientific notation:

   a. $-0.0068 =$ b. $8{,}920 \times 10^{-1} =$

5. Answer in scientific notation:

   a. $10^{-2} \times (6.0 \times 10^{23}) =$

   b. $\frac{3.0 \times 10^{24}}{6.0 \times 10^{23}} =$

   c. $\frac{10^{10}}{2.0 \times 10^{-5}} =$

   d. $\frac{3}{(1000)(9.0 \times 10^{-8})} =$

6. Answer in scientific notation:

   $$\frac{10^{23}}{(2.5 \times 10^{10})(2.0 \times 10^{-6})} =$$

ANSWERS

To make answer pages easy to locate, use a sticky note.

Lesson 1.1

1. Repeated practice to perfection.
2. When processing information not previously memorized.
3. Distributed (spaced) practice.

Lesson 1.2

Practice B 1a. 6,975 1b. 5,248 1c. 1,862 2a. 42 2b. 89 2c. 56

Practice D 1a. 12 1b. 50 1c. 60 1d. 7
2a. 0.333 2b. 0.500 2c. 0.125 2d. 0.250

Practice E 1. 0.25 2. (6.02) $\times 10^{23}$

Lesson 1.3

Practice A 1. 10,000 2. 0.0001 3. 10,000,000 4. 0.00001 5. 1

Practice B 1. When dividing by 1000, move the decimal to the **left** by **three** places.

2a. 420 2b. 0.63 (Must have a zero in front.) 2c. −0.00746

Practice C 1. 3,000 2. 0.00055 3. 770,000 4. −0.0095

Practice D 1. 5.422×10^6 2. 6.7×10^{-7} 3. 2.4×10^1 4. -8.77×10^{-2} 5. 4.92×10^{-15} 6. -6.02×10^{23}

Practice E 1. c. -9.6×10^{14} (Significand *between 1 and 10* followed by *exponential* term.)

2. b and c 3a. 6.28×10^3 3b. 9.3×10^{-3} 3c. 7.41×10^{-1} 3d. -1.28×10^6

Practice F 1a. 0.0924 1b. 24,300 1c. −0.0024 2a. 5.5×10^4 2b. 9.2×10^{-1} 2c. -9.43×10^{-4}

2d. 3.2×10^{-3} 3a. 7.7×10^3 3b. 1.6×10^8 3c. 2.3×10^{-2} 3d. -6.7×10^{-4}

Lesson 1.4

Pretest 1. 1.2×10^{20} 2. 3.3×10^{28}

Practice A 1. 10^8 2. 10^{-11} 3. 10^{-1} 4. 10^{-8} 5. 10^4 6. 10^{-23} 7. 10^4 8. 10^{35}

9. $\frac{100 \times 10^{-2}}{1{,}000 \times 10^6} = \frac{10^2 \times 10^{-2}}{10^3 \times 10^6} = \frac{10^0}{10^9} = \mathbf{10^{-9}}$ 10. $\frac{10^{-3} \times 10^{23}}{10 \times 1{,}000} = \frac{10^{20}}{10^1 \times 10^3} = \frac{10^{20}}{10^4} = \mathbf{10^{16}}$

(For problems 9 and 10, you may use different steps, but you must arrive at the same answer.)

Practice B 1. 1.2×10^{25} 2. 6.0×10^{12} 3. -1.5×10^{-24} 4. 3.0×10^{-19} 5. -2.0×10^{-12} 6. 2.5×10^{17}

7. See Pretest answers.

Practice C 1a. 1.8×10^{24} 1b. 3.0×10^{23} 1c. 4.2×10^{23} 1d. 6.0×10^{26} 1e. -3.0×10^{21} 1f. 1.0×10^{-12}

1g. 1.0×10^{-9} 1h. $\frac{2.0 \times 10^{18}}{6.0 \times 10^{23}} = 0.33 \times 10^{-5} = \mathbf{3.3 \times 10^{-6}}$

1i. $\frac{1.0 \times 10^{-14}}{4.0 \times 10^{-5}} = 0.25 \times 10^{-9} = \mathbf{2.5 \times 10^{-10}}$ 2a. $\frac{2.46 \times 10^{19}}{6.0 \times 10^{23}} = 0.41 \times 10^{-4} = \mathbf{4.1 \times 10^{-5}}$

2b. $\frac{10^{-14}}{0.0072} = \frac{1.0 \times 10^{-14}}{7.2 \times 10^{-3}} = \frac{1.0}{7.2} \times \frac{10^{-14}}{10^{-3}} = 0.14 \times 10^{-11} = \mathbf{1.4 \times 10^{-12}}$

3a. $\frac{10^7 \times 10^{-2}}{10^1 \times 10^{-5}} = \frac{10^5}{10^{-4}} = \mathbf{10^9}$ 3b. $\frac{10^{-23} \times \cancel{10^{-5}}}{\cancel{10^{-5}} \times 10^2} = \mathbf{10^{-25}}$

Lesson 1.5

Pretest 1. 1.25×10^{11} or 1.3×10^{11} 2. 8.8×10^{-15}

Practice You may do the arithmetic using different steps than shown below, but you must get the same answer.

1. $\frac{4 \times 10^3}{(2.00)(3.0 \times 10^7)} = \frac{4}{6} \times 10^{3-7} = \frac{2}{3} \times 10^{-4} = \mathbf{0.67} \times 10^{-4} = \mathbf{6.7 \times 10^{-5}}$

2. $\frac{1}{(4.0 \times 10^9)(2.0 \times 10^3)} = \frac{1}{8 \times 10^{12}} = \frac{1}{8} \times 10^{-12} = \mathbf{0.125} \times 10^{-12} = \mathbf{1.3 \times 10^{-13}}$

3. $\dfrac{(3\times10^{-3})(8.0\times10^{-5})}{(6.0\times10^{11})(2.0\times10^{-3})} = \dfrac{8}{4}\times\dfrac{10^{-3-5}}{10^{11-3}} = 2\times\dfrac{10^{-8}}{10^{8}} = 2\times10^{-8-8} = \mathbf{2.0\times10^{-16}}$

4. $\dfrac{(3\times10^{-3})(3.0\times10^{-2})}{(9.0\times10^{-6})(2.0\times10^{1})} = \dfrac{9}{18}\times\dfrac{10^{-3-2}}{10^{-6+1}} = 0.50\times\dfrac{\cancel{10^{-5}}}{\cancel{10^{-5}}} = 0.50 = \mathbf{5.0\times10^{-1}}$

5. Final in scientific notation: $0.55\times10^{3} = \mathbf{5.5\times10^{2}}$

6. Estimate: $\dfrac{1}{7\times3} = \dfrac{1}{20} = \mathbf{0.05}$; $\dfrac{10^{-2}}{(10^{2})(10^{-15})} = 10^{-2-(-13)} = \mathbf{10^{11}}$

   Estimate in scientific notation: $0.05\times10^{11} = \mathbf{5\times10^{9}}$

   Numbers on calculator: $\dfrac{1}{7.5\times2.8} = \mathbf{0.048}$

   Exponents: same as in estimate.

   Final in scientific notation: $\mathbf{0.048}\times10^{11} = \mathbf{4.8}\times\mathbf{10^{9}}$. Close to the estimate.

7. $\mathbf{4.2\times10^{-18}}$ 8. $\mathbf{2.8\times10^{5}}$ 9. See the Pretest answers.

Review Quiz

1. 8,178 2. 289 3a. 96 3b. 0.75 4a. -6.8×10^{-3} 4b. 8.92×10^{2}

5a. 6.0×10^{21} 5b. 5.0×10^{0}, or 5.0 5c. 5.0×10^{14} 5d. $0.33\times10^{5} = \mathbf{3.3\times10^{4}}$

6. $1/5\times10^{23-10+6} = 0.20\times10^{19} = \mathbf{2.0\times10^{18}}$ in scientific notation

2

The Metric System

Lesson 2.1 Metric Fundamentals

If you get a perfect score on the following Pretest, you may skip to Lesson 2.2. If not, complete Lesson 2.1.

PRETEST From memory, write answers to these, then check your answers at the end of the chapter.

1. Fill in these blanks with metric prefixes (not abbreviations).

   a. 10^3 grams ≡ 1 ________ gram

   b. 10^{-3} second ≡ 1 ________ second

2. Fill in the prefix abbreviations:

   10 _____ m ≡ 1 m ≡ 1000 _____ m ≡ 100 _____ m

3. Add fixed decimal numbers:

   1 liter ≡ ________ mL ≡ ________ cm^3 ≡ ________ dm^3

4. How many liters are in a kiloliter?
5. What is the mass of 15 milliliters of liquid water?
6. One liter of liquid water has what mass in grams?

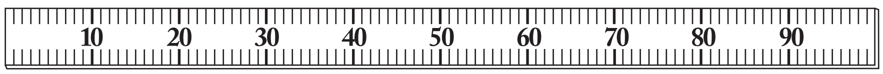
The Importance of Units

The fastest and most effective way to solve calculations in chemistry is to focus on the **units** of measurements.

The physical universe can be described by the **fundamental quantities**, including **distance**, **mass**, and **time**. All measurement systems define **base units** to measure the fundamental quantities. In science, measurements and calculations are done using the **metric system**.

Distance The metric base unit for distance is the **meter**. A *meter* is about 10% longer than the *yard* of the English measurement system.

Just as a dollar can be divided into 100 *cent*s, a meter can be divided into 100 **centi**meters. A meter stick is usually numbered in centimeters.



A meter stick can also be divided into 10 equal **deci**meters. The smallest markings on a meter stick are its 1000 **milli**meters. These definitions mean that

1 meter ≡ **10 deci**meters ≡ **100 centi**meters ≡ **1000 milli**meters

The symbol ≡ is a form of an = sign that means "is *defined* as equal to" and "is *exactly* equal to."

For these definitions, other metric relationships can be written. For example, because 100 **centi**meters ≡ 1000 **milli**meters, we can divide both sides by 100 to get: 1 centimeter ≡ 10 millimeters. But rather than memorize all possible relationships, with the four-part equality in memory we can derive others as needed.

Long distances in the metric system are usually measured in **kilo**meters:

1000 meters ≡ **1 kilo**meter

One kilometer is approximately 0.62 miles.

Kilo-, *deci-*, *centi-*, and *milli-* are termed **metric prefixes**. As one way to define the prefixes, you will need to be able to write *rule* 1 from memory:

1. The "meter-stick" equalities are:

   1 meter ≡ 10 **deci**meters ≡ 100 **centi**meters ≡ 1000 **milli**meters
   and 1000 meters ≡ 1 **kilo**meter

To help in remembering these definitions, visualize a meter stick. Recall what the marks and numbers on a meter stick mean. Use that image to help in writing the four-part equality above.

To remember the kilometer definition, visualize 1000 meter sticks in a row. That's a distance of 1 *kilo*meter: 1 kilometer ≡ 1000 meter sticks.

Rule 1 is especially important because of rule 2.

2. In the meter-stick equalities, you may substitute *any unit* for *meter*.

Rule 2 means that the *prefix* definitions for meters are true for *all* metric units. To use *kilo-*, *deci-*, *centi-*, or *milli-* with *any* metric units, you simply need to be able to recall and write the metric equalities in rule 1.

The two rules above allow us to write a wide range of equalities that we can use to solve science calculations, such as

1 *liter* ≡ 1000 milli*liters*
1 *gram* ≡ 100 centi*grams*
1 kilo*calorie* ≡ 10^3 *calories*

Abbreviations. *Meter* is abbreviated as **m.** In the metric system,

3. Prefix *abbreviations* include:

kilo- = **k-**
deci- = **d-**
centi- = **c-**
milli- = **m-**

Using these abbreviations, the meter-stick equalities can be abbreviated as

1 m ≡ 10 dm ≡ 100 cm ≡ 1000 mm *and* 1000 m ≡ 1 km

One (and only one) prefix *abbreviation* can be written in front of any metric *base* unit abbreviation.

PRACTICE A

Write rules 1, 2, and 3 until you can do so from memory, then complete these problems without looking back at the rules.

1. Add fixed decimal numbers to these blanks.

a. 1 meter = ________ millimeters b. 1 liter = ________ deciliters

(continued)

2. Add full metric prefixes to these blanks.

   a. 1000 grams = 1 ________ gram   b. 1000 ________ liters = 1 liter

3. Add exponential terms (powers of 10) to these blanks.

   a. 1 kilogram = ________ grams   b. ________ mm = 1 m = ________ cm

4. Add prefix *abbreviations* to these blanks.

   a. 10^2 __ m = 1 m = 10 __ m = 10^3 __ m   b. 10^3 m = 1 __ m

Volume **Volume** is the amount of three-dimensional space that a material or shape occupies. Volume is termed a **derived quantity** because it is derived from the fundamental quantity of distance. Any volume unit can be converted to a distance unit cubed.

A cube that is 1 centimeter *wide* by 1 cm *high* by 1 cm *long* has a volume of 1 **cubic** centimeter (1 **cm^3**). In biology and medicine, a cubic centimeter is often abbreviated as "**cc**," but cm^3 is the standard abbreviation in chemistry.

In chemistry, cubic centimeters are usually referred to as **milliliters**, abbreviated **mL**. One milliliter is defined as exactly 1 cubic centimeter. On the basis of this definition, because

- 1000 milli*meters* ≡ 1 *meter* and 1000 milli*anythings* ≡ 1 *anything*
- 1000 milli*liters* is *defined* as 1 **liter**, abbreviated **L**

The milliliter 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 **1 cubic deci<u>m</u>eter (1 dm^3)**. Note how these units are related:

- The volume of a cube that is

$$10 \text{ cm} \times 10 \text{ cm} \times 10 \text{ cm}$$

  has a volume of

$$1000 \text{ cm}^3 = 1000 \text{ mL}$$

- Because 10 cm ≡ 1 dm, the volume of this *same* cube can be calculated as

$$1 \text{ dm} \times 1 \text{ dm} \times 1 \text{ dm} \equiv 1 \text{ cubic } \textit{deci}\text{meter} \equiv 1 \text{ dm}^3$$

These relationships mean that by definition, all of the following terms are *equal*:

$$1 \text{ L} \equiv 1000 \text{ mL} \equiv 1000 \text{ cm}^3 \equiv 1 \text{ dm}^3$$

What do you need to remember about volume? Just two more rules.

4. 1 milliliter (mL) ≡ 1 cm^3
5. 1 liter (L) ≡ 1000 mL ≡ 1000 cm^3 ≡ 1 dm^3

Mass **Mass** measures the amount of matter in an object. Mass and weight are not the same, but in chemistry, unless stated otherwise, we assume that mass is measured at the constant gravity of 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)** was originally defined as the mass of *1 cubic centimeter* of *liquid water* at 4 degrees Celsius, the temperature at which water has its highest density. The modern definition for 1 gram is a bit more complex, but it is still very close to the historic definition, and in calculations involving liquid water we often use the historic definition if high precision is not required.

For most calculations involving *liquid* water at or near room temperature, the following *approximation* may be used.

6. For *liquid water*: 1 $\mathbf{cm^3}$ $H_2O(\ell) \equiv$ 1 **mL** $H_2O(\ell) \approx$ 1.00 **gram** $H_2O(\ell)$

The squiggly equal sign ($\approx$) means "approximately equals."

The substance H_2O is solid when it is ice, liquid when it is water, and gaseous when it is steam or vapor. The notation (*liquid*), abbreviated as (ℓ) after the chemical formula, means that this rule is true *only* if H_2O is in its *liquid* state.

Temperature Metric temperature scales are defined by the properties of water. Temperature in the metric system can be measured in **degrees Celsius** (°C).

0°C ≡ the freezing point of water.

100°C ≡ the boiling point of water if the gas above is at "1 atmosphere pressure."

Room temperature is generally between 20°C (which is 68°F) and 25°C (77°F).

Time The metric base unit for time is the **second** (abbreviated as a lowercase **s**).

Unit Abbreviations The following are metric base-unit abbreviations.

7. meter = **m** gram = **g** second = **s**

Abbreviations for metric units do not have a period at the end, and no distinction is made between singular and plural.

Note that an **m** by itself stands for meter, and an **m** *after* a prefix stands for meter, but an **m** in *front* of a unit abbreviation means *milli-*.

Examples: ms = millisecond mm = millimeter km = kilometer

PRACTICE B

Write rules 1–7 until you can do so from memory, then answer the first three Pretest problems for this lesson without looking at the rules.

SI Units

The modern metric system (*Le Système International d'Unités*) is based on what are termed the **SI units**. SI units choose one preferred metric unit as the standard for measuring each physical quantity. The SI unit for distance is the *meter*, for mass is the *kilogram*, and for time is the *second*.

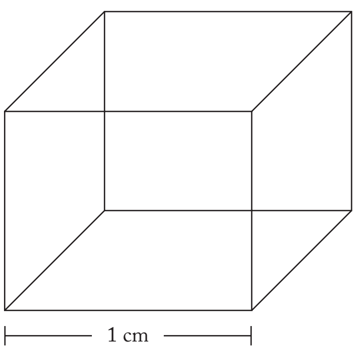
In chemistry, when dealing with laboratory-scale quantities, measurements and calculations frequently use units that are metric but not SI. For example, chemists generally measure volume in liters or milliliters instead of cubic meters and mass in grams instead of kilograms. In Chapter 5, you will learn to convert between non-SI and the SI units required for some types of chemistry calculations.

Learning the Metric Fundamentals

We will use *equalities* to solve most chemistry calculations, and the metric definitions are the equalities that we use most often. A strategy that can help in problem solving is to start each homework assignment, quiz, or test by writing *recently* memorized rules at the top of your paper. By writing the rules at the beginning, you avoid having to remember them under time pressure later in the test.

A Note on Memorization A goal of these lessons is to minimize what you must memorize. It is not possible, however, to eliminate memorization from science courses. When there are facts that you must memorize to solve problems, these lessons will tell you. This is one of those times. Memorize the metric basics in the table on the next page. You will need to recall them automatically from memory as part of most assignments in chemistry.

Memorization Tips When you memorize, it helps to use as many *senses* as you can.



- Say the rules out loud, over and over, as you would learn lines for a play.
- Write the rules 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:
  - Sketch a meter stick, then write metric rule 1 and compare it to your sketch.
  - For volume, mentally picture a 1 cm × 1 cm × 1 cm = 1 $\mathbf{cm^3}$ cube. Call it *1 milliliter*. Fill it with water to have a *mass* of 1.00 *gram*.

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

Metric Basics

1. 1 *meter*	≡ 10 decimeters
	≡ 100 centimeters
	≡ 1000 millimeters
1000 meters	≡ 1 kilometer

2. Any unit can be substituted for *meter* above.
3. Prefixes include: kilo- = **k-**; deci- = **d-**; centi- = **c-**; milli- = **m-**
4. 1 milliliter (mL) ≡ 1 cm^3
5. 1 liter (L) ≡ 1000 mL ≡ 1000 cm^3 ≡ 1 dm^3
6. 1 cm^3 $H_2O(\ell)$ ≡ 1 mL $H_2O(\ell)$ ≈ 1.00 gram $H_2O(\ell)$
7. Base unit abbreviations: meter = m; gram = g; second = s

PRACTICE C

Study the metric basics table until you can write all parts of the table from memory, then answer the following problems in your notebook.

1. In your mind, picture a kilometer and a millimeter. Which is larger?
2. Which is larger, a kilogram or a milligram?
3. Name four units that can be used to measure volume in the metric system.
4. Answer Pretest problems 4–6 at the beginning of this lesson.

Lesson 2.2 Metric Prefixes

Additional Prefixes

For measurements of very large or very small quantities, prefixes larger than *kilo-* and smaller than *milli-* are often used. Ten frequently encountered prefixes, including the four from Lesson 2.1, are listed in the table at right. Note that

- Outside the range between 10^{-3} and 10^3, metric prefixes correspond to powers of 10 divisible by 3.
- When the full prefix name is written, the first letter is *not* normally capitalized.
- For prefixes above **k-**, the abbreviation *must* be *capitalized*.
- For the prefixes **k-** and below, the abbreviation *must* be lowercase.

Prefix	Abbreviation	Means
tera-	T-	$\times 10^{12}$
giga-	G-	$\times 10^{9}$
mega-	M-	$\times 10^{6}$
kilo-	k-	$\times 10^{3}$
deci-	d-	$\times 10^{-1}$
centi-	c-	$\times 10^{-2}$
milli-	m-	$\times 10^{-3}$
micro-	μ (mu) *or* u-	$\times 10^{-6}$
nano-	n-	$\times 10^{-9}$
pico-	p-	$\times 10^{-12}$

Using Prefixes

A metric prefix is interchangeable with the exponential term it represents.

1. An exponential term can be *substituted* for a prefix or prefix abbreviation on the basis of what the prefix means.

Examples:

7.0 *milli*liters = 7.0×10^{-3} liter

5.6 kg = 5.6×10^{3} g

43 nanometers = 43 nm = 43×10^{-9} meter

2. A metric *prefix* can be substituted for its equivalent exponential term.

Examples:

3.5×10^{-12} meter = 3.5 **pico**meters = 3.5 pm

7.2×10^{6} grams = 7.2 **mega**grams = 7.2 Mg

TRY IT

(See "How to Use These Lessons," point 1, p. 000.)

Q1. From memory, fill in these blanks with full prefixes (not the abbreviations).

a. 10^{3} grams = 1 ________ gram   b. 2×10^{-3} meter = 2 ________ meters

Q2. From memory, fill in these blanks with prefix *abbreviations*.

a. 2.6×10^{-1} L = 2.6 __ L   b. 6×10^{-2} g = 6 __ g

Q3. Fill in these blanks with exponential terms (consult the table of prefixes above if needed).

a. 1 gigawatt = 1 × _____ watts   b. 9 μm = 9 × _____ m

STOP

Answers:

1a. 10^{3} grams = 1 **kilo**gram   1b. 2×10^{-3} meter = 2 **milli**meters

2a. 2.6×10^{-1} L = 2.6 **d**L   2b. 6×10^{-2} g = 6 **c**g

3a. 1 gigawatt = 1 × $\mathbf{10^{9}}$ watts   3b. 9 μm = 9 × $\mathbf{10^{-6}}$ m

From the prefix definitions, even if you are not yet familiar with the quantity that a unit is measuring, you can convert between a *prefix* and its equivalent exponential.

Learning the Prefixes

To solve calculations, you will need to recall each row in the table of 10 metric prefixes quickly and automatically. To help, look for patterns as a memory device. Note:

tera- = **T**- = × $10^{\mathbf{t}\text{welve}}$

nano- (which connotes small) = **n-** = × $10^{-\mathbf{n}\text{ine}}$

Focusing on those two can help to "anchor" the prefixes near them in the table.

Then make a self-quiz: On a sheet of paper, draw a table 3 columns across and 11 rows down. In the top row, write

Prefix	**Abbreviation**	**Means**

Then fill in the table. Repeat writing the table until you can do so from memory, then try the problems below without looking at your table.

PRACTICE A

Use a sticky note to mark the answer page at the end of this chapter.

1. From memory, add exponential terms to these blanks.

   a. 7 microseconds = 7 × _____ second   b. 9 kg = 9 × _____ g

   c. 8 cm = 8 × _____ m   d. 1 ng = 1 × _____ g

2. From memory, add full metric prefixes to these blanks.

   a. 6×10^{-2} amps = 6 _________ amps   b. 45×10^{9} watts = 45 _________ watts

3. From memory, add prefix abbreviations to these blanks.

   a. 10^{12} g = 1 ___ g   b. 10^{-12} s = 1 ___ s

   c. 0.01 m = 1 ___ m   d. 0.001 g = 1 ___ g

   e. 6×10^{-9} m = 6 ___ m   f. 5×10^{-1} L = 5 ___ L

   g. 4×10^{-6} L = 4 ___ L   h. 16×10^{6} Hz = 16 ___ Hz

4. When writing prefix abbreviations *by hand*, write so that you can distinguish between (add a prefix abbreviation):

   5×10^{-3} g = 5 _____ g and 5×10^{6} g = 5 _____ g

5. For which prefix abbreviations is the first letter always capitalized?

6. Convert "0.30 gigameters/second" to a value in scientific notation without a prefix.

Converting between Prefix Formats

To solve calculations, we will often use conversion factors that are constructed from metric prefix definitions. For those definitions, we have learned two types of equalities:

- The meter-stick equalities are based on what *one unit* equals:

  1 meter ≡ 10 decimeters ≡ 100 centimeters ≡ 1000 millimeters

- The prefix definitions are based on what *one prefix* equals, such as *nano* = $\times\ 10^{-9}$

It is essential to be able to write *both* forms of metric definitions correctly, because work in science often uses both.

Example: When converting between milliliters and liters, you may see either

- 1 mL = 10^{-3} L, based on what *milli-* means; *or*
- 1000 mL = 1 L, which is an easy-to-visualize definition of 1 liter

Those two equalities are equivalent. The second is simply the first with the numbers on both sides multiplied by 1000. But the numbers in the equalities are different depending on whether the 1 is in front of the *prefix* or the *unit*. Which format should we use? How do we avoid errors?

In these lessons, we will generally use the 1-*prefix* equalities to solve problems. If you need to write or check prefix equalities in the "1 unit =" format, you can derive them from the 1-*prefix* definitions in the prefix definition table if needed.

Example: 1 gram = ? **micrograms**

From the prefix table, 1-micro-unit = 10^{-6} unit. Therefore,

1 **microgram** = 10^{-6} gram

To get a 1 in front of *gram*, we multiply both sides by $\mathbf{10^6}$, so

10^6 micrograms = 1 gram

The steps above can be summarized as the *reciprocal* rule for prefixes:

> Memorize the prefix equalities: 1 *prefix*- = $\mathbf{10^a}$.
>
> If you need 1 *unit* =, write: **1** *prefix* units- = $\mathbf{10^a}$ units, **1 unit** = $\mathbf{10^{-a}}$ *prefix* units.

Another way to state the reciprocal rule for prefixes:

> To change a prefix definition between the "1 **prefix** =" format and the "1 **unit** =" format, change the sign of the exponent.

TRY IT

Q. Using those rules, provide the missing exponential terms below.

a. 1 nanogram = 1 × _____ gram, so 1 gram = 1 × _____ nanograms.

b. 1 dL = 1 × _____ liter, so 1 L = 1 × _____ dL

STOP

Answers:

a. 1 nanogram = 1 × $\mathbf{10^{-9}}$ gram, so 1 gram = 1 × $\mathbf{10^{9}}$ nanograms.

b. 1 dL = 1 × $\mathbf{10^{-1}}$ liter, so 1 L = 1 × $\mathbf{10^{1}}$ dL = 10 dL

To summarize:

- When using metric prefix definitions, be careful to note whether the **1** is in front of the *prefix* or the *unit*.

- To avoid confusing the signs of the exponential terms, commit the table of prefix definitions to memory. Then, if you need an equality with the "*1 unit* = $\mathbf{10^x}$ prefix-unit" format, reverse the sign of the exponent in the table of definitions.

PRACTICE B

Write the table of 10 metric prefixes until you can do so from memory; then answer these without consulting the table.

1. Fill in the blanks with exponential ($10^{\times}$) terms.

   a. 1 terasecond = 1 × _____ seconds, so 1 second = 1 × _____ terasecond.

   b. 1 ng = 1 × _____ gram, so 1 g = 1 × _____ ng

2. Apply the reciprocal rule to add exponential terms to these *1-unit* equalities.

   a. 1 gram = _____ centigrams b. 1 meter = _____ picometers

   c. 1 s = _____ ms d. 1 s = _____ Ms

3. Add fixed decimal numbers to these blanks.

   a. 1000 cm^3 = _____ L b. 100 cm^3 $H_2O(\ell)$ = _____ grams $H_2O(\ell)$

4. Add exponential terms to these blanks. Watch where the 1 is!

   a. 1 micromole = _____ mole b. 1 g = 1 × _____ Gg

   c. _____ ns = 1 s d. 1 pL = _____ L

Lesson 2.3 Flashcards

In scientific fields, initial learning is in many respects like learning a new language. To start, we learn new words and their definitions (such as milli- = $\times 10^{-3}$) then rules for their use (for example, can be put in front of a base unit).

With effort and practice, fundamental facts and procedures can be recalled automatically. This opens space in working memory to focus on the conceptual framework into which new knowledge fits. As additional practice gradually leads to fluency, you are able to use your new knowledge for higher-level work.

To learn the vocabulary of chemistry, in these lessons you will make two types of flashcards:

- "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

If you have access to about thirty 3-in. × 5-in. index cards, you can get started now. Plan to buy about 100–200 additional index cards, lined or unlined. A variety of colors is helpful but not essential. With your first 30 cards, complete these steps:

1. On 12–15 cards (of the same color, if possible), 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.

2. Using the following table, cover the answers in the *right*-side column with an index card. For each question in the left column, verbally answer, then slide the cover sheet down to check your answer. Put a *check mark* beside questions that you answer accurately and without hesitation. When done, write the questions and answers without checks onto the notched cards. For these Chapter 2 cards, write a "2" at the bottom right corner of each card.

Front Side of Cards (with Notch at Top Right)	**Back Side—Answers**
To convert to scientific notation, move the decimal to ____	After the first number that is not a zero
If you make the significand larger, ____	Make the exponent smaller
42^0 = ____	Any number to the zero power = 1
Simplify 1/(1/*X*) = ____	*X*
To divide exponentials, ____	Subtract the exponents
To bring an exponent from the bottom of a fraction to the top: ____	Change its sign
1 cc ≡ 1 ____ ≡ 1 ____	1 cc ≡ 1 cm^3 ≡ 1 ml
0.0018 in scientific notation = ____	1.8×10^{-3}
1 L ≡ ____ mL ≡ ____ dm^3	1 L ≡ 1000 mL ≡ 1 dm^3
To multiply exponential terms, ____	Add the exponents
Simplify: $1/10^x$ = ____	10^{-x}
74 in scientific notation = ____	7.4×10^1
The historical definition of 1 gram is: ____	The mass of 1 cm^3 of liquid water at 4°C
8 × 7 = ____	56
42/6 = ____	7

If there remain multiplication or division facts that you cannot reliably answer instantly, add them to your list of one-sided cards.

3. To make two-way cards, use the index cards as they are, *without* a notch.

   For the following cards, first cover the *right* column, then put a check mark (✓) on the left if you can answer the left-column question quickly and correctly. Then cover the *left* column and check (✓) the right side if you can answer the right side *automatically*.

   When done, if a row does not have *two* checks, make the flashcard.

Two-Way Cards (*without* a Notch)

10^3 g or 1000 g = 1 _____ g	1 kg = _____ g
Boiling temperature of water = _____	100 degrees Celsius (if 1 atm pressure) = _____
1 nanometer = 1 × _____ meter	1 _____ meter = 1 × 10^{-9} meters
Freezing temperature of water = _____	0 degrees Celsius = _____
4.7 × 10^{-3} = _____ (fixed decimal)	0.0047 = 4.7 × $10^?$

1 GHz = $10^?$ Hz	10^9 Hz = 1 _____ Hz
1 pL = $10^?$ L	10^{-12} L = 1 _____ L
3/4 = 0.?	0.75 = ? / ?
1/8 = 0.?	0.125 = 1 / ?

2/3 ≈ 0.?	0.666… ≈ ? / ?
3/2 = ?.?	1.5 = ? / ?
1 dm^3 = 1 _____	1 L = 1 _____
1/4 = 0.?	0.25 = 1 / ?

More Two-Way Cards (*without* a Notch) for the Metric Prefix Definitions

kilo- = × $10^?$	× 10^3 = ? prefix
nano- = × $10^?$	× 10^{-9} = ? prefix
giga- = × $10^?$	× 10^9 = ? prefix
milli- = × $10^?$	× 10^{-3} = ? prefix
deci- = × $10^?$	× 10^{-1} = ? prefix
tera- = × $10^?$	× 10^{12} = ? prefix
pico- = × $10^?$	× 10^{-12} = ? prefix
mega- = × $10^?$	× 10^6 = ? prefix
micro- = × $10^?$	× 10^{-6} = ? prefix
centi- = × $10^?$	× 10^{-2} = ? prefix

d- = × $10^?$	× 10^{-1} = ? abbrev.
m- = × $10^?$	× 10^{-3} = ? abbrev.
T- = × $10^?$	× 10^{12} = ? abbrev.
k- = × $10^?$	× 10^3 = ? abbrev.
n- = × $10^?$	× 10^{-9} = ? abbrev.
μ- = × $10^?$	× 10^{-6} = ? abbrev.
G- = × $10^?$	× 10^9 = ? abbrev.
M- = × $10^?$	× 10^6 = ? abbrev.
p- = × $10^?$	× 10^{-12} = ? abbrev.
c- = × $10^?$	× 10^{-2} = ? abbrev.

micro- abbrev. = ?	μ- = ? prefix
mega- abbrev. = ?	capital M- = ? prefix
kilo- abbrev. = ?	k- = ? prefix
pico- abbrev. = ?	p- = ? prefix
deci- abbrev. = ?	d- = ? prefix
centi- abbrev. = ?	c- = ? prefix
tera- abbrev. = ?	capital T- = ? prefix
milli- abbrev. = ?	m- = ? prefix
nano- abbrev. = ?	n- = ? prefix
giga- abbrev. = ?	capital G- = ? prefix

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

4. **Practice** with one *type* of card at a time.
   - **For front-sided cards**, if you get a card right quickly, place it in the *got-it* stack. If you miss a card, recite the content. Close your eyes. Recite it again. And again. If needed, write it several times. Return that card to the bottom of the *do* stack. Practice until every card is in the *got-it* stack.
   - For two-sided cards, do the same steps in one direction, then the other.
5. Master the cards at least once, then apply them to the Practice on the topic of the new cards. Treat Practice as a practice test.
6. **For three days in a row**, repeat those steps. Repeat them again before working assigned problems and before your next test that includes this material.
7. Make cards for new topics *before* the lectures on a topic if possible. Studying fundamentals first will help in understanding the lecture.
8. Rubber band and carry new cards. Practice during "down times."
9. After a few chapters or topics, change card colors.

This system requires an initial investment of time, but in the long run it will save time and improve achievement. Add cards of your design and choosing as needed.

Flashcards, Charts, or Lists?

The best strategy for learning new information is to practice *multiple* strategies. Flashcards are good for learning simple rules and definitions. For more complex information, practice reciting mnemonics or phrases with meter or rhyme. Being able to write *charts, diagrams,* and *tables* is helpful in recalling information that falls into *patterns*.

For the metric system, writing the seven rules *and* the prefix chart *and* picturing the meter-stick relationships and running the flashcards will all help to fix these fundamentals in long-term memory.

PRACTICE

Run your set of flashcards until all cards are in the *got-it* stack. Then try these problems. Make additional cards if needed.

1. Fill in the following blanks with an exponential (10^x) term.

Format: 1 Prefix	**1 Base Unit**
1 micrometer = _____ meter	1 meter = _____ micrometers
1 gigawatt = _____ watts	1 watt = _____ gigawatt
1 nanoliter = _____ liter	_____ nanoliters = 1 liter

2. Add exponential terms to these blanks. Watch where the 1 is!

   a. 1 picosecond = _____ second b. 1 megawatt = _____ watts

   c. 1 cg = _____ g d. 1 mole = _____ millimoles

   e. 1 m = _____ nm f. 1 μs = _____ s

3. Do these *without* a calculator. Write the fixed decimal equivalent.

   a. 1/5 = __________ b. 1/50 = __________

Lesson 2.4 Calculations with Units

Except as noted, try this lesson without a calculator.

Adding and Subtracting with Units

Most calculations in mathematics consist of numbers without units, but during calculations in science, it is essential to write the *unit* after numbers. Why?

- Scientific calculations are nearly always based on *measurements* of physical quantities. A measurement is a numeric value and its unit.
- Units indicate which steps to take to solve a problem.
- Units provide a check that you have done a calculation correctly.

When solving calculations, the math must take into account *both* the numbers and their units. To do so, apply the following four rules.

1. The *units* must be the *same* in quantities being *added and subtracted*, and those same units must be added to the answer.

TRY IT

Q. Apply rule 1 to these two problems.

1. 5 apples + 2 apples =
2. 5 apples + 2 oranges =

STOP

Answers:

Answer 1 is *7 apples*, but you can't add apples and oranges.

By rule 1, you can add numbers that have the same units, but you *cannot* add numbers directly that do *not* have the same units.

TRY IT

Q. Apply rule 1 to this problem:

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

Answer:

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

If all units are the same, you can add or subtract numbers, but you must add the common unit to the answer.

Multiplying and Dividing with Units

The rule for *multiplying* and *dividing* units is different, but logical.

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

Example: cm × cm = **cm²**

Units obey the laws of algebra.

TRY IT

Q. Simplify:

$$\frac{\text{cm}^5}{\text{cm}^2} =$$

Answer:

Either solve by cancellation:

$$\frac{\text{cm} \cdot \text{cm} \cdot \text{cm} \cdot \cancel{\text{cm}} \cdot \cancel{\text{cm}}}{\cancel{\text{cm}} \cdot \cancel{\text{cm}}} = \mathbf{cm^3}$$

or by the rules for exponents:

$$\frac{\text{cm}^5}{\text{cm}^2} = \text{cm}^{5-2} = \mathbf{cm^3}$$

Both methods arrive at the same answer (as they must).

3. When multiplying and dividing *group* numbers, exponentials, and units separately, solve the three parts separately, then recombine the terms.

TRY IT

Q. If a postage stamp has dimensions of 2.0 cm × 4.0 cm, the surface area of one side of the stamp =

Answer:

$$\begin{aligned}\text{Area of a rectangle} &= l \times w = 2.0\text{ cm} \times 4.0\text{ cm}\\ &= (2.0 \times 4.0) \times (\text{cm} \times \text{cm}) = \mathbf{8.0\ cm^2}\\ &= 8.0\ \textit{square}\text{ centimeters}\end{aligned}$$

By rule 2, the units obey the rules for multiplication and division. By rule 3, unit math is done *separately* from number math.

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

TRY IT

Q. Apply rule 3 to the following:

a. $\dfrac{8.0\text{ L}^6}{2.0\text{ L}^2} =$

b. $\dfrac{9.0\text{ m}^6}{3.0\text{ m}^6} =$

Answer:

a. $\dfrac{8.0\text{ L}^6}{2.0\text{ L}^2} = \dfrac{8.0}{2.0} \cdot \dfrac{\text{L}^6}{\text{L}^2} = 4.0\ \mathbf{L^4}$

b. $\dfrac{9.0\ \cancel{\text{m}^6}}{3.0\ \cancel{\text{m}^6}} = \mathbf{3.0}$ (with no unit)

In science, the *unit math* must be done in calculations. A *calculated* unit *must* be written in a calculated answer (except in rare cases, such as *part b* above, when all of the units cancel).

TRY IT

Q. Apply the rules for numbers, exponential terms, and units.

$$\frac{12 \times 10^{-3}\text{m}^4}{3.0 \times 10^2\text{ m}^2} =$$

Answer:

$$\frac{12 \times 10^{-3}\text{ m}^4}{3.0 \times 10^2\text{ m}^2} = \frac{12}{3.0} \cdot \frac{10^{-3}}{10^2} \cdot \frac{\text{m}^4}{\text{m}^2} = \mathbf{4.0 \times 10^{-5}\ m^2}$$

In science calculations, you will often need a calculator for the number math, but both the *exponential* and *unit* math nearly always can (and should) be done *without* a calculator.

4. If *more than one* unit is being multiplied or divided, the math for *each unit* is done separately.

TRY IT

Q. Use a calculator for the numbers, but not for the exponents and units.

$$4.8 \frac{g \cdot m}{s^2} \cdot 3.0\ m \cdot \frac{6.0\ s}{9.0 \times 10^{-4}\ m^2} =$$

STOP

Answer:

Do the math for numbers, exponentials, and then *each* unit separately.

$$\frac{86.4}{9.0} \cdot \frac{1}{10^{-4}} \cdot \frac{g \cdot \cancel{m}}{s \cdot \cancel{s}} \cdot \cancel{m} \cdot \frac{\cancel{s}}{\cancel{m^2}} = 9.6 \times 10^4 \frac{g}{s}$$

This answer unit can also be written as $g \cdot s^{-1}$

PRACTICE

Do *not* use a calculator except as noted. After completing each problem, check your answer. If you miss a problem, review the rules to find out why before continuing.

1. $16\ cm - 2\ cm =$
2. $12\ cm \cdot 2\ cm =$
3. $(m^4)(m) =$
4. $m^4/m =$
5. $\frac{cm^3}{cm^2} =$
6. $\frac{s^{-5}}{s^2} =$
7. $3.0\ meters \cdot 9.0\ meters =$
8. $3.0\ g/9.0\ g =$
9. $\frac{24\ L^5}{3.0\ L^{-4}} =$
10. $\frac{18 \times 10^{-3}\ g \cdot m^5}{3.0 \times 10^1\ m^2} =$
11. *Without* a calculator, multiply:

    a. $2.0 \frac{g \cdot m}{s^2} \cdot \frac{3.0\ m}{4.0 \times 10^{-2}} \cdot 6.0 \times 10^2\ s =$

    b. $12 \times 10^{-2} \frac{L \cdot g}{s} \cdot 2.0\ m \cdot \frac{2.0\ s^3}{6.0 \times 10^{-5}\ L^2} =$

12. A rectangular box has dimensions of $2.0\ cm \times 4.0\ cm \times 6.0\ cm$. Calculate its volume.

SUMMARY

To prepare for a quiz and/or test on the material in this chapter:

1. Be able to write the “seven metric basics” rules and the 10 rows of the metric prefix table from memory.
2. For several days, run your flashcards until you can quickly answer each card in both directions.
3. In your own words, be able to summarize any shaded rules in the chapter that are unfamiliar.
4. Be able to solve the problems in the Review Quiz and the chapter.

REVIEW QUIZ

Do not use a calculator. Once you start this quiz, do not look at rules written before the quiz.

1. Add exponential terms to these blanks.

   a. 4 centigrams = 4 × _____ gram b. 3 pm = 3 × _____ m

   c. 5 dL = 5 × _____ L d. 1 THz = 1 × _____ Hz

2. Add full metric *prefixes* to these blanks.

   a. 7×10^{-6} liter = 7 _________ liters

   b. 5×10^{3} grams = 5 _________ grams

3. Add prefix *abbreviations* to these blanks.

   a. 10^{6} g = 1 __ g b. 10^{-3} g = 1 __ g

   c. 6×10^{-9} L = 6 __ L d. 2×10^{-1} m = 2 __ m

4. Add exponential terms to these blanks. Watch where the 1 is!

   a. 1 micrometer = _____ meter b. 1 watt = _____ gigawatt

   c. 1 MHz = _____ Hz d. 1 mole = _____ nanomoles

   e. 1 m = _____ km f. 1 ms = _____ s

5. Simplify:

   $$\frac{56 \times 10^{-3}\ \text{m}^4}{8 \times 10^{2}\ \text{m}^{-2}} =$$

6. Solve as if the question is *not* multiple choice, then circle your answer among the choices provided.

   $$5.0 \times 10^{-2}\ \frac{\text{L}^3 \cdot \text{m}}{\text{s}} \cdot 4.0\ \text{m} \cdot \frac{2.0\ \text{s}^3}{8.0 \times 10^{-5}\ \text{L}^2} =$$

   a. $1.0 \times 10^{-4}\ \text{m}^2 \cdot \text{s}^2 \cdot \text{L}$ b. $5.0 \times 10^{-7}\ \text{m}^2 \cdot \text{s} \cdot \text{L}$
   c. $5.0 \times 10^{3}\ \text{m}^2 \cdot \text{s}^2 \cdot \text{L}$ d. $1.0 \times 10^{-3}\ \text{m} \cdot \text{s}^2 \cdot \text{L}$
   e. $5.0 \times 10^{-3}\ \text{m}^2 \cdot \text{s}^2 \cdot \text{L}$

ANSWERS

Lesson 2.1

Pretest 1a. 10^3 grams ≡ 1 **kilo**gram 1b. 10^{-3} second ≡ 1 **milli**second 2. 10 **d**m ≡ 1 m ≡ 1000 **m**m ≡ 100 **c**m 3. 1 liter ≡ **1000** mL ≡ **1000** cm^3 ≡ **1** dm^3 4. 1000 liters 5. 15 grams 6. 1000 grams

Practice A 1a. 1000 1b. 10 2a. 1000 grams = 1 **kilo**gram 2b. 1000 **milli**liters = 1 liter 3a. 1 kilogram = $\mathbf{10^3}$ grams 3b. $\mathbf{10^3}$ mm = 1 m = $\mathbf{10^2}$ cm 4a. 10^2 **c**m = 1 m = 10 **d**m = 10^3 **m**m 4b. 10^3 m = 1 **k**m

Practice B See Pretest answers 1–3 above.

Practice C 1. A kilometer 2. A kilogram 3. Possible answers include cubic centimeters, milliliters, liters, cubic decimeters, cubic meters, and any metric distance unit, cubed.

4. See Pretest answers 4, 5, and 6 above.

Lesson 2.2

Practice A 1a. 7 microseconds $= 7 \times \mathbf{10^{-6}}$ seconds 1b. 9 kg $= 9 \times \mathbf{10^{3}}$ g 1c. 8 cm $= 8 \times \mathbf{10^{-2}}$ m

1d. 1 ng $= 1 \times \mathbf{10^{-9}}$ g 2a. 6×10^{-2} amps = 6 **centi**amps 2b. 45×10^{9} watts = 45 **giga**watts

3a. 10^{12} g = 1 **T**g 3b. 10^{-12} s = 1 **p**s 3c. 0.01 m = 10^{-2} m = 1 **c**m 3d. 0.001 g = 10^{-3} g = 1 **m**g

3e. 6×10^{-9} m = 6 **n**m 3f. 5×10^{-1} L = 5 **d**L 3g. 4×10^{-6} L = 4 **μ**L

3h. 16×10^{6} Hz = 16 **M**Hz 4. 5 **m**g and 5 **M**g 5. **M-**, **G-**, and **T-** 6. $\mathbf{3.0 \times 10^{8}}$ meters/second

Practice B 1a. 1 terasecond $= 1 \times \mathbf{10^{12}}$ seconds, so 1 second $= 1 \times \mathbf{10^{-12}}$ terasecond. 1b. 1 ng $= 1 \times \mathbf{10^{-9}}$ gram, so 1 g $= 1 \times \mathbf{10^{9}}$ ng.

2a. 1 gram = $\mathbf{10^{2}}$ centigrams (For "1 *unit* = ," reverse sign of prefix definition.)

2b. 1 meter = $\mathbf{10^{12}}$ picometers 2c. 1 s = $\mathbf{10^{3}}$ ms 2d. 1 s $= 1 \times \mathbf{10^{-6}}$ Ms 3a. 1000 cm^3 = **1** L

3b. 100 cm^3 $H_2O(\ell)$ = **100** grams $H_2O(\ell)$ 4a. 1 micromole = $\mathbf{10^{-6}}$ moles 4b. 1 g $= 1 \times \mathbf{10^{-9}}$ Gg

4c. $\mathbf{10^{9}}$ ns = 1 s 4d. 1 pL = $\mathbf{10^{-12}}$ L

Lesson 2.3

Practice

1. 1 micrometer = $\mathbf{10^{-6}}$ meter	1 meter = $\mathbf{10^{6}}$ micrometers
1 gigawatt = $\mathbf{10^{9}}$ watts	1 watt = $\mathbf{10^{-9}}$ gigawatt
1 nanoliter = $\mathbf{10^{-9}}$ liter	$\mathbf{10^{9}}$ nanoliters = 1 liter

2a. 1 picosecond = $\mathbf{10^{-12}}$ second 2b. 1 megawatt = $\mathbf{10^{6}}$ watts 2c. 1 cg = $\mathbf{10^{-2}}$ g

2d. 1 mole = $\mathbf{10^{3}}$ millimoles 2e. 1 m = $\mathbf{10^{9}}$ nm 2f. 1 μs = $\mathbf{10^{-6}}$ s 3a. 1/5 = **0.20**

3b. 1/50 = **0.020**

Lesson 2.4

Practice Both the *number* and the *unit* must be written and correct.

1. **14 cm** 2. **24 cm^2** 3. $m^{(4+1)} = \mathbf{m^5}$ 4. $m^{(4-1)} = \mathbf{m^3}$ 5. **cm** 6. $\mathbf{s^{-7}}$ 7. **27 meters^2**

8. **0.33** (*no* unit) 9. **8.0 L^9** 10. $\mathbf{6.0 \times 10^{-4}\ g \cdot m^3}$ 11a. $\mathbf{9.0 \times 10^{4}\ \frac{g \cdot m^2}{s}}$ (Answer unit could also be written as: $g \cdot m^2 \cdot s^{-1}$)

11b. $\mathbf{8.0 \times 10^{3}\ \frac{g \cdot m \cdot s^2}{L}}$ (Answer unit could also be written as: $g \cdot m \cdot s^2 \cdot L^{-1}$)

12. $V_{\text{rectangular solid}}$ = length *multiplied by* width *multiplied by* height = **48 cm^3**

Review Quiz

1a. 4 centigrams $= 4 \times \mathbf{10^{-2}}$ gram 1b. 3 pm $= 3 \times \mathbf{10^{-12}}$ m 1c. 5 dL $= 5 \times \mathbf{10^{-1}}$ L

1d. 1 THz $= 1 \times \mathbf{10^{12}}$ Hz 2a. 7×10^{-6} liter = 7 **micro**liters 2b. 5×10^{3} grams = 5 **kilo**grams

3a. 10^{6} g = 1 **M**g 3b. 10^{-3} g = 1 **m**g 3c. 6×10^{-9} L = 6 **n**L 3d. 2×10^{-1} m = 2 **d**m

4a. 1 micrometer = $\mathbf{10^{-6}}$ meter 4b. 1 watt = $\mathbf{10^{-9}}$ gigawatt 4c. 1 MHz = $\mathbf{10^{6}}$ Hz

4d. 1 mole = $\mathbf{10^{9}}$ nanomoles 4e. 1 m = $\mathbf{10^{-3}}$ km 4f. 1 ms = $\mathbf{10^{-3}}$ s 5. 7×10^{-5} m^6 6. **c**

3

Atoms—and Significant Figures

Lesson 3.1 The Atoms (Part 1)

Atoms are the building blocks of matter. In Earth's crust are 92 different kinds of atoms, from hydrogen, the lightest atom, to uranium, the heaviest. Additional (heavier) atoms can be formed in high-energy nuclear reactions.

The periodic table organizes the atoms in a way that facilitates prediction of their properties. If you know where to *look* for an atom in the table, you can quickly find additional data that a detailed periodic table provides. When you can automatically associate the name, symbol, and periodic table position for each of the ~40 atoms that are most frequently encountered in first-year chemistry, it opens space for working memory to note concepts and move them into long-term memory.

Your brain gains fluency with new vocabulary gradually, with repeated effort. To begin to learn the language of chemistry, your assignment is:

- For the first 20 atoms, be able to fill in an empty chart like the one below with the names and symbols entered in their correct locations.
- Note how the atoms are numbered going across each row. Each of these whole numbers represents the **atomic number** of the respective atom.
- Space your practice to learn the first 12 atoms by the end of Chapter 3 and all 20 atoms shown by the end of Chapter 4.

PERIODIC TABLE

1A	2A		3A	4A	5A	6A	7A	8A
1 **H** Hydrogen								2 **He** Helium
3 **Li** Lithium	4 **Be** Beryllium		5 **B** Boron	6 **C** Carbon	7 **N** Nitrogen	8 **O** Oxygen	9 **F** Fluorine	10 **Ne** Neon
11 **Na** Sodium	12 **Mg** Magnesium		13 **Al** Aluminum	14 **Si** Silicon	15 **P** Phosphorus	16 **S** Sulfur	17 **Cl** Chlorine	18 **Ar** Argon
19 **K** Potassium	20 **Ca** Calcium							

Lesson 3.2 Uncertainty and Significant Figures

Rounding Numbers

Most chemistry calculations require *rounding* of numbers to obtain a final answer. The rules for rounding in science follow (but may be more detailed than) those you have learned in mathematics. In chemistry, use these terms and rules.

1. **Place value**. Recall that in the number 12.345, the 1 is said to be in the *tens place*, the 2 in the *ones* place, the 3 in the *tenths* place (one place to the right of the decimal), the 4 in the *hundredths* place, and the 5 in the *thousandths* place.

   In 12.345, the *highest* place with a digit is the tens place and the *lowest* is the thousandths place.

2. **Rounding: Up or Down?** When rounding, if the number *beyond* the place you are rounding to is

   a. *less* than 5: drop it (round *down*).

      Example: 1.<u>3</u>42 rounded to *tenths* = 1.3

   b. *greater* than 5: round *up*.

      Example: 1.7<u>3</u>8 rounded to the <u>underlined</u> place = 1.74

   c. a **5** followed by *any non-zero* digits: round *up*.

      Example: 1.0<u>2</u>502 = 1.03

3. **Look only *one* place past** the place you are rounding to.

   Example: Rounding 9.<u>7</u>49 to tenths = 9.**7**

   When rounding the 7, look *only* at the 4. The 4 rounds down.