RELEVANT PROBLEMS *for Chemical Principles*

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PREFACE

The instructor who regards the plethora of introductory college texts as but another example of increasing entropy has our common sympathy. Moreover, apparently few texts are satisfactory to all instructors. Our experience with the shortcomings of most texts led us to establish two priorities in writing this supplementary problems book: We would provide detailed solutions to *every* problem, and we would include as many problems as possible to show the student that even a limited knowledge of the principles of chemistry would enable him to solve problems concerning real situations encountered not only in chemistry, but in other sciences, and even everyday life. Thus, we have included problems about space science, medicine, geology, dentistry, archaeology, biochemistry, urban pollution and hygiene, engineering, and solar and nuclear energy.

Another of our objectives was to allow students to proceed at their own pace through the book. We have purposely used a multiple-choice format, not to remind the student of the computer age on campus but to construct incorrect answers that correspond to common errors. The reasons for these incorrect answers are often discussed in the solution of the problem that appears on the page immediately following the problem. So the student can either work through the solution to find he is correct or to find his error, or he can check only the discussion of the incorrect answer. For the well-prepared student, however, the number corresponding to the correct answer is prominently displayed within a circle at the end of the solution section so he need not work through an entire solution.

We have taken advantage of the fact that this book is designed to form a part of the complete teaching system accompanying the text *Chemical Principles*, by Richard E. Dickerson, Harry B. Gray, and Gilbert P. Haight, Jr. Throughout both the text and this book, there are cross references that are intended to indicate to the student the areas in which he might find additional review. The student who continually chooses the wrong answer is referred to the appropriate section in *Programed Reviews of Chemical Principles*, by Jean D. Lassila *et al.* This book, which is another part of the teaching system, offers an introduction to systematic problem-solving that is of use when working the problems in our book.

Although the book closely parallels the text *Chemical Principles*, we have not hesitated to include additional material where we thought it warranted. For example, in Chapter 2, there is a section on molecular beams, and in Chapter 3, there are a number of problems on mass spectrometry.

Not only are students often uncertain of how much they must memorize, but generally they memorize too much. In a "memorization section" in the introduction to each chapter, the student is told exactly what he must memorize to solve the problems. We have tried to keep the memorization to a minimum by showing the student, within a problem, how to proceed quickly from the few memorized facts and equations to the ones necessary to solve the problem. Thus, there are a number of problems that build on each other, in which the results of one are used in the next, and so on. Therefore, we consider some of the problems to be "teaching problems."

The student is periodically invited to evaluate his own progress by performing two-hour examinations, which are grouped in Appendix 1. We have not provided detailed solutions but have included answers to all of the examination questions.

We wish to thank our students and colleagues (especially Ferenc Kalos, Garry Stein, Donna Stern, Theodore Waech, Ivor Whorf, and Professor James J. Hogan) who so carefully worked all the problems and criticized our solutions. We would particularly like to thank Professor David N. Harpp, who wrote the problems for Chapter 11, "The Special Role of Carbon." Finally, we alone are, alas, responsible for any errors or inconsistencies throughout the book and would welcome any criticism and suggestions so we may improve it.

IAN S. BUTLER
ARTHUR E. GROSSER

Edgartown, Massachusetts
September 1969

NOTE TO THE STUDENT

A book of introductory chemistry problems usually seems like a formidable and tiresome epic with neither plot nor characters, and with insufficient narrative. Moreover, the exercises seem to be just that: a chemistry professor's equivalent to a muscle building course.

Our intention is to provide a change from this drudgery. Although we are primarily interested in helping you to master problems in chemistry, we think that it is also important to be learning something about how chemical principles relate to the real world. For this reason, we have tried to think of problems that involve areas such as space science, medicine, geology, archaeology, engineering, biochemistry, and a host of other fields from which you might derive some feeling of involvement.

Our method is to state a problem and to give five possible answers. Then we give a relatively detailed solution (not the *only* way to solve the problem, of course, and not even the shortest; we simply present an understandable way). We have chosen this multiple-choice format so we could deliberately construct incorrect answers that correspond to common errors. The reasons for these errors are often discussed in the solution. Nevertheless, if you are answering the questions correctly, you need not read through the entire solution. The number giving the correct answer is prominently displayed on the page. But if you are having trouble with these problems, we refer you periodically to *Programed Reviews of Chemical Principles*, by Jean D. Lassila *et al.*, for remedial work. This arrangement should allow you to proceed at you own pace. (In addition, we have cross-referenced to the text, *Chemical Principles*, by Richard E. Dickerson, Harry B. Gray, and Gilbert P. Haight, Jr. We follow the format of this text on a chapter-by-chapter basis.)

A word about memorization. We do not believe that it is important to commit a large quantity of information to memory. (Other scientists appear to agree, for they continually surround themselves with libraries and computers.) But some facts are so basic that it would be cumbersome to look them up time after time. We indicate at the beginning of each chapter what material you should, in our opinion, memorize. We believe that it is minimal.

Finally, we remain aware, even after watching TV commericals, that there are no panaceas. Nature will answer our questions, but only if we know how to ask them. And learning how to ask nature the proper questions is the business of scientists. In learning how to answer these questions, we hope that you learn to ask your own.

CONTENTS

CHAPTER 1 ATOMS, MOLECULES, AND MOLES

This chapter covers the concepts of atoms, gram-atoms, molecules, and moles, and introduces the quantitative aspects of chemical reactions. It is the interrelationship of these concepts with our everyday measures of quantity (weight and volume) that constitutes the basic vocabulary of the chemist.

You should be able to solve problems with a minimum of memorization. But that minimum is not zero. We will suggest what is necessary to memorize at the beginning of each chapter.

Memorize:

$N = 6.0 \times 10^{23}$ atoms g-atom^{-1}
or molecules mole^{-1}
1 liter = 10^3 cm^3
1 kg = 10^3 g

PROBLEM 1-1

You may recall watching the deployment of a solar wind experiment during the Apollo 11 moonwalk. The solar wind collector was an aluminum strip of approximately 3000 cm^2 area (11.5 in. $\times$ 40 in.). If the solar wind strikes this foil (and sticks) with an intensity of 1×10^7 H atoms cm^{-2} sec^{-1}, what *mass* of H atoms was collected during the approximately 100-min experiment?

(at. wt: H = 1.0)

1 1×10^{-13} g
2 5×10^{-12} g
3 3×10^{-10} g
4 1 g
5 1.8×10^{14} g

PROBLEM 1-2

In World War I, 120,000 short tons (1.1×10^8 kg) of poison gas were fired on the Allied forces. (In 1918, half the shells fired by the Germans contained gas.) If the gas is assumed to be phosgene ($COCl_2$), how many *molecules* of the gas correspond to the amount fired on the Allied forces?

(at. wt: C = 12.0, O = 16.0, Cl = 35.5)

1 $1.1 \times 10^9/(6.0 \times 10^{23}) = 1.9 \times 10^{-15}$
2 $1.7 \times 10^9/(6.0 \times 10^{23}) = 2.9 \times 10^{-15}$
3 $6.0 \times 1.1 \times 10^{29} = 6.6 \times 10^{29}$
4 $6.0 \times 1.1 \times 10^{32} = 6.6 \times 10^{32}$
5 $6.0 \times 1.7 \times 10^{32} = 10 \times 10^{32}$

SOLUTION 1-1

If you have trouble manipulating exponents, see Appendix 2.

The first thing that we want to do is to calculate the number of H atoms that strikes the foil per second

$$\text{H atoms sec}^{-1} = 1 \times 10^7 \text{ atoms sec}^{-1} \text{ cm}^{-2} \times 3 \times 10^3 \text{ cm}^2$$
$$= 3 \times 10^{10} \text{ atoms sec}^{-1}$$

The number that strikes the foil during the 100 min is

$$\text{H atoms} = 3 \times 10^{10} \text{ atoms sec}^{-1} \times 10^2 \text{ min} \times 60 \text{ sec min}^{-1}$$
$$= 18 \times 10^{13} \text{ atoms}$$

To calculate the *weight* of hydrogen we should convert this number of atoms to gram-atoms, and then use the atomic weight to obtain the number of grams

If you could not solve this problem, you may want to study Section 1-1 of Programed Reviews of Chemical Principles *by Lassila* et al.

$$\text{g-atoms H} = \frac{18 \times 10^{13} \text{ atoms}}{6 \times 10^{23} \text{ atoms g-atom}^{-1}}$$
$$= 3 \times 10^{-10} \text{ g-atom}$$

and since that atomic weight of hydrogen *atoms* is 1.0

$$\text{g of H} = 3 \times 10^{-10} \text{ g-atom} \times 1.0 \text{ g g-atom}^{-1}$$
$$= 3 \times 10^{-10} \text{ g}$$

3 is correct.
1 The aluminum area was not included.
2 You forgot to convert minutes to seconds.
4 This is, of course, just the atomic weight of hydrogen.
5 You forgot to divide by *N*.

(3)

SOLUTION 1-2

For a review of the concept of moles, see Lassila's book, Section 1-2.

The molecular weight of $COCl_2$ is

$$12 + 16 + 2 \times 35.5 = 99 \text{ g mole}^{-1}$$

In 1.1×10^8 kg there are 1.1×10^{11} g and

$$\frac{1.1 \times 10^{11} \text{ g}}{99 \text{ g mole}^{-1}} \simeq 1.1 \times 10^9 \text{ moles}$$

[*Note:* $\simeq$ means "approximately equal to."] Since each mole contains 6.0×10^{23} molecules, the total number of molecules is

$$1.1 \times 10^9 \text{ moles} \times 6.0 \times 10^{23} \text{ molecules mole}^{-1}$$

or

$$6.0 \times 1.1 \times 10^{32} \text{ molecules} = 6.6 \times 10^{32} \text{ molecules}$$

4 is correct.
1 Division by *N*. This could have been avoided if you had checked units.
5 Wrong molecular weight. The atomic weight for Cl must be multiplied by two.
2 Both the above mistakes.
3 You forgot to change from kilograms to grams.

(4)

PROBLEM 1–3

The molecular weight of hydrogen peroxide (H_2O_2) is 34. What are the *units* of molecular weight?

(at. wt: $H = 1, O = 16$)

1 g
2 mole
3 g $mole^{-1}$
4 mole g^{-1}
5 No units.

PROBLEM 1–4

Which of the following statements concerning an isotope ${}^{A}_{Z}M$ of an element M is *incorrect?*

(a) Z is the mass number of the element.
(b) A is the mass number of the element.
(c) Z is the number of positive charges on the nucleus.
(d) Z is the atomic number.
(e) A is the sum of the number of protons and the number of neutrons in the nucleus.

1 (a) and (c)
2 (a)
3 (b) and (e)
4 (b) and (d)
5 (d) and (e)

PROBLEM 1–5

Which of the following are pairs of isotopes?

(a) ${}^{2}_{1}H^{+}$ and ${}^{3}_{1}H$
(b) ${}^{3}_{2}He$ and ${}^{4}_{2}He$
(c) ${}^{12}_{6}C$ and ${}^{14}_{7}N^{+}$
(d) ${}^{3}_{1}H$ and ${}^{4}_{2}He^{-}$

1 (b) only
2 (a) and (d)
3 (a) and (c)
4 (c) only
5 (a) and (b)

SOLUTION 1-3

Molecular weight is the weight of a mole of the substance and has the units of g mole^{-1}. We have stressed the importance of this approach to our calculations in the two previous problems, and we will continue to do so. The continued use of units in solving problems will take some time, but will prevent many errors.

(3)

SOLUTION 1-4

Consider the general term for an isotope, $^{A}_{Z}M$. A is the mass number of the element and is the sum of the number of protons and the number of neutrons in the nucleus. Z is the atomic number of the element and is equal to the number of protons (positively charged particles) in the nucleus. Consequently, only statement (a) is incorrect, and the required answer is **2**.

(2)

SOLUTION 1-5

The atomic number determines the element. Different atomic numbers correspond to different elements.

An element has only one atomic number, but usually several atomic masses. Different atomic masses for the same atomic number correspond to different isotopes of the element. (c) and (d) pair different *elements*. (a) and (b) pair the same element but different atomic masses; therefore, they are pairs of isotopes. Answer **5** is correct.

The charge on the element doesn't enter into these considerations, since isotopes involve just the numbers of protons and neutrons in the nucleus. For instance, the pair $^{2}_{1}H^{+}$ and $^{3}_{1}H$ are isotopes of H in which $^{2}_{1}H^{+}$ has had its only electron removed. If you thought the positive charge was obtained by adding a proton to the nucleus, remember that this would change the chemical species of the substance.

(5)