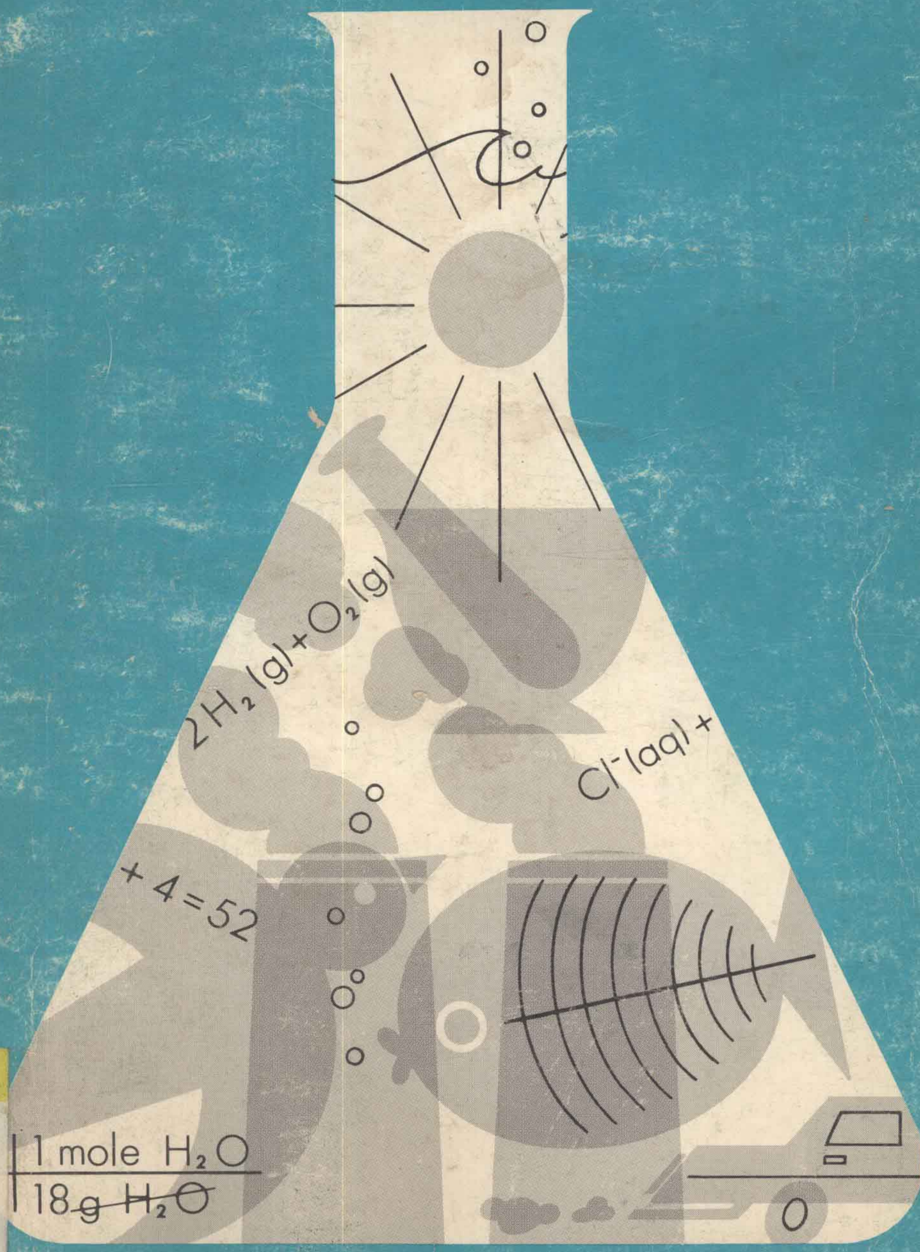
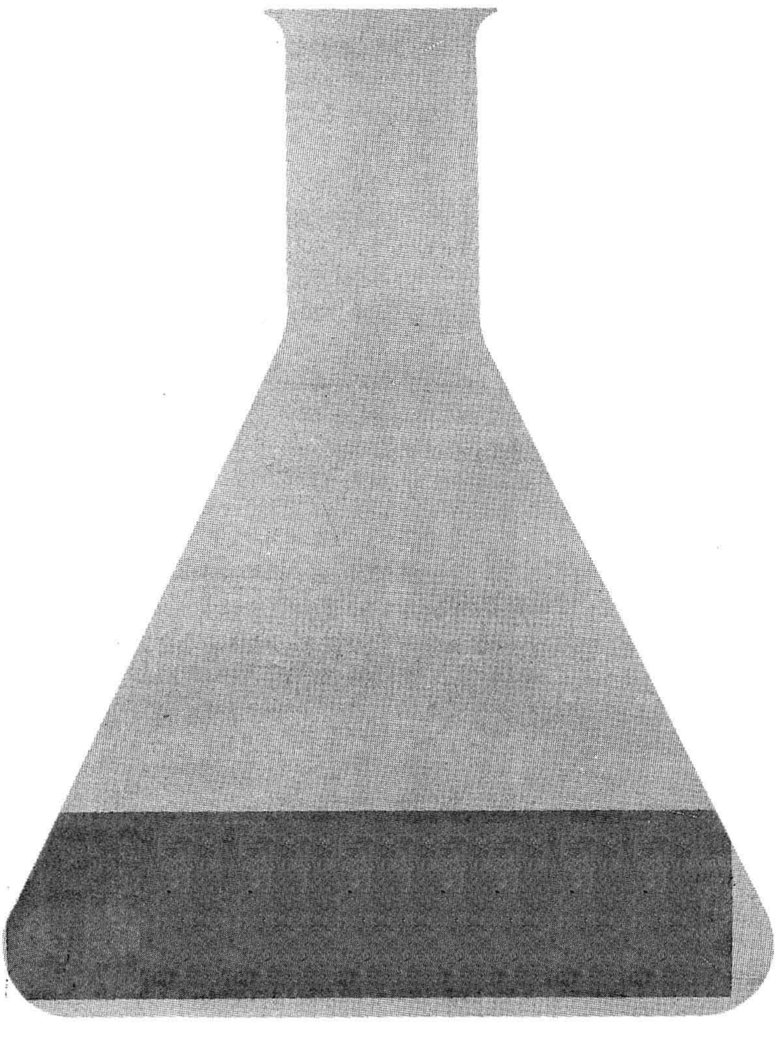
SOLVING PROBLEMS IN *CHEMISTRY*

HIMES



SOLVING PROBLEMS IN *CHEMISTRY*

Gary K. Himes



Charles E. Merrill Publishing Company
A Bell & Howell Company
Columbus, Ohio 43216

A Merrill Science Text

Project Editor: Martha Althauser
Book Designer: William Venrick
Cover Design: Lester Shumaker

ISBN 0-675-07527-0

Published by
CHARLES E. MERRILL PUBLISHING CO.
A Bell & Howell Company
Columbus, Ohio

Printed in the United States of America

International Atomic Masses

Element	Symbol	Atomic number	Atomic mass	Element	Symbol	Atomic number	Atomic mass
Actinium	Ac	89	227*	Mercury	Hg	80	200.59
Aluminum	Al	13	26.98154	Molybdenum	Mo	42	95.94
Americium	Am	95	243*	Neodymium	Nd	60	144.24
Antimony	Sb	51	121.75	Neon	Ne	10	20.179
Argon	Ar	18	39.948	Neptunium	Np	93	237.0482*
Arsenic	As	33	74.9216	Nickel	Ni	28	58.70
Astatine	At	85	210*	Niobium	Nb	41	92.9064
Barium	Ba	56	137.34	Nitrogen	N	7	14.0067
Berkelium	Bk	97	247*	Nobelium	No	102	255*
Beryllium	Be	4	9.01218	Osmium	Os	76	190.2
Bismuth	Bi	83	208.9804	Oxygen	O	8	15.9994
Boron	B	5	10.81	Palladium	Pd	46	106.4
Bromine	Br	35	79.904	Phosphorus	P	15	30.97376
Cadmium	Cd	48	112.40	Platinum	Pt	78	195.09
Calcium	Ca	20	40.08	Plutonium	Pu	94	244*
Californium	Cf	98	251*	Polonium	Po	84	209*
Carbon	C	6	12.011	Potassium	K	19	39.098
Cerium	Ce	58	140.12	Praseodymium	Pr	59	140.9077
Cesium	Cs	55	132.9054	Promethium	Pm	61	145*
Chlorine	Cl	17	35.453	Protactinium	Pa	91	231.0359*
Chromium	Cr	24	51.996	Radium	Ra	88	226.0254
Cobalt	Co	27	58.9332	Radon	Rn	86	222*
Copper	Cu	29	63.546	Rhenium	Re	75	186.207
Curium	Cm	96	247*	Rhodium	Rh	45	102.9055
Dysprosium	Dy	66	162.50	Rubidium	Rb	37	85.4678
Einsteinium	Es	99	254*	Ruthenium	Ru	44	101.07
Erbium	Er	68	167.26	Samarium	Sm	62	150.4
Europium	Eu	63	151.96	Scandium	Sc	21	44.9559
Fermium	Fm	100	257*	Selenium	Se	34	78.96
Fluorine	F	9	18.99840	Silicon	Si	14	28.086
Francium	Fr	87	223*	Silver	Ag	47	107.868
Gadolinium	Gd	64	157.25	Sodium	Na	11	22.98977
Gallium	Ga	31	69.72	Strontium	Sr	38	87.62
Germanium	Ge	32	72.59	Sulfur	S	16	32.06
Gold	Au	79	196.9665	Tantalum	Ta	73	180.9479
Hafnium	Hf	72	178.49	Technetium	Tc	43	98.9062*
Helium	He	2	4.00260	Tellurium	Te	52	127.60
Holmium	Ho	67	164.9304	Terbium	Tb	65	158.9254
Hydrogen	H	1	1.0079	Thallium	Tl	81	204.37
Indium	In	49	114.82	Thorium	Th	90	232.0381
Iodine	I	53	126.9045	Thulium	Tm	69	168.9342
Iridium	Ir	77	192.22	Tin	Sn	50	118.69
Iron	Fe	26	55.847	Titanium	Ti	22	47.90
Krypton	Kr	36	83.80	Tungsten	W	74	183.85
Lanthanum	La	57	138.9055	Uranium	U	92	238.029
Lawrencium	Lr	103	256*	Vanadium	V	23	50.9414
Lead	Pb	82	207.2	Xenon	Xe	54	131.30
Lithium	Li	3	6.941	Ytterbium	Yb	70	173.04
Lutetium	Lu	71	174.97	Yttrium	Y	39	88.9059
Magnesium	Mg	12	24.305	Zinc	Zn	30	65.38
Manganese	Mn	25	54.9380	Zirconium	Zr	40	91.22
Mendelevium	Md	101	258*	Element 104†		104	257*
				Element 105†		105	260*

* The mass number of the isotope with the longest known half-life.

† Names for elements 104 and 105 have not yet been approved by the IUPAC. The USSR has proposed Kurchatovium (Ku) for element 104 and Bohrium (Bh) for element 105. The United States has proposed Rutherfordium (Rf) for element 104 and Hahnium (Ha) for element 105.

PREFACE

SOLVING PROBLEMS IN CHEMISTRY is designed for use in an introductory general chemistry course. Students often have difficulty in applying their mathematical skills to solving problems encountered in a general chemistry course. This book, through the use of examples and practice problems, helps to develop problem-solving skills.

Each chapter covers an area of chemistry introduced in most first-year general chemistry courses. The main principles involved in a given area are briefly explained. Examples and sample problems of every type commonly encountered are provided. Sample problems have detailed solutions, with each step carefully explained. Practice problems are included, with answers available at the end of the book so that the students can check their own progress. The "factor-label" method of problem solving, used throughout the book, provides the student with a clear, versatile, and logical method for problem solving.

Review in using exponents, scientific notation, and logarithms are provided, along with exercises to familiarize students with metric units. Also provided are detailed, illustrated instructions for using the slide rule.

In the third edition of SOLVING PROBLEMS IN CHEMISTRY, emphasis has been placed on practical applications of the information derived. Industrial and everyday uses of chemicals are explained. Environmental concerns are also discussed. For example, the section on gas laws contains information on measuring amounts of air pollutants, and the chapter on organic chemistry contains a discussion of automobile exhaust.

The author is a former chemistry teacher and is now involved in recruiting and training personnel for the chemical industry. He coordinates a cooperative program sponsored by his company, offering internships to students interested in pursuing careers in the chemical industry.

It is hoped that today's chemistry students, in addition to learning principles and concepts of this area of science, will also become familiar with ways in which these principles affect their daily lives. Students should become aware of the wide range of career opportunities requiring some knowledge of chemistry. These include some careers which require a high school diploma and on-the-job training or technical school, as well as those requiring college degrees. Fields offering opportunities to chemistry students include the medical and paramedical fields, pharmacy, environmental protection, and patent law. Careers in chemical industry include research, quality control, sales, and management.

SOLVING PROBLEMS IN CHEMISTRY can be used as a basic text, a guide to independent study, or a supplement for most standard chemistry textbooks. Students will find SOLVING PROBLEMS IN CHEMISTRY an invaluable aid for a better understanding of chemistry. Instructors will find it an excellent source of supplementary materials, problems, and exercises for developing needed skills.

PERIODIC CLASSIFICATION OF THE ELEMENTS

(BASED ON $^{12}C = 12.0000$)

Light Metals: IA, IIA — Transition Metals: IIIB to IIB (VIIIB) — Nonmetals: IIIA to VIIIA

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 **H** 1.0079																	2 **He** 4.00260
3 **Li** 6.941	4 **Be** 9.01218											5 **B** 10.81	6 **C** 12.011	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.99840	10 **Ne** 20.179
11 **Na** 22.98977	12 **Mg** 24.305											13 **Al** 26.98154	14 **Si** 28.086	15 **P** 30.97376	16 **S** 32.06	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.098	20 **Ca** 40.08	21 **Sc** 44.9559	22 **Ti** 47.90	23 **V** 50.9414	24 **Cr** 51.996	25 **Mn** 54.9380	26 **Fe** 55.847	27 **Co** 58.9332	28 **Ni** 58.70	29 **Cu** 63.546	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.9216	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.9059	40 **Zr** 91.22	41 **Nb** 92.9064	42 **Mo** 95.94	43 **Tc** 97	44 **Ru** 101.07	45 **Rh** 102.9055	46 **Pd** 106.4	47 **Ag** 107.868	48 **Cd** 112.40	49 **In** 114.82	50 **Sn** 118.69	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.9045	54 **Xe** 131.30
55 **Cs** 132.9054	56 **Ba** 137.34	* 71 **Lu** 174.97	72 **Hf** 178.49	73 **Ta** 180.9479	74 **W** 183.85	75 **Re** 186.207	76 **Os** 190.2	77 **Ir** 192.22	78 **Pt** 195.09	79 **Au** 196.9665	80 **Hg** 200.59	81 **Tl** 204.37	82 **Pb** 207.2	83 **Bi** 208.9804	84 **Po** 209	85 **At** 210	86 **Rn** 222
87 **Fr** 223	88 **Ra** 226	** 103 **Lr** 256	104 257	105 260													

* **Lanthanide series**	57 **La** 138.9055	58 **Ce** 140.12	59 **Pr** 140.9077	60 **Nd** 144.24	61 **Pm** 145	62 **Sm** 150.4	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.9254	66 **Dy** 162.50	67 **Ho** 164.9304	68 **Er** 167.26	69 **Tm** 168.9342	70 **Yb** 173.04
** **Actinide series**	89 **Ac** 227	90 **Th** 232.0381	91 **Pa** 231	92 **U** 238.029	93 **Np** 237	94 **Pu** 244	95 **Am** 243	96 **Cm** 247	97 **Bk** 247	98 **Cf** 251	99 **Es** 254	100 **Fm** 257	101 **Md** 258	102 **No** 255

CONTENTS

CHAPTER 1

Measurement, Conversion, and Scientific Notation

1:1 Units

A chemist who has just made a startling new discovery must be able to transmit his discovery to other chemists if it is to be of any value. To describe the chemical reaction with which he has been experimenting, he must tell how much of each substance he used (grams), the temperature to which he had to heat the material before a reaction occurred (degrees Celsius), and how much of each product he obtained (grams).

If other chemists are to understand him, he must use standard units which are familiar to them, such as grams or kilograms, degrees Celsius, centimeters or meters, and cubic centimeters or liters.

The standard unit of mass (weight)* is the kilogram.
The standard unit of time is the second.
The standard unit of distance is the meter.
The standard unit of volume is the liter.

The comparison of a standard unit with something you wish to describe in terms of the unit is called measurement. For instance, you can measure (compare) the height of a person with a foot ruler and find that he is six times taller or longer than the length of the ruler. You say the person is six feet tall and everyone knows how tall the person is because a foot is a standard unit of measurement. What is measurement? It is the comparison of a standard unit to something you wish to describe in terms of the standard unit. In chemistry, the most commonly used standard units are:

Measure	*Metric*	*English*
mass	kilogram or gram	slug
weight	newton, dyne	pound
length or distance	meter	foot, yard, mile
time	second	second
temperature	degrees Celsius	degrees Fahrenheit
pressure	millimeters of mercury	pounds per square foot
area	square centimeters	square inches, square feet
volume	cubic centimeters, liter	cubic inches, quart

* The terms *weight* and *mass* refer to two different concepts, and thus, are not interchangeable in usage. In current practice, however, the word weight is often used where mass is the correct term. Mass is a measure of the quantity of matter of an object. Weight is the measure of gravitational attraction between the earth and an object.

The English system is included here only because you are familiar with it. All scientific work is reported in metric system units.

1:2 Converting Numbers and Units—The Factor-Label Method

When numbers in a measurement are converted by adding, subtracting, multiplying, and dividing, the units must be converted also.

Sample Problem 1: 2 ft + 10 in. = ?

Solution: Measurements can be added if they are expressed in similar units. Feet must be converted to inches, or inches must be converted to feet. (Remember, 12 in. = 1 ft)

Convert inches to feet:

$$2 \text{ ft} + \tfrac{10}{12} \text{ ft} = 2\tfrac{10}{12} \text{ ft} = 2\tfrac{5}{6} \text{ ft}$$

Convert feet to inches:

$$24 \text{ in.} + 10 \text{ in.} = 34 \text{ in.}$$

In either solution, the units of the answer can be converted to the other unit. To express an answer in feet, simply convert inches to feet using the relationship, 12 inches = 1 foot. To express an answer in inches, convert feet to inches by reversing the procedure, 1 foot = 12 inches.

Convert inches to feet:

$$2 \text{ ft} + \left(\frac{10 \cancel{\text{in.}}}{} \Big| \frac{1 \text{ ft}}{12 \cancel{\text{in.}}}\right) = 2 \text{ ft} + \frac{10}{12} \text{ ft} = 2\frac{5}{6} \text{ ft}$$

Convert feet to inches:

$$\left(\frac{2 \cancel{\text{ft}}}{} \Big| \frac{12 \text{ in.}}{1 \cancel{\text{ft}}}\right) + 10 \text{ in.} = 2(12) \text{ in.} + 10 \text{ in.} = 34 \text{ in.}$$

In the first solution, the unit inches canceled; the unit feet remained. In the second solution, the unit feet canceled; the unit inches remained. Both solutions involve multiplication by a ratio equal to 1:

$$\frac{1 \text{ ft}}{12 \text{ in.}} = 1 \text{ and } \frac{12 \text{ in.}}{1 \text{ ft}} = 1$$

Whenever a quantity is multiplied by 1, the value is unchanged. This is a good way to convert one unit to an equivalent unit.

$$\frac{1 \text{ foot}}{12 \text{ inches}} = \frac{12 \cancel{\text{inches}}}{12 \cancel{\text{inches}}} = \frac{12}{12} = 1 \text{ and } \frac{12 \text{ inches}}{1 \text{ foot}} = \frac{1 \cancel{\text{foot}}}{1 \cancel{\text{foot}}} = \frac{1}{1} = 1$$

Notice that the labels, the inches unit and the foot unit, cancel and that the ratio is equal to 1. By choosing the proper ratios, you can change any measurement into any other *related* measurement.

$$\frac{2\ \cancel{\text{feet}}}{1}\Bigg|\frac{12\ \text{inches}}{1\ \cancel{\text{foot}}} = \frac{24\ \text{inches}}{1} = 24\ \text{inches}$$

In the example, both

$$\left(\frac{2\ \text{feet}}{1}\right) \quad \text{and} \quad \left(\frac{12\ \text{inches}}{1\ \text{foot}}\right)$$

are factors. A factor is a number or ratio that is multiplied by (or divided into) another number. For instance, the algebraic expression $(2a + 4b)$ can be factored into the two factors, (2) and $(a + 2b)$ because $(2a + 4b) = 2(a + 2b)$.

The factor,

$$\frac{12\ \text{inches}}{1\ \text{foot}},$$

is called a conversion factor because it is used to convert 2 feet into 24 inches.

You may, at first, find it hard to understand how to determine whether to use

$$\frac{12\ \text{in.}}{1\ \text{ft}} \quad \text{or} \quad \frac{1\ \text{ft}}{12\ \text{in.}}.$$

This is easy to determine if you use the following reasoning:

> You know that the number given is expressed in feet and the answer is to be expressed in inches. Therefore, the conversion ratio must contain the two units (labels), feet and inches. The conversion factor must express the relationship between feet and inches. Since 2 ft is the same as
>
> $$\frac{2\ \text{ft}}{1},$$
>
> to set the problem up so that the ft units (label) will cancel and leave inches, you must use the ratio in the form
>
> $$\frac{12\ \text{in.}}{1\ \text{ft}} \quad \text{and not} \quad \frac{1\ \text{ft}}{12\ \text{in.}}:$$
>
> $$\frac{2\ \cancel{\text{ft}}}{1}\Bigg|\frac{12\ \text{in.}}{1\ \cancel{\text{ft}}} = 24\ \text{in.}$$
>
> This works, but
>
> $$\frac{2\ \text{ft}}{1}\Bigg|\frac{1\ \text{ft}}{12\ \text{in.}} = \frac{(2\ \text{ft})(1\ \text{ft})}{(1\ \text{ft})} = \frac{2\ \text{ft}^2}{1\ \text{ft}} = 2\ \text{ft}$$
>
> This doesn't work because the foot units do not cancel.

This approach to problem solving; using unit factors (that is, ratios equal to one) and setting up the problem so that the undesired labels (units) cancel leaving the desired units; is called the *factor-label method.*

Sample Problem 2: $250 \text{ yd} + 1 \text{ mi} = ?$

Solution: The units of the answer can be inches, feet, yards, or miles.

$$(3 \text{ ft} = 1 \text{ yd}; 5280 \text{ ft} = 1 \text{ mi}; 1760 \text{ yd} = 1 \text{ mi})$$

Convert yards and miles to feet:

$$\left(\frac{250 \cancel{\text{yd}}}{} \middle| \frac{3 \text{ ft}}{1 \cancel{\text{yd}}}\right) + \left(\frac{1 \cancel{\text{mi}}}{} \middle| \frac{5280 \text{ ft}}{1 \cancel{\text{mi}}}\right) = 250(3) \text{ ft} + 1(5280) \text{ ft} = 6030 \text{ ft}$$

Convert miles to yards:

$$250 \text{ yd} + \left(\frac{1 \cancel{\text{mi}}}{} \middle| \frac{1760 \text{ yd}}{1 \cancel{\text{mi}}}\right) = 250 \text{ yd} + 1(1760) \text{ yd} = 2010 \text{ yd}$$

Convert yards to miles:

$$\left(\frac{250 \cancel{\text{yd}}}{} \middle| \frac{1 \text{ mi}}{1760 \cancel{\text{yd}}}\right) + 1 \text{ mi} = \frac{250 \text{ mi}}{1760 \text{ yd}} + 1 \text{ mi}$$

$$= 0.142 \text{ mi} + 1 \text{ mi} = 1.142 \text{ mi}$$

In the two sample problems, the units to be converted were multiplied by a ratio equal to 1. This ratio is called a *conversion ratio.* You are not limited to one conversion at a time, many different units can be converted in the same calculation by multiplying by all of the proper conversion ratios.

Sample Problem 3: $\frac{60 \text{ ft}}{\text{sec}} = ? \frac{\text{mi}}{\text{hr}}$

Solution: Convert feet to miles and seconds to hours (1 hr = 60 min; 1 min = 60 sec):

$$\frac{60 \cancel{\text{ft}}}{1 \cancel{\text{sec}}} \middle| \frac{1 \text{ mi}}{5280 \cancel{\text{ft}}} \middle| \frac{60 \cancel{\text{sec}}}{1 \cancel{\text{min}}} \middle| \frac{60 \cancel{\text{min}}}{1 \text{ hr}} = \frac{60(60)(60) \text{ mi}}{5280 \text{ hr}} = \frac{41 \text{ mi}}{\text{hr}}$$

PROBLEMS

Work the following problems using these conversion relations:

Length	*Time*	*Volume*	*Weight*
12 in. = 1 ft	60 sec = 1 min	2 pt = 1 qt	16 oz = 1 lb
3 ft = 1 yd	60 min = 1 hr	4 qt = 1 gal	2000 lb = 1 ton
5280 ft = 1 mi	24 hr = 1 day		

1. *Convert:*

a. 50 ft to ? yd **b.** $\frac{1}{2}$ mi to ? in. **c.** 2 mi to ? ft

d. 3500 sec to ? hr **e.** 250 in. to ? ft **f.** 1 day to ? min

2. *Convert two units:*

a. $\frac{250 \text{ ft}}{\text{hr}}$ to $\frac{? \text{ ft}}{\text{sec}}$ b. $\frac{2 \text{ pt}}{\text{min}}$ to $\frac{? \text{ gal}}{\text{hr}}$

c. $\frac{60 \text{ mi}}{\text{hr}}$ to $\frac{? \text{ ft}}{\text{sec}}$ d. $\frac{1 \text{ pt}}{\text{lb}}$ to $\frac{? \text{ gal}}{\text{lb}}$

e. $\frac{20 \text{ gal}}{\text{day}}$ to $\frac{? \text{ pt}}{\text{min}}$ f. $\frac{1 \text{ ton}}{\text{day}}$ to $\frac{? \text{ oz}}{\text{sec}}$

3. It is estimated that about 200 million tons of man-made pollutants each year enter the air above the United States. Convert this figure to pounds per person per day. (Assume the population of the United States to be 200 million.)

4. A car is traveling 50 mi/hr. How fast is the car going in ft per sec?

5. A workman can move 50 lb of dirt per min. How many tons can he move each day? (Assume that one work day = 8 hr.)

6. The density of an unknown liquid is 40 oz per pt. What is the density in lb per gal?

1:3 The Metric System

The United States is one of the few countries still using the traditional and often awkward English system of measurement.

The metric system is used in most scientific work and in most parts of the world. Some common units in the metric system are the millimeter, the centimeter, and the meter for *length*; the milliliters and the liter for *volume*; the milligram, the gram, and the kilogram for *mass*; and the second for *time*.

The metric system is a *decimal system*. A decimal system is based upon ten. The size of units is indicated by prefixes.

	Prefix		*Definition (times greater or smaller than the standard unit)*	
Greek Prefixes (*Greater than* 1.)	Mega-	one million	1,000,000	1×10^6
	Kilo-	one thousand	1000	1×10^3
	Hecto-	one hundred	100	1×10^2
	Deka-	ten	10	1×10^1
Basic unit			1	1×10^0
Latin Prefixes (*Less than* 1.)	Deci-	one tenth	0.1	1×10^{-1}
	Centi-	one hundredth	0.01	1×10^{-2}
	Milli-	one thousandth	0.001	1×10^{-3}
	Micro-	one millionth	0.000001	1×10^{-6}

The standard mass unit is the kilogram; the standard volume unit is the liter; and the standard length unit is the meter.

Mass:	1000 g	= 1 kg
	1000 mg	= 1 g
Volume:	1000 ml	= 1 l
	1 ml	= 1 cm^3
Length:	1000 mm	= 1 m
	100 cm	= 1 m
	1000 m	= 1 km

To gain an awareness of the physical size of metric units, try to establish a few mental reference points. Note the following approximate relationships between the metric system and the English system:

Weight and Mass:	1 kg (mass) = 1000 g (mass) = 2.20 lb (weight)
	453.59 g (mass) = 1 lb (weight)
Volume:	1 l = 1000 ml = 1.06 qt
	946.3 ml = 0.9463 l = 1 qt
Length:	2.54 cm = 25.4 mm = 1 in.
	30.48 cm = 1 ft
	1 m = 39.37 in.
	1 km = 0.6214 mi

These relationships may be rounded to whole numbers if accuracy is not important.

Sample Problem 4: A package weighing 2 lb is mailed to a country where the metric system is used. What is the mass of the package in grams?

Solution: Convert pounds to grams:

$$\frac{2\ \cancel{\text{lb}}}{} \left| \frac{454\ \text{g}}{1\ \cancel{\text{lb}}} \right. = 2(454)\ \text{g} = 908\ \text{g}$$

Sample Problem 5: Convert 1 ton to kilograms.

Solution: What is the relationship between ton and kilogram? None has been stated, but the relationships between ton and pound and kilogram and pound are known.

1 ton = 2000 lb   2.20 lb = 1 kg

Use the factor-label method to set up these relationships so that all units cancel except kilogram:

$$\frac{1\ \cancel{\text{ton}}}{} \left| \frac{2000\ \cancel{\text{lb}}}{1\ \cancel{\text{ton}}} \right| \frac{1\ \text{kg}}{2.20\ \cancel{\text{lb}}} = \frac{(1)(2000)(1)\ \text{kg}}{(1)(2.20)} = 908\ \text{kg}$$

If the relationship between pound and kilogram were not known, the relationship between pound and gram could have been used:

$$454\ \text{g} = 1\ \text{lb}$$

$$\frac{1\ \cancel{\text{ton}} \mid 2000\ \cancel{\text{lb}} \mid 454\ \cancel{\text{g}} \mid 1\ \text{kg}}{\mid 1\ \cancel{\text{ton}} \mid 1\ \cancel{\text{lb}} \mid 1000\ \cancel{\text{g}}} = \frac{(2000)(454)(1)\ \text{kg}}{1000} = 908\ \text{kg}$$

You will probably not be doing English–metric conversion problems in chemistry class, since your measurements will all be taken in metric units. However, these conversions are a good exercise in becoming familiar with the size of metric units compared with the more familiar English measurements. Several conversion problems follow.

PROBLEMS

7. A contest relay race is the running of 100 m. What distance is this in feet?

8. Eight 15 g samples of table salt are taken from a bottle which originally contained 1 lb of table salt. How many grams of table salt are left in the bottle?

9. A car travels 25 mi per gal of gasoline. Express this quantity in kilometers per liter.

10. If a man can move 35 lb of dirt per min, how many kilograms can he move in 3 hr?

1:4 Scientific Notation

The average distance between the earth and the sun is 150,000,000 km. This large number can be written as 1.5×10^8 km. The diameter of atoms is in the order of 0.00000005 cm. This small number can be written as 5.0×10^{-8} cm.

Both large and small numbers can be manipulated with more ease and accuracy by converting the numbers to a product of a number between 1 and 10 and a power of 10. When a number is expressed as a power of 10, it is usually written in standard notation, but it could be written as a number between 10 and 100, 100 and 1000, etc., multiplied by a power of 10. Thus 150,000,000 can be expressed as 1.5×10^8, 15.0×10^7, 150×10^6, or even 0.15×10^9. In scientific notation, any number can be expressed as a number between 1 and 10 multiplied by a power of 10. Count the number of places from the original decimal point to the desired decimal point. For 150,000,000, this number is 8 and it becomes the power of 10 or the exponent of 10. Counting to the left of the decimal point indicates that the exponent should be positive.

Similarly, 0.00000005 can be written as 5.0×10^{-8} by counting from the original decimal point to 5. This number of places is 8, and counting to the right from the decimal point indicates that the power or exponent of 10 is a negative number.

These numbers are read "1.5 times 10 to the eighth power" and "5 times 10 to the negative eighth power."

Multiples of 1 can be expressed as follows:

$$
\begin{aligned}
0.00001 &= 1 \times 10^{-5} \quad \text{or} \quad 10^{-5}\\
0.0001 &= 1 \times 10^{-4} \quad \text{or} \quad 10^{-4}\\
0.001 &= 1 \times 10^{-3} \quad \text{or} \quad 10^{-3}\\
0.01 &= 1 \times 10^{-2} \quad \text{or} \quad 10^{-2}\\
0.1 &= 1 \times 10^{-1} \quad \text{or} \quad 10^{-1}\\
1.0 &= 1 \times 10^{0} \quad \text{or} \quad 10^{0}\\
10.0 &= 1 \times 10^{1} \quad \text{or} \quad 10^{1}\\
100.0 &= 1 \times 10^{2} \quad \text{or} \quad 10^{2}\\
1000.0 &= 1 \times 10^{3} \quad \text{or} \quad 10^{3}\\
10{,}000.0 &= 1 \times 10^{4} \quad \text{or} \quad 10^{4}\\
100{,}000.0 &= 1 \times 10^{5} \quad \text{or} \quad 10^{5}
\end{aligned}
$$

Any number can be expressed in powers of 10. For example, in the following expressions the number 1 is replaced by the numbers 3.0 and 6.7.

$$
\begin{aligned}
0.0003 &= 3.0 \times 10^{-4} & 0.00067 &= 6.7 \times 10^{-4}\\
0.003 &= 3.0 \times 10^{-3} & 0.0067 &= 6.7 \times 10^{-3}\\
0.03 &= 3.0 \times 10^{-2} & 0.067 &= 6.7 \times 10^{-2}\\
0.3 &= 3.0 \times 10^{-1} & 0.67 &= 6.7 \times 10^{-1}\\
3.0 &= 3.0 \times 10^{0} & 6.7 &= 6.7 \times 10^{0}\\
30.0 &= 3.0 \times 10^{1} & 67.0 &= 6.7 \times 10^{1}\\
300.0 &= 3.0 \times 10^{2} & 670.0 &= 6.7 \times 10^{2}\\
3000.0 &= 3.0 \times 10^{3} & 6700.0 &= 6.7 \times 10^{3}\\
30{,}000.0 &= 3.0 \times 10^{4} & 67{,}000.0 &= 6.7 \times 10^{4}
\end{aligned}
$$

1:5 Scientific Notation Summary

For convenience and ease of handling, very large and very small numbers can be written in scientific notation. Numbers expressed in scientific notation have the form $M \times 10^n$. M represents the original number, which is usually written so it is between 1 and 10. The exponent, n, is obtained by counting the number of places between the original decimal point and the new decimal point. Counting to the left of the original decimal point gives a positive power; counting to the right gives a negative power. If M decreases, the exponent n must increase. If M increases, the exponent n must decrease.

$$300.0 = 300.0 \times 10^0 = 30.0 \times 10^1 = 3.0 \times 10^2 = 0.30 \times 10^3$$

or

$$300.0 = 300.0 \times 10^0 = M \times 10^n = 3.0 \times 10^n = 3.0 \times 10^2$$

Two places to the left of the original decimal point.

M becomes smaller, thus n must increase.

$65{,}000{,}000.0 = 65{,}000{,}000.0 \times 10^0 = M \times 10^n = 6.5 \times 10^n = 6.5 \times 10^7$

Seven places to the left of the original decimal point. — M becomes smaller, thus n must increase.

$0.00000043 = 0.00000043 \times 10^0 = M \times 10^n = 4.3 \times 10^n = 4.3 \times 10^{-7}$

Seven places to the right of the original decimal point. — M becomes larger, thus n must decrease.

$M \times 10^n = 0.350 \times 10^5 = 3.50 \times 10^4 = 35.0 \times 10^3$

$\rightarrow$ M becomes larger, thus n becomes smaller.
$\leftarrow$ M becomes smaller, thus n becomes larger.

$M \times 10^n = 0.540 \times 10^{-2} = 5.40 \times 10^{-3} = 54.0 \times 10^{-4}$

$\rightarrow$ M becomes larger, thus n becomes smaller.
$\leftarrow$ M becomes smaller, thus n becomes larger.

Scientific notation involves numbers in exponential form. Review the addition, subtraction, multiplication, and division of exponential numbers.

Addition and Subtraction

To add or subtract numbers with exponents ($M \times 10^n$), all exponents must be the *same* before you can add or subtract the values of M.

Note that the following procedure gives the wrong answer.

$$10^3 + 10^2 = 10^5$$

this translates into

$$1000 + 100 \neq 100{,}000$$

The correct way to add $10^3 + 10^2$ is:

$$\begin{aligned} 1.0 \times 10^3 &= 10 \times 10^2 \\ 1.0 \times 10^2 &= \underline{1.0 \times 10^2} \\ & \quad 11.0 \times 10^2 = 1100 \end{aligned}$$

Sample Problem 6: Add (6.5×10^2), (2.0×10^3), and (30×10^3).

Solution: Change (6.5×10^2) to $(M \times 10^3)$: $6.5 \times 10^2 = 0.65 \times 10^3$

$$(0.65 \times 10^3) + (2.0 \times 10^3) + (30.0 \times 10^3)$$
$$= (0.65 + 2.0 + 30.0) \times 10^3 = 32.65 \times 10^3$$

Sample Problem 7: Subtract (5.5×10^4) from (7.8×10^5).

Solution: Change (5.5×10^4) to $(M \times 10^5)$: 5.5×10^4 from 7.8×10^5

$$(7.8 \times 10^5) - (0.55 \times 10^5) = (7.8 - 0.55) \times 10^5 = 7.25 \times 10^5$$

Change (7.8×10^5) to $(M \times 10^4)$: $7.8 \times 10^5 = 78.0 \times 10^4$

$$(78.0 \times 10^4) - (5.5 \times 10^4) = (78.0 - 5.5) \times 10^4 = 72.5 \times 10^4$$

Sample Problem 8: Add (3.5×10^{-2}) and (2.0×10^{-3}).

Solution: Change (2.0×10^{-3}) to $(M \times 10^{-2})$: $2.0 \times 10^{-3} = 0.2 \times 10^{-2}$

$$(3.5 \times 10^{-2}) + (0.2 \times 10^{-2}) = (3.5 + 0.2) \times 10^{-2} = 3.7 \times 10^{-2}$$

Change (3.5×10^{-2}) to $(M \times 10^{-3})$: $3.5 \times 10^{-2} = 35.0 \times 10^{-3}$

$$(35.0 \times 10^{-3}) + (2.0 \times 10^{-3}) = (35.0 + 2.0) \times 10^{-3} = 37.0 \times 10^{-3}$$

Sample Problem 9: Subtract (5.5×10^{-4}) from (7.5×10^{-3}).

Solution: Change (5.5×10^{-4}) to $(M \times 10^{-3})$: $5.5 \times 10^{-4} = 0.55 \times 10^{-3}$

$$(7.5 \times 10^{-3}) - (0.55 \times 10^{-3}) = (7.5 - 0.55) \times 10^{-3} = 6.95 \times 10^{-3}$$

Change: (7.5×10^{-3}) to $(M \times 10^{-4})$: $7.5 \times 10^{-3} = 75.0 \times 10^{-4}$

$$(75.0 \times 10^{-4}) - (5.5 \times 10^{-4}) = (75.0 - 5.5) \times 10^{-4} = 69.5 \times 10^{-4}$$

Multiplication

To multiply numbers with exponents $(M \times 10^n)$, multiply the values of M and add the exponents. The exponents do not need to be alike as they do in addition and subtraction.

This translates into:

$$10^2 \times 10^3 = 10^{2+3} = 10^5$$

$$(100) \times (1000) = (100{,}000) = 10^5$$

To multiply 2×10^2 by 3×10^3 use the following procedure:

$$\overbrace{(2 \times 10^2)(3 \times 10^3)}^{add} = (2 \times 3) \times 10^{2+3}$$

$$\underbrace{}_{multiply} \qquad = 6 \times 10^5$$

Sample Problem 10: Find the product of $(1 \times 10^3)(1 \times 10^4)(1 \times 10^{-2})$

Solution: Add the exponents: $3 + 4 + (-2) = 5$.

Multiply the values of M: $(1)(1)(1) = 1$

$$(1 \times 10^3)(1 \times 10^4)(1 \times 10^{-2}) = 1 \times 10^{3+4-2} = 1 \times 10^5 \quad \text{or} \quad 10^5$$

Sample Problem 11: Multiply (3×10^5) by (2×10^4).

Solution: Add the exponents: $5 + 4 = 9$

Multiply the values of M: $3 \times 2 = 6$

$$(3 \times 10^5)(2 \times 10^4) = (3 \times 2) \times 10^{5+4} = 6 \times 10^9$$

Sample Problem 12: Find the product of $(4 \times 10^{-2})(3 \times 10^{-4})(2 \times 10^1)$.

Solution: Add the exponents: $-2 + (-4) + 1 = -5$

Multiply the values of M: $4 \times 3 \times 2 = 24$

$$(4 \times 10^{-2})(3 \times 10^{-4})(2 \times 10^1) = (4 \times 3 \times 2) \times 10^{-2-4+1}$$

$$= 24 \times 10^{-5} = 2.4 \times 10^{-4}$$