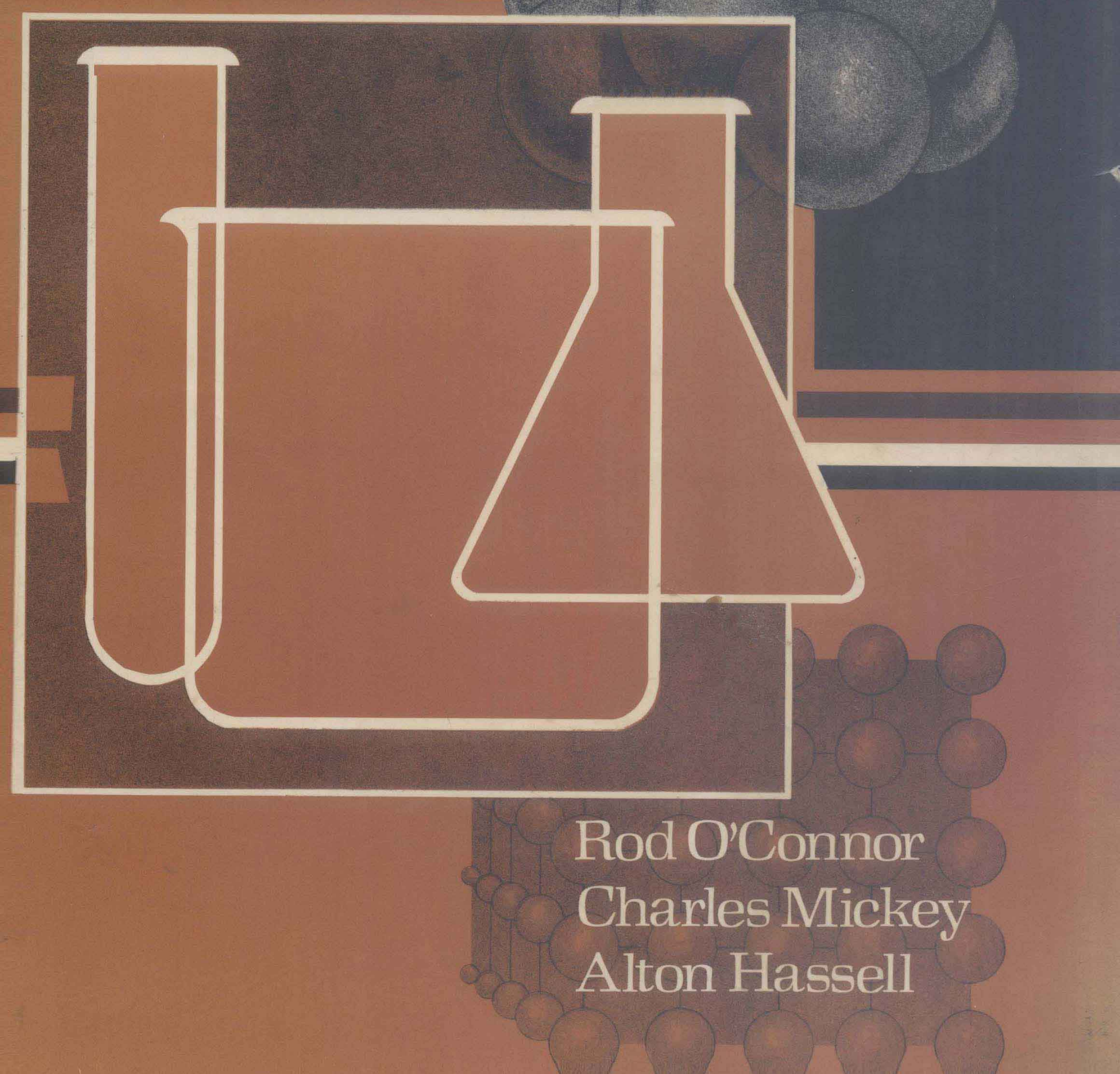
SECOND EDITION

Solving Problems in Chemistry:

With Emphasis on Stoichiometry and Equilibrium



Rod O'Connor
Charles Mickey
Alton Hassell

SOLVING PROBLEMS
IN CHEMISTRY

SOLVING PROBLEMS IN CHEMISTRY with emphasis on stoichiometry and equilibrium, Second Edition

 For information address Harper & Row, Publishers, Inc., 10 East 53rd Street, New York, N.Y. 10022.

ISBN 0-06-044882-2

SOLVING PROBLEMS in CHEMISTRY

Second Edition

with emphasis on STOICHIOMETRY and EQUILIBRIUM

and applications in

Agriculture & Marine Sciences

Biological & Medical Sciences

Industrial Chemistry

Environmental Sciences

ROD O'CONNOR

Professor and Director of First Year Chemistry Programs
Texas A&M University

CHARLES MICKEY

Assistant Professor of Chemistry
Moody College of Marine Sciences

ALTON HASSELL

Assistant Program Director, First Year Chemistry
Texas A&M University

HARPER & ROW, PUBLISHERS

New York, Hargerstown, San Francisco, London

DEDICATION

To our wives, Shirley O'Connor, Betty Mickey, and Pat Hassell, and to our excellent typists, Carla and Gary Wesson.

They sometimes thought *<u>we</u>* *were the "problems".*

- PREFACE -

This is not a textbook of chemistry. It is an introduction to methods and skills used in solving problem situations in some of the more important areas of chemistry and is designed to be used in conjunction with a textbook or other supplementary materials. Its purpose is to provide additional help and practice for those seeking competency or proficiency in chemical problem solving or for those desiring the experience and challenge provided by problem situations.

It is not essential that all Units be studied or that they be followed in sequence. You many wish to concentrate your efforts on those Units whose topics represent areas of some difficulty to you, so that extra practice and more examples are useful, or on Units in which you have some particular interest in achieving greater proficiency.

Each Unit begins with a brief summary of necessary background information, referenced to suitable textbook sections or single-topic booklets which provide theoretical and factual background material. Your instructor may wish to suggest other references.

Following this introduction are brief statements of learning objectives at two levels, <u>*competency*</u> *and* <u>*proficiency*</u>*. The distinction between these levels is basically that we would consider a* <u>*competency*</u> *level to be roughly equivalent to that expected of a C-grade student in a typical university general chemistry course, while the* <u>*proficiency*</u> *level corresponds to that of A and B student work. You may find that your own interests and needs are adequately satisfied for some areas by the* <u>*competency*</u> *level work, while the more challenging* <u>*proficiency*</u> *level may be more appropriate in other areas. (All* <u>*proficiency*</u> *level material is identified by an asterisk [*].)*

Immediately following the statements of objectives are Pre-Test questions, at both levels. Successful completion of the <u>*competency*</u> *level questions offers you a choice of proceeding on to the* <u>*proficiency*</u> *level, working on appropriate* <u>*competency*</u> *level Exercises or Relevant Problems, or terminating -- if "competency" (ability to handle simpler problem situations) is sufficient for your needs. If you have difficulties with the* <u>*competency*</u> *level Pre-Test, you should study the "Methods" work at that level. Successful completion of the* <u>*proficiency*</u> *level Pre-Test, or the final Self-Test questions based on the* <u>*proficiency*</u> *level "Methods" work, offers you the choices of terminating or proceeding on to the more challenging Relevant Problems in areas of your own interest.*

The Relevant Problems are arranged in four categories: (A) Agriculture and Marine Sciences, (B) Biological and Medical Sciences, (I) Industrial Chemistry, and (E) Environmental Sciences. Problem solving may thus be practiced in an area related to personal interests or, by working problems from more than one Set, as exercises in examining a broad scope of chemical applications.

We hope you will find this book useful in expanding you capabilities to handle problems in chemistry and that the Relevant Problems will illustrate for you some of the many applications of chemistry to other fields. Your comments and suggestions would be most welcome.

Rod O'Connor
Charles Mickey
Alton Hassell

Texas A&M University
July 1977

SOLVING PROBLEMS
IN CHEMISTRY

CONTENTS

INTRODUCTION: PROBLEM SOLVING

Some people seem to have an intuitive grasp of how to approach a problem to obtain a rapid and efficient solution. Although there is little doubt that some are more gifted than others in this respect, it is a talent that can be acquired. Proficiency in this skill, as in all skills, improves with practice.

When a mechanically inept customer takes his car to a mechanic with the complaint that it is getting poor gas mileage and makes a "funny rumbling sound," this poses a problem for the mechanic. Although the talented mechanic might not express it this way, his approach to this problem involves certain distinguishable phases:

1. Identification of what he wants to find out.
2. Recognition of what information is given that might be useful.
3. Identification of other information needed, but not given (i.e., information that must be obtained from memory and from other sources).
4. Selection of a method of attack on the problem.
5. Manipulation of information and tools to achieve a solution.
6. Checking that the solution is probably satisfactory.

For the mechanic, these steps might involve:

1. *Finding out what is causing the poor gas mileage and unusual engine noise.*
2. *Given: poor mileage + "funny rumbling sound."*
3. *Other information: memory of previous experience with similar problems + application of various suitable test instruments and other pertinent observations.*
4. *Selecting parts to be replaced, adjustments to be made, and tools to be used.*
5. *Fixing the engine.*
6. *Test driving.*

This system is a general one for solving all kinds of problems. It is the basis for most scientific research, and it is the key to solving all sorts of mathematical problems. The more problems you solve, the easier it becomes, until you, like the competent mechanic, can solve problems without formally thinking out each step of the method. Until the stage of "intuitive" proficiency is reached, however, it is worthwhile to proceed slowly and systematically through the various phases of problem solving.

Let us illustrate the approach by a "case study" of three problems.

PROBLEM 1

A dozen assorted ball bearings weighs 180 grams. What is the average mass of a bearing in this assortment?

SOLUTION

Step 1: Find: *mass per bearing* (in grams)

Step 2: Given: *180 grams per dozen* (of bearings)

Step 3: Needed, not given: *How many items per dozen?*

Answer (from memory): 12 per dozen

Step 4: Method of attack:

Divide mass by number to find average mass of each. Use unity factor method.

Step 5: Manipulation:

$$\frac{180 \text{ grams}}{\cancel{\text{dozen}} \text{ (bearings)}} \times \frac{1 \cancel{\text{ dozen}}}{12} = \frac{180 \text{ grams}}{12 \text{ (bearings)}} = 15 \text{ grams (per bearing)}$$

Step 6: Check:

a. Dimensions canceled properly.

b. Math check:

15 grams x 12 = 180 grams

PROBLEM 2

A manufacturing concern plans to distribute nut/bolt/washer sets. Each set will consist of one 18.5 g nut, one 31.0 g bolt, and two 5.50 g washers. The sets will be sold in "1-dozen set" packages. What will be the net mass of each package?

SOLUTION

Step 1: Find: *net mass of a "1-dozen" package of the sets*

Step 2: Given: *1 nut/set @ 18.5 g/nut; 1 bolt/set @ 31.0 g/bolt; 2 washers/set @ 5.50 g/washer; 1 dozen per package.*

Step 3: Needed, not given:

How many items per dozen?

Answer (from memory): 12 per dozen

What does "net mass" mean?

Answer (from memory): mass of package *contents* (i.e., 1 dozen sets)

Step 4: Method of attack:

Find the mass of each set and multiply by the number of sets per package. Use unity factor method where appropriate.

(Note: Often there is no unique method of attack. Here, for example, we might have decided to find the mass of 1 dozen nuts, 1 dozen bolts, and 2 dozen washers and then added these together.)

Step 5: Manipulation:

$$\left[\frac{18.5\ g}{1\ \cancel{nut}} \times \frac{1\ \cancel{nut}}{1\ set}\right] + \left[\frac{31.0\ g}{1\ \cancel{bolt}} \times \frac{1\ \cancel{bolt}}{1\ set}\right] + \left[\frac{5.50\ g}{1\ \cancel{washer}} \times \frac{2\ \cancel{washers}}{1\ set}\right]$$

$$= \frac{[\ 18.5 + 31.0 + (2)(5.50)]\ g}{1\ set} = \frac{60.5\ g}{1\ set}$$

$$\frac{60.5\ g}{1\ \cancel{set}} \times \frac{1\ \cancel{dozen}\ \cancel{sets}}{1\ pkg} \times \frac{12}{1\ \cancel{dozen}} = \frac{(60.5 \times 12)\ g}{1\ pkg}$$

Estimate

$$6.05 \times 10^1 \times 1.2 \times 10^1 \simeq 6 \times 1 \times 10^2\ (\sim 600)$$

Solve

$$\frac{(6.05 \times 1.2 \times 10^2)\ g}{1\ pkg} = 7.26 \times 10^2\ g/pkg \quad (726\ g/pkg)$$

Step 6: Check:

a. Dimensions canceled properly.

b. Arithmetic rechecked for accuracy.

---

* PROBLEM 3

What is the maximum mass of nut/bolt/washer sets, as described in Problem 2, that could be prepared from 8.00 kg of nuts, 18.2 kg of bolts, and 12.2 kg of washers?

SOLUTION

Step 1: Find: *maximum mass of sets from given masses of components*

Step 2: Given: *8.00 kg of nuts, 18.2 kg of bolts, 12.2 kg of washers*

Step 3: Needed, not given:

Composition of a set

Answer: (Given in Problem 2)

1 nut + 1 bolt + 2 washer

Masses of components

Answer: (Given in Problem 2)

18.5 g/nut, 31.0 g/bolt, 5.50 g/washer

* Proficiency Level

Mass of a set

Answer: (Found during solution to Problem 2)

60.5 g/set

Step 4: Method of attack:

The word "maximum" in the problem suggests that there is some limitation other than just the sum of the masses of the components given. It must be recognized that we can no longer make sets when we run out of any one component. Thus, the *maximum* mass of sets will correspond to the mass obtainable from the limiting component (i.e., the smallest of the masses of sets obtainable from the masses of each component available). Since we are dealing with masses (rather than numbers), some appropriate equivalents would be useful in constructing unity factors.

18.5 g nuts = 60.5 g sets

31.0 g bolts = 60.5 g sets

(2 x 5.50) g washers = 60.5 g sets

Then we must calculate the mass of sets obtainable by using up all of each component available and select the smallest of these values as the limit on the mass of sets obtainable.

Step 5: Manipulation:

From nuts

$$\frac{60.5 \text{ g sets}}{18.5 \text{ g } \cancel{\text{nuts}}} \times \frac{8.00 \text{ kg } \cancel{\text{nuts}}}{1} = 26.2 \text{ kg sets}$$

From bolts

$$\frac{60.5 \text{ g sets}}{31.0 \text{ g } \cancel{\text{bolts}}} \times \frac{18.2 \text{ kg } \cancel{\text{bolts}}}{1} = 35.5 \text{ kg sets}$$

From washers

$$\frac{60.5 \text{ g sets}}{11.0 \text{ g } \cancel{\text{washers}}} \times \frac{12.2 \text{ kg } \cancel{\text{washers}}}{1} = 67.1 \text{ kg sets}$$

Since our calculations show that we shall run out of nuts when 26.2 kg of sets have been constructed, the maximum mass of sets obtainable is 26.2 kg.

Step 6: Check:

a. Dimensions cancel.

b. Arithmetic rechecked for accuracy.

c. Logic rechecked.

Each new problem poses its own unique challenges, and there is no "magic formula" for problem solving. The stepwise approach suggested should prove useful in establishing a systematic technique. Facility will improve with practice.

STOICHIOMETRY

UNIT 1 : CHEMICAL FORMULAS

A chemical formula uses a combination of element symbols and subscript numbers to represent a compound or polyatomic grouping.

sodium chloride	methane	nitrate ion
NaCl	CH_4	NO_3^-

Three general types of formulas are of considerable utility in chemistry. Empirical formulas, indicating only the simplest whole number ratio of combined atoms, are most useful for simple inorganic compounds such as potassium bromide (KBr) or magnesium sulfate ($MgSO_4$). Such formulas reveal little information about more complex species. Carbon, for example, forms a tremendous variety of covalent compounds (organic compounds) and empirical formulas provide no real description of most organic compounds. Such different species as benzene and acetylene, for example, are both represented by CH, while a number of complex sugars have the empirical formula CH_2O. (Does this seem appropriate for a "carbo-hydrate"?)

Molecular formulas indicate the actual number of each kind of atom in a unique chemical combination. Such formulas thus distinguish between benzene (C_6H_6) and acetylene (C_2H_2). Molecular formulas, such as $C_6H_{12}O_6$ for glucose, are sufficient for many purposes, including stoichiometric calculations.

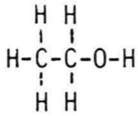
Structural formulas of various types show how atoms are connected in molecules or polyatomic ions. These formulas may be relatively simple, such as $CH_3CH_2CH_3$ for propane, or - in expanded forms - they may offer more sophisticated descriptions of structure, ranging from two-dimensional formulations to representations of three-dimensional characteristics. To write structural formulas, we need to know a fair amount about chemical bonding and some common conventions. The experimental evidence required and its interpretation may be quite complex.

Empirical and molecular formulas can be determined from relatively simple experimental data, using rather straightforward mathematical techniques. Since more knowledge and experience are required for interpreting structural information, we shall reserve this topic for more detailed texts.

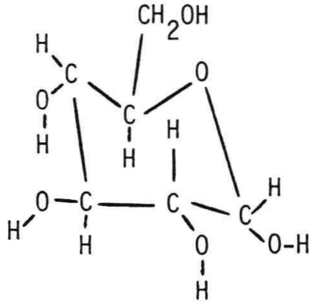
a compressed structural formula for ethyl alcohol

C_2H_5OH

an expanded structural formula for ethyl alcohol



a 3-dimensional structural formula for α-D-glucose



- References -

1. O'Connor, Rod. 1977. Fundamentals of Chemistry, second edition. New York: Harper & Row (Units 3, 4, 6, 7, 28, and Excursion 5)
2. Brown, Theodore, and H. Eugene LeMay, Jr. 1977. Chemistry: The Central Science. Englewood Cliffs, N.J.: Prentice-Hall (Chapters 3, 8, 9, 24)
3. Masterton, William, and Emil Slowinski. 1977. Chemical Principles, fourth edition. Philadelphia: W.B. Saunders (Chapters 3, 8, 10)
4. Nebergall, William, F.C. Schmidt, and H.F. Holtzclaw, Jr. 1976. College Chemistry, fifth edition. Lexington, MA: D.C. Heath (Chapters 1, 4, 6, 27)
5. Kieffer, W.F. 1963. The Mole Concept in Chemistry. New York: Van Nostrand/Reinhold

OBJECTIVES:

(1) *Given the percentage composition of a compound, be able to calculate its empirical formula.*

(2) *Given the formula weight and the empirical formula of a compound, be able to calculate its molecular formula.*

(3) *Given appropriate analytical data for a binary (two-element) compound, be able to calculate its empirical formula.*

*(4) *Given appropriate analytical data for a multi-element compound, be able to calculate its empirical formula.*

*(5) *Given the empirical formula of a volatile compound and vapor density data, be able to calculate the molecular formula.*

*Proficiency Level

PRE-TEST:

Necessary Atomic Weights:

carbon	(C)	12.01	nitrogen	(N)	14.01
copper	(Cu)	63.54	oxygen	(O)	16.00
hydrogen	(H)	1.008	sulfur	(S)	32.06

(1) A red-orange dye called Alizarin is an organic compound consisting of 70.02% carbon, 3.36% hydrogen, and 26.64% oxygen (each analysis being accurate to $\pm$ 0.01%). What is the empirical formula for Alizarin? ______________________

(2) The formula weight of Alizarin is 240.2. What is its molecular formula? ____________

(3) A sulfide of copper was treated with acid in such a way as to convert essentially all of the sulfur to hydrogen sulfide (H_2S). If a 0.8144 g sample of the copper salt produced 0.1744 g of hydrogen sulfide, what was the empirical formula of the original salt? ____________________________

*(4) Combustion of a 0.3082 g sample of hexamethylenediamine, a compound used in the production of Nylon-66, formed 0.7003 g of carbon dioxide and 0.3821 g of water. A separate nitrogen assay, using 1.270 g of the compound, produced 0.3723 g of ammonia (NH_3). What is the empirical formula of the original compound? ____________________

*(5) The vapor density of a sample of hexamethylenediamine, corrected to Standard Temperature and Pressure (STP), was reported as 5.19 g $liter^{-1}$. Using the information that 22.4 liters of gas, under ideal conditions, contains 1.00 mole of the gas at STP, calculate the molecular formula of this compound. _________________________________

Answers and Directions:

(1) $C_7H_4O_2$, (2) $C_{14}H_8O_4$, (3) Cu_2S. *If all are correct, go on to* *(4) *and* *(5) *or to* RELEVANT PROBLEMS, UNIT 1. *If you missed any, study* METHODS, *sections 1.1 through 1.3.*
*(4) C_3H_8N, *(5) $C_6H_{16}N_2$. *If both are correct, go on to* RELEVANT PROBLEMS, UNIT 1. *If you missed either, study* METHODS, *sections 1.4 and 1.5.*

*Proficiency Level