STUDY GUIDE

For Chemical Principles, Fourth Edition

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by Dickerson, Gray, Darensbourg, and Darensbourg

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To the Student

This book is designed to help you study efficiently. In each chapter you will find the following elements:

- Chapter Overview and Objectives: The main topics in the chapter are summarized here. The learning objectives are specific skills you should master before leaving the chapter and proceeding to the next one.

- Section Summaries: These summarize the important ideas in each section of the chapter. Worked examples and alternate explanations of concepts are provided as well.

- Terms to Know: Important vocabulary words are listed in alphabetical order near the end of the chapter. In chemistry, as in any of the sciences, language is very powerful, so be sure that you can correctly define the terms in these lists.

- Test Yourself: A selection of problems for you to work closes each chapter. Completely worked out solutions to these are found in the Appendix. Be sure to answer all the self-study questions and problems at the end of each chapter in the text as well.

As you use the Study Guide, you will encounter many diagrams and charts, especially in Chapters 2 through 5. Their purpose is to help you see how to solve a problem before the calculations are given. Flowcharts summarize the thought processes involved in solving problems. The unknown, i.e. the answer you are seeking, is usually found at the top of a flowchart. Once you have identified the unknown, you can work backwards to the information that is given in the problem.

Take advantage of all the resources for learning available to you. These resources include not only the text, this Study Guide, and material in the library, but also your instructor and other students. Studying with another person in the course can be enormously helpful. You will need to set aside some regularly scheduled time for studying. Also, lectures will benefit you most if you have read the material beforehand. Chemistry is an exciting science. Have fun!

To the Instructor

The intent of this Study Guide is not only to explain and reinforce chemical concepts, but also to teach students problem-solving logic. While some general chemistry students have weak mathematical backgrounds, the majority of those who experience difficulty lack training and experience in applying the mathematics they know to physical situations. Specific skills, such as dimensional analysis and the use of logarithms, are presented in the early chapters. Other helpful notes are included throughout the guide in the examples, which are worked out step by step. In addition, the thought processes used in solving problems are deliberately articulated in the examples. This is most evident in Chapters 2 and 3, where flow diagrams are used, and in Chapters 4 and 5.

Each chapter begins with an overview and list of objectives. Key ideas are summarized, and reinforced with examples. Important terms are collected in a vocabulary list at the end of each chapter. After working the problems in the text, students can test themselves with the questions following each chapter of the Study Guide. Detailed solutions to these questions are provided in the Appendix.

The problem-solving techniques used in this guide have been classroom-tested. Using the Study Guide together with the text allows you to design your course such that weaker students are given the extra support they need, while the attention of the well-prepared ones is maintained.

Special thanks go to colleague Margaret Kastner for reviewing the manuscript and for very helpful discussion. I would also like to acknowledge Valerie Fassbender, who provided most of the solutions to the Test Yourself questions.

P. L. Samuel

Contents

1 Atoms, Molecules, and Ions

CHAPTER OVERVIEW AND OBJECTIVES

This introductory chapter summarizes much that is known about atoms, ions, and molecules. Later chapters discuss how this information is acquired as well as questions about matter and its behavior which have not yet been answered and are topics of current chemical research.

When you finish this chapter you should be able to:

1. Define the terms printed in boldface type in the text and emphasized here;

2. Tell how many protons, neutrons, and electrons are present in an isotope of an atom or monatomic ion;

3. Understand the chemical counting unit the mole, and use it quantitatively, in combination with molecular weights and formula weights;

4. Briefly describe the attractive forces which exist between atoms, molecules, and ions in compounds and solutions;

5. Write formulas and names for ionic compounds derived from the ions listed in Section 1-6.

SECTION 1-1: THE STRUCTURE OF ATOMS

The terms that follow are part of the basic vocabulary you need to know when talking about atoms. If any of the definitions are new to you, be sure to take special note.

- atom: an electrically neutral particle of matter consisting of a nucleus and electrons
- nucleus: the portion of an atom containing most of its mass; very dense (mass/volume ratio is large) and positively charged
- electron, $\bar{e}$: small, very light subatomic particle with a charge of -1
- proton, p: subatomic particle with +1 charge found in the nucleus, of mass about 1 amu
- neutron, n: neutral (uncharged) subatomic particle found in the nucleus, with mass of about 1 amu
- atomic mass unit, amu: a unit of mass equal to 1/12 the mass of one atom of carbon-12, which consists of 6p, 6n, and 6$\bar{e}$
- symbol: the letter designation for an element; first letter only capitalized, e.g., Zn, the symbol for the metallic element zinc
- element: matter consisting of atoms all having the same atomic number

- formula: letter designation for chemical species containing more than one atom, e.g., HF, formula for hydrogen fluoride, which contains one atom of hydrogen and one of fluorine
- atomic number, *Z*: the number of protons in the nucleus of an atom
- mass number, *A*: the number of protons and neutrons in the nucleus

Because atoms are electrically neutral, they contain equal numbers of electrons and protons. The number of neutrons in an atom can, and does, vary.

Example 1

How many protons, neutrons, and electrons are there in these atoms?

a.	Tc:	$Z = 43$	$A = 99$
b.	B:	$Z = 5$	$A = 11$
c.	B:	$Z = 5$	$A = 8$
d.	Am:	$Z = 95$	$A = 243$

Solution: The names of these atoms are given on the back endpapers of the text. The atomic number, *Z*, is the number of protons and the number of electrons in an atom. The mass number, *A*, is the sum of the protons and neutrons.

a.	Tc, technetium:	43p,	43ē,	56n
b.	B, boron:	5p,	5ē,	6n
c.	B, boron:	5p,	5ē,	3n
d.	Am, americium:	95p,	95ē,	148n

Notice that cases b and c are atoms of the same element, boron, because both have the same number of protons.

Example 2

What is the difference between NO and No?

Solution: No is the symbol for the element nobelium, element 102. NO is the formula for the compound nitric oxide, or nitrogen monoxide. You can tell that NO is a formula of a compound and not the symbol for an element, because it contains more than one capital letter. A molecule of nitric oxide contains one atom of nitrogen, N, and one atom of oxygen, O.

SECTION 1-2: ISOTOPES

Isotopes are atoms of the same element having different numbers of neutrons. In Example 1, two isotopes of the element boron are given, boron-11 and boron-8. Symbols for isotopes follow the form

$$^{A}_{Z}\mathrm{X}$$

where subscript Z = atomic number
superscript A = mass number

Symbols for the two isotopes of boron are $^{11}_{5}\mathrm{B}$ and $^{8}_{5}\mathrm{B}$.

The atomic weight of an isotope is its mass expressed in atomic mass units, amu. The atomic weight is somewhat less than the sum of the masses of the protons, neutrons, and electrons in the atom because some mass is converted to energy to provide the binding energy for the nucleus. The mass that is lost is called the mass excess of the atom.

Example 3

Calculate the mass excess for $^{11}_{5}B$, atomic weight 11.00931.

Solution: The mass excess is the difference between the sum of the masses of the protons, neutrons, and electrons in the atom and the observed atomic weight:

$$\text{mass excess} = (\text{mass p} + \text{mass n} + \text{mass } \bar{e}) - \text{atomic weight}$$

There are 5p, $5\bar{e}$, and 6n in an atom of boron-11.

$$\text{mass excess} = (5p)(1.00728 \text{ amu/p}) + (6n)(1.00867 \text{ amu/n}) + (5\bar{e})(0.00055 \text{ amu}/\bar{e}) - 11.00931 \text{ amu}$$

$$= (5.03640 + 6.05202 + 0.00275) \text{ amu} - 11.00931 \text{ amu}$$

$$= (11.09117 - 11.00931) \text{ amu} = 0.08186 \text{ amu}$$

The natural atomic weight of an element is the weighted average of the atomic weights of the isotopes of that element which are found in nature. It is the natural atomic weights that are listed in the table at the end of the text and in the periodic table.

Example 4

Lithium has two naturally occurring isotopes, lithium-6 and lithium-7, atomic weight 7.01600. The natural atomic weight of lithium is 6.941. Naturally occurring lithium is 92.58% of the heavier isotope. Calculate the atomic weight of lithium-6.

Given: natural atomic weight of Li, 6.941 amu
atomic weight ^{7}Li = 7.01600
92.58% of naturally occurring Li is ^{7}Li

Find: atomic weight of ^{6}Li

Solution: Start with the fact that the natural atomic weight of Li is 6.941 amu and write an equation showing how that is calculated as a weighted average.

$$\text{natural atomic weight} = (\%^{7}Li)(\text{atomic weight } ^{7}Li) + (\%^{6}Li)(\text{atomic weight } ^{6}Li)$$

Everything in this equation is given in the statement of the problem except the atomic weight of ^{6}Li (the unknown) and its percent natural abundance. Because there are only two isotopes, however,

$$\%^{6}Li + \%^{7}Li = 100\%$$

$$\%^{6}Li = 100.00\% - 92.58\% = 7.42\%$$

Now we have one equation and one unknown, and the rest is a matter of arithmetic. Substitute the appropriate numbers into the equation and let x = atomic weight of ^{6}Li.

$$6.941 \text{ amu} = (92.58\%)(7.01600 \text{ amu}) + (7.42\%)(x)$$

92.58% written as a decimal is 0.9258, 7.42% is 0.0742.

$$6.941 \text{ amu} = (0.9258)(7.01600 \text{ amu}) + 0.0742x$$

$$6.941 \text{ amu} = 6.4954 \text{ amu} + 0.0742x$$

(Carry along an extra significant figure until you reach the final answer.)

$$(6.941 - 6.4954) \text{ amu} = 0.0742x = 0.446 \text{ amu}$$

$$x = 0.446 \text{ amu}/0.0742 = 6.01 \text{ amu}$$

(Notes on significant figures (sig. fig.): Only three sig. fig. are allowed in the answer to 6.941 - 6.4954 because the least number of sig. fig. to the right of the decimal point is three. Only three sig. fig. are allowed in the final answer because the least number of sig. fig. in the quotient 0.446/0.0742 is three.)

SECTION 1-3: MOLECULES

A molecule is an electrically neutral chemical species composed of two or more atoms held together by covalent bonds. A covalent bond is formed by the sharing of electrons between atoms. Molecules may contain atoms of one element, such as H_2, N_2, S_8, and P_4, or more than one element, such as CO_2 or HF. Molecules containing atoms of more than one kind of element are compounds. A molecular formula tells how many of each kind of atom there are in a molecule.

Example 5

Perchloric acid molecules contain 1 atom of hydrogen, 1 atom of chlorine and 4 atoms of oxygen. Write the molecular formula.

Solution: We need the symbols of hydrogen, chlorine, and oxygen. They can be found in the table at the back of the text and are H, Cl, and O, respectively. The formula is then

$$HClO_4$$

The subscripts telling the number of each kind of atom are written to the right of the symbol for the element: N_2, not $_2N$. For instance, NO_2 and N_2O are different compounds. NO_2 contains 1 N atom and 2 O atoms, while N_2O is composed of 2 N atoms and only 1 O atom.

Molecular diagrams indicate which atoms are bonded together, but don't show the shape of the molecule. You cannot draw a molecular diagram just by looking at the molecular formula. For NO_2, you can write both

O - N - O (correct)	or	N - O - O (incorrect)

Molecular weight is just the sum of the natural atomic weights of the atoms in a molecule. You need to know the molecular formula of a molecule in order to calculate its molecular weight.

Example 6

What is the molecular weight of acetic acid, CH_3COOH?

Solution: The formula could also be written $C_2H_3O_2H$ or $C_2H_4O_2$.

molecular weight (MW) = sum of atomic weights (AW)

MW of acetic acid = (4 H atoms)(1.008 amu/H atom)
+ (2 C atoms)(12.011 amu/C atom)
+ (2 O atoms)(15.999 amu/O atom)

MW = (4.032 + 24.022 + 31.998) amu = 60.052 amu

SECTION 1-4: FORCES BETWEEN MOLECULES

Forces between molecules are much, much weaker than the covalent bonds which hold atoms together within molecules. For example, you can spread water out into a thin layer of molecules with your hands, but you can't rip the molecules apart into individual hydrogen and oxygen atoms without applying a large amount of energy. Be sure to learn the terms in the list that follows:

- van der Waals forces: weak attractive forces between molecules which generally increase with increasing molecular weight
- temperature: quantitative measure of heat energy, which is a consequence of molecular motion; heat and temperature are different but are often confused
- solid state: phase of matter having definite shape and volume because molecules are organized into a crystalline lattice
- liquid state: phase of matter having definite volume but variable shape because intermolecular attractions are weaker than those in the solid state
- gaseous state: phase of matter characterized by having neither definite volume nor shape, and by wild, chaotic molecular motion, due to nearly nonexistent intermolecular forces
- melting point, T_m: temperature of transition between the solid and liquid phases of a substance
- boiling point, T_b: temperature of transition between the liquid and gas phases of a substance
- polar molecule: one in which the electrons in the covalent bonds are not shared equally between the atoms, e.g., HF, $\overset{\delta^+\delta^-}{H-F}$, CO, $\overset{\delta^+\delta^-}{C-O}$
- electronegativity: degree of attraction an atom has for the electrons in a covalent bond which it makes with another atom
- hydrogen bond: an especially strong attraction (but not as strong as a covalent bond) between a hydrogen atom in one molecule and a F, O, or N atom in another molecule, or in another section of a large molecule

SECTION 1-5: MOLECULES AND MOLES

The most important term to understand in this section is the chemical counting unit called the mole. A mole of anything is 6.022×10^{23}, or Avogadro's number, of that thing. Anything at all can be counted by moles. In concept, a mole is just like other counting units:

dozen	12 things
gross	144 things
ream	500 things, usually sheets of paper
decade	10 things
score	20 things, usually years
century	100 years

Granted, a mole is a huge number of things, but it has to be, because what is usually counted by moles are atoms and molecules, and these are incredibly small. In order to see and measure a collection of atoms or molecules, we have to count out a tremendous number of them. An entire mole of hydrogen molecules, H_2, weighs only 2 grams; that's 6.022×10^{23}, Avogadro's number, of H_2 molecules.

To get a feel for just how huge a number Avogadro's number is, take your pulse, and calculate how many years it would take to count up a mole of heartbeats.

In chemical calculations, the mole unit helps make the transition between counting out individual atoms or molecules and measuring out enough atoms or molecules of a substance to weigh (mass) on a laboratory balance. The mole is the link between the microscopic world of atoms and molecules and the macroscopic world of bulk materials that we deal with every day.

Example 7

A sample of carbon tetrachloride, CCl_4, contains 0.250 mol CCl_4 molecules.

a. How many molecules does it contain?

Solution: The size of 1 mole of anything is 6.022×10^{23}. Thus, 0.250 mol of anything contains $(1/4)(6.022 \times 10^{23}) = 1.50 \times 10^{23}$ things. Thus, there are 1.50×10^{23} molecules in the sample.

b. How many atoms of C and of Cl does it contain?

Solution: Examine the molecular formula. In one molecule of CCl_4, there are 1 C and 4 Cl atoms. The sample contains 1.50×10^{23} molecules, so there are an equal number of C atoms, and 4 times as many Cl atoms, or 6.02×10^{23} Cl atoms.

c. How much does the sample weigh, in grams?

Solution: The definition of the mole states that exactly 12 g of ^{12}C contains Avogadro's number of ^{12}C atoms. In practical terms, this means that the atomic weight of an atom, expressed in grams, contains one mole of atoms. Similarly, the molecular weight of a molecule, given in grams, contains one mole of molecules.

In the case given here, there is 0.250 mol of CCl_4 molecules. One mole of CCl_4 weighs as much as the molecular weight in grams, or $(12.011 + (4 \times 35.453))$ g = 153.823 g. Then 0.250 mol weighs

$$(0.250 \text{ mol})(153.823 \text{ g mol}^{-1}) = 38.456 \text{ g} = 38.5 \text{ g}$$

d. Another sample of CCl_4 weighs 10.00 g. How many moles of CCl_4 does this sample contain?

Solution: We can immediately say that a 10.00 g sample contains less than one mole, because the molecular weight is 153.823 g/mol. A 10.0 g sample is about 1/15 mole.