COMPARATIVE ANALYSIS OF CHEM STUDY AND ITS REVISIONS

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ABSTRACT

The purpose of this study is to provide an analysis of the revisions of CHEM Study materials. Each revision is compared with CHEM Study in order to identify deletions of information, additions of information, and differences in style.

Each chapter of the CHEM Study textbook and the experiments that are relevant to the chapter have been compared in detail with the corresponding sections of the Raytheon, Houghton Mifflin, and Prentice-Hall revisions in turn. The organization and chapter coverage of teachers' guides and progress tests for all four versions were examined.

The format is most appealing in the Prentice-Hall and Raytheon revisions since the margins are wider and there is only one column of print. The scientific models contained in these two versions are the most imaginative and most representative of real phenomena. For example, Raytheon and Prentice-Hall respectively represent energy levels in the hydrogen atom by an irregular-staircase model and a bookcase model rather than the triple-beam-balance model that is provided in the other two versions. Prentice-Hall shows that activated-complex formation is analogous to pole-vaulting. There is greater scientific rigour in the revisions than in CHEM Study in definition of rate of reaction and in description of "noble" gases. Raytheon and Prentice-Hall explain chemical phenomena from first principles more frequently than the other versions and have the least recitation of facts. They also contain the most laboratory work. Information in Prentice-Hall includes more up-to-date scientific

developments than the other versions. The four teachers' guides are very much alike. Progress tests for all versions are multiple-choice and mainly open-book tests. Houghton Mifflin is the only version which provides a separate test for each chapter of the textbook in addition to cumulative tests.

Regular patterns in nomenclature should be pointed out more clearly in all versions, to allow students to understand the symbolism and understand the structure of chemistry. Some adjustments still need to be made to familiarize students with industrial applications of chemistry. Photographs have not been well chosen and are over-used in Houghton Mifflin.

CHEM Study and the Houghton Mifflin revision are not as good high school textbooks as the other two versions since they do not have sufficient integration of ideas, clarity, and relevance. The Prentice-Hall revision has clarity of expression, a style which establishes rapport with the youthful reader without any sacrifice of depth, and information that is most up-to-date. It is the best choice for students who plan to study post-secondary chemistry. The Raytheon version is well suited for the student who will terminate his formal study of chemistry in secondary school.

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CHAPTER I

INTRODUCTION

Statement of the Problem

The purpose of this study is to provide chemistry teachers and curriculum planners with an analysis of the revisions of CHEM Study.

The CHEM Study textbook, Chemistry - An Experimental Science[1] and laboratory manual, published by W. H. Freeman and Company, San Francisco, have been available since July 1963. In 1968, two authorized revisions were published - Chemistry - Experiments and Principles, published by Raytheon Education Company, and Chemistry: An Investigative Approach, published by Houghton Mifflin Company. Toward the end of 1969, Prentice-Hall Incorporated published Chemistry: Experimental Foundations. Publication of these three revisions was authorized by the CHEM Study Steering Committee in 1966.

The textbook authorized for grade eleven chemistry in Manitoba is the Freeman publication. This thesis will give an objective presentation of the properties of the three revisions where they differ from the Freeman version to point out specific variations in models and explanations used, in relevant facts presented, and in originality of problem sets. Content of experimental work, achievement tests, and teachers' guides will also be compared.

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[1]Hereinafter referred to as the Freeman version.

Importance of the Study

The CHEM Study Steering Committee selected three author-publisher teams from seven applicant teams to be the producers of revisions. The Steering Committee was confident that it would thus "guarantee the existence of a variety of excellent high school chemistry textbooks" and "reduce the likelihood that textbooks of the future might, by their failure to keep pace with the accelerating movement of science, make repeated curriculum studies necessary" (CHEMS Newsletter, June, 1969). This statement suggests that the revisions should be assessed as potential textbooks for Manitoba schools.

In the event that some or all of the revisions are authorized for use in Manitoba, teachers will need some evidence to enable them to judge which set of materials would best meet the needs of their students. This study will present objectively the differences in content between the three revisions and the original version. If not all the revisions are accepted as alternative textbooks for grade eleven in Manitoba, the contents of this study may enable teachers and students to use the revisions more efficiently as resource materials.

Design of the Study

In this thesis, the events and considerations that led to the publication of the original CHEM Study materials are examined. All materials authorized by the CHEM Study Steering Committee and evidences of their success are enumerated.

The bulk of this thesis is a detailed comparison of each of the three authorized revisions with the Freeman laboratory experiments and textbook. Explanations and models are compared chapter by chapter using the sequence from Freeman, for the four different versions. The originality of problems and questions in each of the three revisions as compared with the Freeman version is examined quantitatively. The comparison of the four laboratory manuals is designed to assist the teacher to select efficiently from a variety of experiments that are relevant to a given chapter in the Freeman edition. The teachers' guides and achievement tests are examined, since they will partly determine the curriculum offered to a class.

CHAPTER II

REVIEW OF THE LITERATURE

The Origin of CHEM Study

The CHEM Study story began in the fall of 1959. Three men, representing the American Chemical Society and the National Science Foundation, met with Dr. Glenn Seaborg in Washington and described to him their idea for a new high school chemistry course. They persuaded him to assume responsibility for the development of the course.

Dr. Seaborg received his Ph.D. from Berkeley in 1937 at the age of 25. He and Professor Edwin McMillan shared the Nobel Prize for Chemistry in 1951, for producing neptunium and plutonium. From 1958-1961, he was Chancellor of the University of California at Berkeley, and in 1961, was appointed Chairman of the U.S. Atomic Energy Commission.

Dr. Seaborg accepted the chairmanship of CHEM Study in 1959 on the condition that J. Arthur Campbell of Harvey Mudd College, Claremont, California, would be Director of the programme. It was Dr. Campbell who named the project the Chemical Education Material Study, or CHEM Study. This Study was supported by the National Science Foundation through grants totalling $2,800,000 to the University of California, Berkeley, and to Harvey Mudd College.

Seaborg and Campbell selected a Steering Committee to include themselves and 17 men from 11 states (Minnesota, New York, Pennsylvania, Texas, and others), including university professors, a publisher, high school teachers, university administrators, an American Chemical Society representative, a film specialist from Encyclopedia Britannica, and a representative from industry. The Committee met in January, 1960 at Berkeley to set up objectives and a time schedule.

Selection of Authors and Mechanics of Production

The Steering Committee made some suggestions and a selection of exceptional American secondary school and university persons known for the high quality of their teaching, research, and writing were then contacted by the Director. Their participation was requested in designing materials for the new course. All of the persons contacted agreed to participate.

Their first meeting was held in April 1960 for four days of discussion. A series of chapter outlines was developed. Each contributor chose or was assigned a section to be prepared for the summer writing session.

By the end of July, 1960, materials had been re-written twice. The course was used in 23 trial schools and one junior college by about 1300 students in the 1960-61 academic year, in more than 130 schools by over 12,000 students in 1961-62, and in 550 schools by about 45,000 students in 1962-63 (Freeman, p. vii). Each summer the textbook and laboratory manual were revised until finally, the hard cover edition of the textbook was ready for the schools in July, 1963 (Merrill and Ridgway, pp. 24-26).

Philosophy of the Authors

The Garrett Committee[1] and the Steering Committee were convinced that chemistry courses generally being offered in high schools had three weaknesses. First, they involved memorization of much chemical history, descriptive detail, and technology that were somewhat out of date and/or relatively unimportant. Another weakness was insufficient emphasis on understanding major unifying concepts and principles. Also, laboratory work was often "cookbook exercises", not as meaningful as it should have been, and not representative of scientific investigation (Merrill and Ridgway, p. 26).

The general objectives of CHEM Study, as conceived by the Steering Committee in January, 1960, were to develop new teaching materials for high school chemistry including a textbook, laboratory experiments, and films. The more specific objectives were to reduce the then current separation between scientists and teachers in the understanding of science, to encourage teachers to keep pace with scientific advances by taking further courses and thereby improving their teaching methods, to stimulate and prepare high school students whose purpose was to continue the study of chemistry in college, and to further in students who would not continue formal study of chemistry after high school an understanding of the importance of science in human affairs (Merrill and Ridgway, p. vi).

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[1]The Garrett Committee (1959) was a 6-man committee set up by the American Chemical Society, to study the possible organization of a high school chemistry course.

It was decided that the course should be presented using an experimental approach, since chemistry deals with things as well as with ideas, and since there is some evidence that students retain longer what they see and manipulate than what they only discuss (Merrill and Ridgway, p. 117).

The Director of CHEM Study considered that experiments should be student-performed rather than demonstrated and that the answer should not be known before the experiment is begun, but discoveries should be made by the student as the experiment progresses. Experiments should give the student an opportunity to observe chemical systems and gather data for development of principles which would later be discussed in the textbook and in class. There should be increasing practice in organizing and interpreting data.

It was recommended by Dr. Campbell that the student should be left at the end of the course with

> a feeling for both the power and limitations of science, with a feeling for what current ideas and methods are accomplishing, but even more, with an understanding of the inevitability of change in scientific thinking and a realization that it is possible even for a non-scientist to keep abreast, in a general way, of these changes if he has a feeling for the basic methods, ideas, and facts used by scientists (Merrill and Ridgway, p. 122).

Six basic units for the new course were suggested, as follows: (1) introduction, (2) an introduction to Structural Chemistry, including atomic, molecular, and macromolecular structures, (3) an introduction of Chemical Dynamics, (4) an introduction to Systematic Chemistry, (5) an intensive study of the chemistry of a single element or family of elements, and (6) a review paper of some area of current chemical interest.

Selection of Content

Criteria for Selection of Content

During the early meetings of the contributing authors, many questions on content were thoroughly discussed.

The criteria used in deciding which concepts and major principles to include and deciding the strength of emphasis suitable, were as follows:

1. Is the idea so important in modern chemistry that a first course would be incomplete without it?

2. Can the idea be developed honestly to be comprehensible to high school students?

3. Is the idea essential to other major ideas in the course?

4. Can the idea be developed from the high school students' experimental results or from data that these students can understand?

There was uncertainty about the emphasis that should be placed on industrial applications. In response to feedback from trial schools, a problem on manufacture of sulfuric acid was introduced in Chapter 13, as well as other problems involving industrial processes. The film, "Bromine - Element from the Sea" was produced.

There were decisions to be made about inclusion of unstable, recently-discovered compounds, about suitable depth of algebraic treatment of gas laws and equilibrium, about interpretation of the mole concept, and about depth of treatment of the topic of radioactivity. Many secondary school teachers felt that the concept of oxidation potential (E^o) was too difficult for high school students, but they were over-ruled. Teacher experience has since shown that E^o should be in the course.

Noteworthy Omissions of Topics

Concepts that were considered but were omitted in the final edition are the following (Merrill and Ridgway, pp. 31-32).

1. Quantitative use of colligative properties was omitted because molecular weights and support for the theory of ionization were developed through other evidence. Molality was also excluded because it would not be used.

2. The perfect gas equation, PV=nRT, was omitted since the broader idea of the kinetic energy of molecules, used in the study of reaction kinetics, was considered more effective for this course.

3. Lewis acid-base theory was omitted from the acid-base chapter because it is not useful later in the course and because the necessary underlying concepts are not developed until later in the book.

4. Normality and equivalent weights are omitted because they would not be useful to the beginning student. Balanced equations and the mole concept are used instead, in solving problems that could otherwise be handled using normality and equivalent weights.

5. The Bohr planetary model of the atom was not included because it is of historical interest only and is no longer useful to chemists. It was felt that the Bohr model would interfere with the learning of a model based on modern evidence.

6. Electronegativity was omitted because differences in ionization energy were sufficient to explain bond polarity.

7. The Born-Haber cycle, to analyze energy effects on bonding, was omitted because students were drawing mistaken ideas from it about reaction mechanisms and bonding.

8. Valence (as a noun) was not used since it has too many meanings. The terms ionic charge, bonding capacity, oxidation number, and coordination number were used instead.

Advanced Topics Included

Some advanced topics are included in the final edition of CHEM Study.

1. Discussion of inert gases was altered to include the compounds discovered in 1962.

2. Nuclear reactions were given more thorough treatment since PSSC physics ignored the topic.

Certain advanced topics were introduced which had previously not been presented at all in the prescribed high school chemistry curricula, at least in some parts of Canada, including Ontario. These topics are as follows:

1. The concept of heat of reaction, quantitatively interpreted, including determination of heat of reaction in experiments and problems

2. Concepts of activation energy and threshold energy and their graphical representation

3. Explanation of catalytic function in terms of a new mechanism

4. Quantitative treatment of chemical equilibria and solubility equilibria and interpretation and calculation of the associated constants

5. Qualitative idea of entropy and use of the concept of opposing drives toward minimum energy and maximum randomness to explain solubility equilibria

6. Bronsted-Lowry theory of acids and bases

7. Concept of oxidation potential and its use in determining whether a redox reaction will proceed and in balancing equations

8. Determination of quantitative characteristics of light given off or absorbed by atoms whose electrons move to different energy levels

9. Interpretation and study of ionization energies and the resulting effect on bond type and ionic character

10. Atomic orbitals and their orientation in space and the resulting shapes of molecules

11. Mole concept.

The Table of Contents from the Freeman version (Appendix A) gives the form of presentation that was finally selected.

CHEM Study Publications and Films

Production of the CHEM Study textbook was the major task. The first two-thirds of the book emphasizes chemical concepts, principles, and theories and the last third applies them in dealing with descriptive chemistry.

The laboratory manual emphasizes the discovery approach and enables the student to observe chemical systems, and gather data for development of principles which are subsequently discussed in the textbook.

The Teachers Guide is largely based on requests for help expressed by teachers in the trial years (1960-63). It is practical and detailed, providing help in lesson and laboratory preparation, enrichment material for gifted students, and a variety of quiz questions for student tests.

Two sets of multiple-choice achievement tests have been published. They are open-book tests that attempt to measure whether a student can interpret experimental data and whether he understands significant concepts and can apply them to new situations. Each set of seven tests covers Chapters 1-17. Statistical analysis was done on the test items and adjustments were made to establish an intended average raw score of 60% (Merrill and Ridgway, p. 36).

Other printed materials include charts produced and distributed by Welch Scientific Company and Central Scientific Company, based on the CHEM Study textbook and programmed instruction pamphlets on use of the slide rule and on exponential notation. Two books were written as extensions of CHEM Study course materials - Man-Made Transuranium Elements by Glenn T. Seaborg and Why Do Chemical Reactions Occur? by J. Arthur Campbell. The CHEMS Newsletter, started in November, 1960, is still being distributed free of charge on request.

Twenty-seven films were produced to be used as teaching tools. These films show experiments that the teacher would find difficult or impossible to demonstrate in the classroom due to expense, extreme size, extreme speed, danger, time limitations, or complexity. Many of them clarify mental models of structure or dynamic process through animation. A teacher's guide to the films is available from Modern Learning Aids, New York. A total of 15 lecture films were developed for training teachers who had not attended CHEM Study Institutes. Two ½-hour televized panel discussions between CHEM Study staff and high school teachers are also available in film.

Adoption

CHEM Study is used by approximately 50% of chemistry students in the United States (Merrill and Ridgway, p. 73). There were twelve different foreign-language translations of all or parts of the textbook authorized by December, 1968, including Chinese, French, Hebrew, Hindi, and Spanish.

In 1968, the Russian translation of the textbook appeared, unauthorized by the Study. The preface indicated that it was translated "at the recommendation of the greatest scientists of the Academy of Science of the USSR and the Academy of Pedagogic Sciences of the RSFSR (Merrill and Ridgway, p. 54).

By 1967, income from the CHEM Study materials exceeded the $2,800,000 total National Science Foundation grants and this amount had been returned to the U.S. Treasury. The project has more than paid for itself.

Part of the impact of CHEM Study is probably related to the discoveries that CHEM Study students have a distinct advantage in selective courses[1] at universities and that a smaller proportion of CHEM Study students than traditional-course students drop out of university chemistry courses. This improved completion record suggests that they are more persistent and more interested in chemistry because of their background (Merrill and Ridgway, p. 66).

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[1] In universities where a qualifying screening test is required for science entrance.

Van Cleave[1] (1970) has reported that most university students in Saskatchewan who are graduates of traditional high-school chemistry find themselves at a distinct disadvantage when they must compete with students having a CHEM Study background. The traditional course still exists because teachers are authorized to use CHEM Study in Saskatchewan schools only if they have at least two university courses in chemistry plus a six-week up-dating course, specifically related to CHEM Study. In 1968, 32% of Grade 11 students and 41% of Grade 12 students were completing the traditional course.

On the Regina Campus, the student who has received a grade of more than 70% in CHEM Study is placed a semester ahead of his counterpart who has taken traditional chemistry, unless the latter performs very well in a special examination. In Saskatoon, where there is no semester system, both groups of students are in the same first-year chemistry class. The result is a high dropout and failure rate among Grade 12 graduates of the traditional course. These Canadian records indicate that the CHEM Study graduate is better prepared for university chemistry.

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[1]Professor of Chemistry, University of Saskatchewan, Regina.

Origin of the Three Revisions

The CHEM Study was perceived as a temporary task force. In October, 1965, the Steering Committee invited publishers to submit proposals for revising the textbook, laboratory manual, and teacher's guide, to ensure that CHEM Study would not become a "new orthodoxy" or a "national curriculum". It was decided that three views would give "maximum assurance of a variety of revisions in terms of their different direction and levels of sophistication" (Merrill and Ridgway, p. 72).

Proposals from the applicants were to include statements concerning the nature of revisions contemplated so that there would be substantial changes made (Merrill and Ridgway, p. 71). The main criteria for selection were the scientific competence, writing ability, and teaching experience of the chemists and teachers, and the standing and experience of the publisher in high school textbook publication and distribution.

An examination of the selected authors' statements of what they hoped to accomplish is worth examining in relation to their finished product.

Lynch, who was a co-author of the Houghton Mifflin book, emphasized their integration of the laboratory manual within the textbook, increase in number of drill problems related to factual information, and lack of any deliberate attempt to re-write all of the Freeman textbook.

MacNab, who was a co-author of the Raytheon book, stated that his author team attempted to overcome the "sibling transfer" difficulty in problem sets that are used from year to year by developing new problems and in increased number so that they could be divided into sets to be used in separate years. He noted that the Raytheon book relies more heavily on diagrams and charts and less on photographs, to increase efficiency in emphasizing important factors.

Parry, a co-author of the Prentice-Hall book, states that their book is a complete re-write, which gives another approach to the CHEM Study philosophy (CHEMS Newsletter, 1969).

CHAPTER III

DETAILED COMPARISON OF FREEMAN VERSION WITH THE THREE REVISIONS: FUNDAMENTAL CONCEPTS IN CHEMISTRY

Chapters 1 to 6 of the Freeman version deal with fundamental concepts in chemistry including scientific method, atomic theory, chemical reactions, the gas phase, liquid and solid phases, structure of the atom, and the periodic table.

The sequence of topics in this chapter of the thesis will be taken from the Freeman text. A detailed comparison will be made first between Chapter 1 of the Freeman version and the parallel treatment given to the same body of knowledge in the three revisions, to identify the specific differences in the information presented. From the laboratory manuals, experiments relevant to Chapter 1 of Freeman will be examined. Then the contrasting items will be listed in condensed form in tables. This procedure will be followed for each of the chapters from the Freeman version.

Scientific Method

Chapter 1 of the Freeman version discusses the basic activities of science: observation, organization of information, seeking regularities, finding explanations of the regularities, and communicating the findings. Variations in approach in the four versions occur in their illustration of the search for regularities.

The Freeman edition uses a fable about a child, lost and feeling cold. The child collected some materials and started a fire. By observing the fire, he could generalize that cylindrical objects burn. When he observed ginger ale bottles and pieces of pipe that were placed on the fire, he had to discard this rule. A new theory of burnable objects could then be formed, based on the composition rather than the shape of objects. In science too, a theory is retained only as long as it agrees with the known facts or aids in organizing knowledge. The Raytheon textbook uses this same fable. The Prentice-Hall version uses a variation of the same fable, about Martin, the Martian, who has landed on earth, is cold, and starts a fire with glowing cylinders left from a fire built by earthlings. Prentice-Hall emphasizes the provisional nature of scientific theories by reference to the pre-1962 definition of rare gases - those composed of inert atoms. This concept was destroyed in 1962 by Bartlett's discovery of the reactivity of xenon. The Houghton Mifflin version omits the fable as the authors felt that the students were sensitive about being talked down to, and that the story was too naive for grade eleven age level (CHEMS Newsletter, June, 1969). The Houghton Mifflin version merely states that through systematic study of data, patterns or regularities become apparent which will enable the student to predict future results.

In the Prentice-Hall version (textbook, p. 4), an excerpt from a Sherlock Holmes mystery is quoted to indicate that keen powers of observation, requiring concentration, alertness to detail, patience and practice, are essential to the detective. It is advised that the scientist must be as observant as a detective.

A variety of models are used to explain the behaviour of gases. These explanations are to be found in Chapter 1 of each textbook. Both Freeman and Houghton Mifflin use the analogy of a billiard ball striking the cushion of the billiard table and rebounding to represent a molecule of gas experiencing elastic collision. Prentice-Hall uses "super rubber" balls in a container, while Raytheon uses steel ball bearings shaken in a plastic box.

In explaining uncertainty in derived quantities, all versions except Raytheon agree that uncertainty in a product or quotient is the sum of percentage uncertainties of the components. The Raytheon laboratory manual and textbook contradict each other. The laboratory manual defines percentage uncertainty in the same way as Freeman, but the textbook states that percentage uncertainty in a product or quotient equals the percentage uncertainty in the least certain component used.

In the Freeman, Raytheon, and Prentice-Hall versions, the metric system, density, use of exponential numbers, and discussion of uncertainty are given in the laboratory manuals with application questions for the student. Houghton Mifflin deals with these topics in Chapter 2 of the textbook only, since the laboratory experiments are integrated directly into the textbook in this version.

There is considerable variety in questions at the end of Chapter 1. Questions in Freeman require the student to have knowledge of the burning candle. Raytheon provides 23 questions involving such topics as controlled experiments, noting regularities, gas pressure, and Archimedes' Principle. Houghton Mifflin's 14 questions examine general and specific use of scientific method. Prentice-Hall supplies 6 questions - on gas pressure, uncertainty, and the candle.

The laboratory work for Chapter 1 involves some additions in the Raytheon version and a reduced number of experiments in Houghton Mifflin as compared with Freeman. There are six experiments in the Freeman laboratory manual that are relevant to Chapter 1 of the textbook. In all four versions, the observations of a burning candle constitute the first experiment. Raytheon does not give instruction in the use of the Bunsen burner.

All versions except Raytheon investigate the behaviour of solids on warming. The technique in Houghton Mifflin and Freeman requires the use of a tin can lid on which the samples are placed for heating. The student must determine the order of melting when a candle is placed under the centre of the lid and when a Bunsen flame is placed under the centre of the lid. Dr. Giesinger[1] has observed that some students who have completed university courses in chemistry are unable to list the seven substances in order of increasing melting points after they have completed this experiment. It is too difficult to observe seven substances at once.

The Prentice-Hall manual directs that each material is to be held in the flame in turn, with tongs, instead of being placed on a lid. The student must divide the substances into the following three groups: substances melted by the candle flame, substances melted by the Bunsen flame but not by the candle flame, and substances melted by neither of the two flames. This method exercises the student's skill in making

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[1]From discussion, February, 1970, with Dr. Giesinger, Professor of Chemistry Methods, Faculty of Education, University of Manitoba.

observations much less than the Freeman method does. The use of tongs will produce messy results when the molten wax and sulfur samples fall into the candle and into the barrel of the burner. For these reasons, the tin can lid is a better piece of equipment than tongs for this experiment.

Dr. Giesinger has suggested that the published methods for the experiment should be revised. The seven samples could be divided into three groups. One group would consist of substances that are melted by a candle flame. These substances (wax and sulfur) would be placed on the lid equidistant from the centre, the flame would be applied, and the order of melting could be observed. Since the melting point of wax is lowest, it is not necessary to heat the sulfur beyond its melting point and the quantity of irritating gas, sulfur dioxide, produced can be minimized. (With the Freeman method, in the process of melting tin, lead, and silver chloride in the Bunsen flame, the sulfur is burned, producing enough sulfur dioxide to make breathing difficult). Another group of samples, consisting of substances that can be melted by the Bunsen flame, would then be placed on a clean tin can lid and tested first with the candle flame and then with the Bunsen flame so that their order of melting could be observed. The remaining group of samples, whose melting points are higher than the temperature of the Bunsen flame, should be tested on a clean lid by exposure to the candle flame and Bunsen flame. Only Prentice-Hall includes in this experiment the observation of a coil of copper wire lowered into a candle flame.

An experiment in Raytheon examines the interaction between aluminum foil and an aqueous solution of a blue solid (cupric chloride). In all four versions, one experiment investigates the melting point of _p_-dichlorobenzene. Houghton Mifflin provides a diagram of the labelled axes for the graph to be drawn plotting temperature against time. Raytheon introduces an experiment that does not appear in the other versions, requiring determination of densities of metals.

In Houghton Mifflin and Prentice-Hall, there is an experiment in identification of products of combustion of a candle. Raytheon's experiment dealing with the relation between the apparent mass of an object in water and in air (a discovery of Archimedes' Principle) is not in the other versions.

An experiment in all versions except Raytheon consists of comparison between energy involved in phase change and chemical change per gram of wax. Raytheon includes only determination of heat of combustion of wax. Freeman and Prentice-Hall provide an experiment that further investigates a burning candle using glass tubing and a match, cardboard, aluminum foil, and various wicks. Freeman also uses the copper coil for the same test as in Prentice-Hall's experiment on the warming of solids.

Summary

Table 1. Comparison of Chapter 1 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated: Regularities	Gas molecules	% uncertainty, in prods. & quotients	Additional	Chapter-end exercises
Freeman	lost child fable	billiard ball model	from 2 components		15 (candle)
Raytheon	lost child fable	ball bearings model	text contradicts lab. manual		23 (varied)
Houghton Mifflin	no fable	billiard ball model	from 2 components	lab. work all in textbook	14 (varied)
Prentice-Hall	Martin, the Martian	super-rubber ball model	from 2 components	Sherlock Holmes story	6 (varied)

Table 2. Comparison of Experiments in the Four Versions, Relevant to Chapter 1 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.[1]	P-H.[2]
Burning candle	1[3]	1	1	1
Warming of solids	2		2	2
p-dichlorobenzene	3	12	3	3
Candle, combustion prods.	4		4	S-1
Phase change vs. chem. change	5	25 (chem)	5	9
Tests on burning candle	4a			S-2
Interaction		2		
Density of metal		3		
Buoyancy of fluids		4		

[1]H.M. represents Houghton Mifflin.

[2]P-H. represents Prentice-Hall.

[3]Each entry in the body of the table identifies the experiment as numbered in the laboratory manual.

The Atomic Theory

In Chapter 2 of the Freeman version, the atomic theory[1] accounts for the pressure-volume relationships and other characteristics of gases. There is explanation of the combination of atoms to form molecules, each type of gaseous molecular substance having its own density at a given temperature and pressure. Data on the combining volumes of ammonia and hydrogen chloride gases are used to introduce Avogadro's Hypothesis, which leads to the concept of relative weights of molecules. Data on combining volumes of gases (such as two volumes of hydrogen and one volume of oxygen yield two volumes of water vapour) are used to predict the formulas of reactant molecules. Intermolecular distances in the three different phases of a given compound are compared. Terms such as element, compound, chemical formula, mole, atomic weight, and molecular weight are given definitions which are reinforced with examples.

Comparison of the four versions reveals that Freeman and Houghton Mifflin have a different definition of "molecular weight" than Prentice-Hall has. The Raytheon version avoids the term by introducing another term, "molar mass". The Freeman version (textbook, p. 33) states that the "molecular weight of a compound is the weight in grams of Avogadro's number of molecules". Houghton Mifflin (textbook, p. 57) states that it is "the weight in grams of a mole (an Avogadro's number of molecules) of the substance".

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[1]"Atomic theory" is used in the sense of "particle theory" to explain the physical properties of gases. The correct name for the Freeman "Proposal" (textbook, p. 28) is "kinetic-molecular theory".

Prentice-Hall (textbook, p. 43) identifies molecular weight of a substance as the "relative mass of a molecule of the substance expressed on a scale on which the oxygen molecule is assigned a value of 32.00 amu". The atomic mass unit is calculated in a footnote to be $1.66X10^{-24}g$ (textbook, p. 34). This unit does not appear in the other three versions. Raytheon (textbook, p. 33) states that "molar mass of an element or of a compound in the molecular state is the mass of N molecules".

There is disagreement between the textbooks in the interpretation of "atomic weight", for which Raytheon substitutes "molar mass of an element in the atomic state". Prentice-Hall (p. 43) gives atomic weight of an atom as "relative mass of that atom expressed on a scale in which an oxygen atom is assigned a value of 16.00". One mole of atoms "has a mass equal to the atomic weight of the element expressed in grams. For oxygen the atomic weight is 16.00. One mole of oxygen atoms has a mass of 16.00g".

Prentice-Hall is the only version that discusses the new atomic weight standard that was accepted in 1961. Until 1961, physicists and chemists had separate atomic weight scales. Largely through the efforts of Edward Wichers (Prentice-Hall textbook, p. 45), the new scale of atomic weights based on the carbon-12 standard assigned a value of 12.000000 was accepted in 1961.

Prentice-Hall (textbook, pp. 32-33) emphasizes the arbitrary weight standard assigned to molecules. For example, CO_2 might have been given a weight of 1 or of 22, but was taken as 44 so that the lightest atom, the hydrogen atom, has a weight of 1.0.

The concept of molar volume of gases is developed for oxygen at STP in Houghton Mifflin (textbook, p. 59), and for four different gases including oxygen at STP, in Prentice-Hall (textbook, p. 35).

To illustrate Boyle's Law, Prentice-Hall (textbook, pp. 22-24) uses a direct method. More and more bricks are supported on the plunger of a vertically-held syringe, compressing the gas in the cylinder of the plastic syringe. In Table 2-2, where the data are recorded, the products, pressure x volume, from the experimental values are not identical numerical values, but their range is within the limits of acceptable error. Houghton Mifflin (p. 45) uses Boyle's J-tube to demonstrate the same law and the products given in Table 3-1 for PxV are not identical numerical values here either although there is agreement within the limits of acceptable error. Freeman (textbook, p. 19) and Raytheon (textbook, pp. 21-22) show all their PV products as being identical numerical values for a given sample of gas. It is worthwhile to consider which presentation is preferable for the purpose of giving the student some realistic concept of the type of data he should be producing in his experiments. The question of influence on integrity of character of the student may even be involved, in a subtle way.

In Chapter 2, Prentice-Hall gives the rules for naming binary compounds and also introduces the prefix system for naming two or more compounds of the same two elements. Freeman and Raytheon give the prefix system but no rules for naming binary compounds. In the Houghton Mifflin version, the general rules for writing formulas without using oxidation numbers are in Chapter 4. Here also are the rules for balancing equations, with three ways of interpreting equations.

In Chapter 3, Houghton Mifflin introduces partial pressure and Charles' Law, which appear in a later chapter in the other textbooks. Houghton Mifflin (p. 42) introduces a pressure unit called the Torr (for Torricelli) which does not appear in the other three versions (1 Torr = 1/760 atmosphere).

At the end of Chapter 2, Freeman has 31 questions and problems. Raytheon has 42 - of which 27 are from Freeman (or 64%) and 15 differ. Houghton Mifflin, Chapter 4, has 48 questions and problems of which 14 are from Freeman (or 29% of the total). Prentice-Hall, Chapter 2, ends with 26 questions and problems of which 19 (or 66%) are from Freeman.

The numbers of questions repeated from Freeman in the revisions are given in Appendix B for the benefit of teachers who are using Freeman as their main textbook and the three revisions as sources of additional problems for students. To save time and energy when choosing a variety of problems for students to solve, teachers can mark the letter F in a given revision beside each problem or question that also appears in the Freeman textbook. In this thesis, the percentage of chapter-end questions copied from Freeman are consistently given just preceding the summary-table of laboratory work relevant to a chapter in the Freeman textbook.

In the laboratory work, Prentice-Hall's experiment on behaviour of gases is not in the other three versions. In this experiment, identical books are stacked on the plunger of a syringe that has its needle-end sealed off by a rubber stopper. The syringe is supported in a vertical position by a clamp. Qualitative observations can be made of the compressibility of the gases and a quantitative relationship between gas pressure and gas volume can be determined.

The procedure for determining weights of equal volumes of gases involves finding the weight of oxygen in a plastic bag, then the weight of carbon dioxide that the same bag would hold. The volume of the bag is determined so that correction may be made for the buoyancy of air.

The behaviour of solid copper in an aqueous solution of silver nitrate is examined in all four versions. For the Houghton Mifflin and Freeman procedures, the reaction vessel is a beaker whereas in the other two versions it is a test-tube. If the beaker method is used, the copper wire must be left in the solution overnight rather than approximately thirty minutes. In Houghton Mifflin, 5 ml dilute $AgNO_{3(aq)}$ is added to the separated silver crystals to ensure that all copper has reacted. In Prentice-Hall, the silver crystals are collected and dried in a filter paper cone but in the other three versions they are dried in a beaker.

The three revisions have added a few additional experiments. Raytheon has an experiment involving reaction between iron and copper sulphate solution to determine the ratio moles of iron: moles of copper for the reaction.

In Houghton Mifflin there is a study of the decomposition of sugar by heat. Prentice-Hall provides direction for construction of models of methane-related molecules and models of elements and compounds from styrofoam balls and pipe-cleaners to illustrate the balancing of equations. Also, spheres are weighed to study relative, atomic, and molecular weights.

Summary

Table 3. Comparison of Chapter 2 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated: Molecular wt. represents	PV products, gas sample	Naming	Additional	Chapter-end exercises
Freeman	1 mole	identical	prefix system		31
Raytheon	substitute molar mass	identical	prefix		42 (64% from Freeman)
Houghton Mifflin	1 mole	agreement, not identical	(formula rules)	molar volumes; new unit, the Torr	48 in Ch. 4 (29% from Freeman)
Prentice-Hall	1 molecule	agreement, not identical	binary cpds, prefix	C-12 standard; atomic mass unit; molar volume	28 (66% from Freeman)

Table 4. Comparison of Experiments in the Four Versions, Relevant to Chapter 2 of Freeman Textbook

Subject of experiment	Experiment Number[1]			
	Freeman	Raytheon	H.M.	P-H.
Weights of equal volumes of gases	6	5	6	5
Mole ratio for reaction $Cu_{(s)} + AgNO_{3(aq)}$	7	7	11	7
Boyle's Law (books-syringe)				4
Mole ratio for reaction $Fe_{(s)} + CuSO_{4(aq)}$		6		
Decomposition of sugar			8	
Molecular models				6

[1]The numbers by which an experiment is identified in the respective laboratory manuals are given in order that experiments may be readily located in the manuals.

Chemical Reactions

In Chapter 3 of Freeman, chemical reaction is exemplified by the combustion of hydrogen to form water and by the decomposition of water to hydrogen and oxygen. The writing and balancing of chemical equations is explained, emphasizing that mass, in the form of atoms, is conserved in reactions. Calculations based on chemical equations are presented. Chapter 3 of Freeman corresponds with Chapter 3 in Prentice-Hall and Raytheon and with parts of Chapter 4 in Houghton Mifflin.

Prentice-Hall (textbook, p. 62) identifies chemical change by stating that the "...breaking of chemical bonds and formation of new bonds is the defining characteristic of a chemical process". Such changes in bonds are also mentioned by the Raytheon and Freeman versions.

Houghton Mifflin is the only version with no mention of the terms exothermic reaction, endothermic reaction, and heat of formation of water at this stage in the course. However, question 23 at the end of Chapter 4 involves manipulation of the heat factor in an endothermic reaction.

In Freeman's Chapter 3, there is a very brief section on calculations based on chemical reactions, with two samples illustrated. Raytheon also illustrates two such examples using the same type of format, but with a more structured solution. Houghton Mifflin does not show a solution method for problems based on equations although some are assigned at the end of Chapter 4. Prentice-Hall uses the simple unit analysis method and works out four of these problems (textbook, pp. 59-60). Prentice-Hall also uses this method (textbook, pp. 51-53) for problems on conversion of a number of molecules to moles, conversion of a weight of hydrogen gas to moles and molecules, and conversion of a volume of chlorine gas to moles of chlorine. Examples are shown below to indicate the difference between the Freeman and Prentice-Hall solution methods.

In section 3-2.3 (Freeman textbook, p. 44) there is a problem - to determine the number of moles of water produced when 68 grams of ammonia is burned, in the reaction

$$2\ NH_3 + \frac{3}{2}\ O_2 \longrightarrow N_2 + 3\ H_2O$$

One mole of ammonia weighs 17 grams.

$$\frac{68\ \text{grams}}{17\ \text{grams/mole}} = 4.0\ \text{moles of ammonia}$$

(From the chemical equation:)
2 moles of ammonia produce three moles of water
so 4 moles of ammonia produce six moles of water

We see that 68 grams (4 moles) of ammonia produce six moles of water.

In problem 2a (Prentice-Hall textbook, p. 59) the balanced equation is

$$4\ NH_3 + 5\ O_2 \longrightarrow 4\ NO + 6\ H_2O$$

How many moles of oxygen are required to burn 68 g of ammonia?

First, we might ask: How many moles of ammonia are found in 68 g of NH_3?

$$\frac{68\ g\ NH_3}{\dfrac{17\ g\ NH_3}{\text{mole}\ NH_3}} = 68\ g\ NH_3 \times \frac{1\ \text{mole}\ NH_3}{17\ g\ NH_3}$$

$$= \frac{68}{17}\ \text{moles}\ NH_3 = 4.0\ \text{moles}\ NH_3$$

The balanced equation now tells us that 5.0 moles O_2 will be needed to burn 68 g of ammonia.

At the end of Chapter 3, Freeman has 19 questions and problems. Raytheon provides 31, of which 23 are from Chapters 3 and 13 of Freeman. The questions for Chapter 4 of Houghton Mifflin have been discussed in Table 3 of this thesis. Prentice-Hall supplies 24 questions and problems at the end of Chapter 3, 16 of which are from Freeman.

The laboratory work in all four versions contains an experiment on conservation of mass, in which the total weight of $AgNO_3$ and NaCl reactants is compared with the total weight of the products of the reaction. Freeman and Prentice-Hall have a supplementary experiment on conservation of mass, involving the reaction between lead (II) nitrate and potassium chromate.

In all versions, there is an experiment to determine the formula of a hydrate by heating it to drive off all the water. The weight of one mole of the anhydrous salt is given by the teacher. Raytheon (laboratory manual, pp. 27-28) shows a simple desiccator - for cooling the anhydrous salt - consisting of a large jar containing the drying agent and a clay triangle with the three wire extensions bent to form legs so that the crucible can be securely supported in the jar on the triangle. The jar is sealed with a lid. This arrangement is an effective improvisation.

Summary

Table 5. Comparison of Chapter 3 of Freeman Textbook with Corresponding Material in the Three Revisions

	Topics treated		
Version	Chemical reaction	Calculations re equations	Chapter-end exercises
Freeman	bonds break + form	brief problem method	19
Raytheon	bonds break + form	structured problem method	31 (74% from Freeman)
Houghton Mifflin	no mention of bonds	no problem method	See Table 3, this thesis
Prentice-Hall	bonds break + form	simple unit analysis method	24 (67% from Freeman)

Table 6. Comparison of Experiments in the Four Versions, Relevant to Chapter 3 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Conservation of mass ($AgNO_3 + NaCl \rightarrow ...$)	8	8	12	8
Conservation of mass ($Pb(NO_3)_2 + K_2CrO_4 \rightarrow ...$)	8a			S-3
Formula of a hydrate	8b	9	S-1	S-4

The Gas Phase: Kinetic Theory

Chapter 4 of the Freeman textbook examines properties of gases that are the basis for development of the kinetic molecular theory. The pressure-volume behaviour suggests that gases consist of particles. Differences in solubility, colour, odour, and density show that particles of one gas differ from particles of another gas. Determination of molecular weight and molecular formula of a gas are possible through application of Avogadro's Hypothesis. Real gases approximate perfect gas behaviour to three significant figures at standard temperature and pressure (Freeman textbook, p. 61). The absolute temperature scale is introduced in Chapter 4 and its relationship to the kinetic energy of molecules is described.

The Freeman, Raytheon, and Prentice-Hall versions record the molar volume of a molecular species in each of the three states of matter. Prentice-Hall (textbook, p. 68) points out, "If we assume that the size of a molecule itself does not change significantly ... free space between gaseous molecules must be about 650 times larger than the space between the liquid molecules". This deduction is based on comparison of molar volume of gaseous nitrogen (22.4 litres at STP) and liquid nitrogen (34.6 ml at approximately -210°C.). Molar volumes of four different gases at 25°C. and 1 atmosphere pressure are determined from experimental data in Freeman (p. 51) and Prentice-Hall (p. 71).

Houghton Mifflin continues to express gas pressure in Torr. One Torr is the pressure exerted by a column of pure mercury one millimetre high at 0°C at sea level and 45° latitude (Houghton Mifflin textbook, p. 42). To express pressures of much less than one atmosphere, the Torr is a much more convenient unit than the atmosphere. The Torr is also a less confusing pressure unit than the millimetre of mercury since the millimetre is a unit of length. However, Torr is used only in the Houghton Mifflin version.

To explain partial pressure of a gas, all four versions have similar illustrative approaches to the extent that one vessel or compartment contains gas 1, another vessel or compartment contains gas 2, and the two samples are combined to form a gas mixture. In Houghton Mifflin (p. 58) and Freeman (p. 55), the volume of the gas mixture is equal to the volume of the gas 1 sample, which is equal to the volume of the gas 2 sample, all measured at the same temperature. Thus, the total pressure exerted by the mixture will be the sum of the pressures in the two original samples. The partial pressure of each gas is the pressure that it would exert if it alone occupied the container.

Illustrations of the partial pressure concept in Raytheon (p. 56) and Prentice-Hall (p. 78) show the volume of the gas mixture to be the sum of the original volumes of the gas 1 sample and the gas 2 sample. Since the original samples were both at the same temperature and pressure, the gas mixture will have the same total pressure as each component gas had separately before mixing. The partial pressure due to a given component gas within the mixture will be less than the pressure that was exerted by that component gas in the smaller volume occupied before mixing occurred. The partial pressure of each component gas in the mixture can be determined by substitution into Boyle's Law which states that the produce of pressure times volume is constant for a given sample of gas (Prentice-Hall, p. 78). Both of these types of partial pressure interpretations should be understood by the student since the volume occupied by a component gas may or may not change when the gas enters into a mixture.

Specific values of molecular speed are supplied by all versions except Houghton Mifflin. Freeman states that at room temperature, the average speed of nitrogen molecules is ¼-mile per second. Raytheon (textbook, pp. 63-65) describes a rotating disc experiment to measure velocity of tin molecules and provides a table (p. 65) indicating average velocities of five different types of molecules in the gaseous state along with escape velocity from earth's gravitational field and velocity of a jet airplane, for comparison.

In Freeman and Prentice-Hall, properties of matter at temperatures near $0^{o}K$ are discussed, such as superconductivity of some metals. It is stated that if helium is subjected to reduced pressure it will boil at a temperature lower than its normal $4^{o}K$ boiling point, providing a means of reaching temperatures near $1^{o}K$.

Freeman (textbook, p. 59) and Prentice-Hall (textbook, pp. 87-88) use the kinetic theory to prove Avogadro's Hypothesis. Prentice-Hall develops the ideal gas law, PV = nRT, from Boyle's Law (pp. 82-84) and also from the kinetic theory. The other three versions do not mention the ideal gas law.

At the end of Chapter 4, Freeman provides 28 questions and problems to test student knowledge of the gas phase. Raytheon lists 31 exercises, of which 30 are from Chapters 4 and 13 of Freeman. Chapter 3 of Houghton Mifflin supplies 21 questions, of which 9 are from Chapter 4 of Freeman, and 24 problems, 11 of which are from Freeman. Prentice-Hall provides 27 questions and problems at the end of Chapter 4, 23 of which are from Freeman.

The laboratory work in all four versions contains an experiment to determine the molar volume of hydrogen gas. This determination is based on the reaction of a known mass of magnesium with excess hydrochloric acid. The volume of hydrogen produced at the known temperature and pressure is recorded. Given the fact that 1 mole of Mg reacts to produce 1 mole of H_2, the student can determine the molar volume of dry hydrogen at room conditions.

Raytheon provides an experiment to determine the temperature-volume relationship for gases (Charles' Law) using a capillary tube containing air trapped by a plug of mercury. The temperature of the trapped air is regulated by a water bath. The length of the air column (representing the volume of air) is recorded for each temperature that is uniformly established throughout the water bath. A line graph can be constructed with temperature plotted against volume of gas. By extrapolation, the temperature corresponding with zero volume of air can be determined and the temperature-volume relationship can then be expressed mathematically.

Summary

Table 7. Comparison of Chapter 4 of Freeman Textbook with Corresponding Material in the Three Revisions

	Topics treated			
Version	Molar volumes	Partial pressure	Additional	Chapter-end exercises
Freeman	N_2 (3 states) 4 different gases	Constant volume	properties near 0^oK molecular velocity, N_2 Avog. Hypoth. proof	28
Raytheon	NH_3 (3 states)	vol. of gas mixture $>$ vol. of component before mixing	molecular vel., 5 gases molecular vel., measurement	31 (97% from Freeman)
Houghton Mifflin		constant volume	Torr	21 (43% from Freeman)
Prentice-Hall	N_2 (3 states) 4 different gases	vol. of mixture $>$ vol. of component before mixing	properties near 0^oK molecular vel., N_2 $PV = nRT$ Avog. Hypoth. proof	27 (85% from Freeman)

Table 8. Comparison of Experiments in the Four Versions, Relevant to Chapter 4 of the Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Molar volume of H_2	9	11	7	10
Charles' Law		10		

Liquids and Solids: Condensed Phases of Matter

Chapter 5 in the Freeman version is a study of the types of liquids and solids known to man. More than ninety-nine percent of compounds prepared by chemists are liquids and solids. Chapter 5 of Freeman examines the properties of pure substances and of solutions and then describes the electrical properties of the condensed phases.

The presentations of these topics in the three textbook revisions contain little variation from the facts given in Freeman. However, in two of the revisions, as the next few pages will show, there is a greater effort to make the new concepts meaningful to the high school student by deliberately integrating them with his previously acquired knowledge of chemistry. It seems reasonable to conclude that this integration will facilitate comprehension and retention of the concepts.

The descriptions of phase change from gas to liquid illustrate the two types of presentation. Freeman (textbook, p. 66) simply states, "When water vapour condenses to liquid water, the molecules release the energy it took to separate them". The quantity of heat energy released is given as 10 kcal per mole. Prentice-Hall also uses this approach, but Houghton Mifflin does not deal with the topic. Raytheon (textbook, p. 71) clearly describes the phase change from gas to liquid in molecular terms as follows:

> The average kinetic energy of gas molecules is large enough to overcome the attractive forces between molecules. As the temperature is lowered, the kinetic energy of the gas molecules

decreases. Eventually the attractive forces between the molecules become important relative to the kinetic energy of the molecules.
- The gas condenses to a liquid.

In describing the molecular behaviour associated with boiling, Raytheon (p. 76) states that the energy to vaporize a liquid at its boiling point is being used to overcome attractive forces in the liquid, forcing the molecules far apart. The molecules of vapour store potential energy by being far apart, while still maintaining the same temperature and therefore the same kinetic energy as the boiling liquid. The other three versions do not interpret the phenomenon of heat of vaporization on a microscopic (molecular) scale.

The influence exerted on vapour pressure of a liquid by the presence of "inert" gases mixed with the vapour in the liquid-vapour equilibrium is described by Prentice-Hall (textbook, p. 102) in the following way. The "inert" gas molecules (which are molecules that do not react or condense in the system) block equally, by collision, the molecules that are returning to the liquid state and molecules escaping from the liquid state. Thus, the "inert" molecules slow down the rate of evaporation and condensation but they do not alter the partial pressure of the vapour (vapour pressure). In contrast, Houghton Mifflin (textbook, p. 330), and Freeman (p. 67) give the same type of account as Raytheon (p. 78) which says, "The vapour pressure of a liquid is the same whether or not other gases are present. It is a property of the liquid." This is a more authoritarian approach, with no account being given of the effect produced by the "inert" gases.

Raytheon (p. 78) and Prentice-Hall (p. 101) both account, in molecular terms, for the increase in vapour pressure of a liquid as temperature increases. They state that increase in temperature of the liquid is associated with increase in average kinetic energy of molecules, which enables a larger number of molecules to overcome the forces of attraction in the liquid and escape into the vapour. Thus, vapour pressure will increase with temperature. Freeman and Houghton Mifflin simply make the authoritarian statement that vapour pressure of every liquid increases as temperature is raised, and give a few measurements to illustrate the fact.

Prentice-Hall (p. 101) explains differences in vapour pressure in terms of attractions. Consider two liquids which are both at the same temperature. The liquid which has the stronger intermolecular forces will have the lower vapour pressure. Prentice-Hall (p. 109) accounts in a similar way for the vapour pressure of salt solution being lower and therefore the boiling point of the salt solution being higher than for pure water, because the water molecules are restricted in motion by their attraction for the dissolved salt. Additional heat energy is required to overcome this attraction. The other three versions (Raytheon, Freeman, and Houghton Mifflin) give no explanation of the differences in vapour pressure for different substances at the same temperature.

Raytheon (p. 73) is the only version that gives a description of melting in terms of molecular behaviour. Raytheon (pp. 85-86) explains the continuing decrease in temperature, while freezing continues in a salt solution, as resulting from the fact that the frozen product being formed contains no solute. Houghton Mifflin (p. 241) is the only version to quantitatively represent the extent that freezing point is depressed by dissolved solutes.

Prentice-Hall (p. 103) is the only version which describes the pressure inside vapour bubbles in a boiling liquid as being slightly higher than the atmospheric pressure. This excess is associated with the bubbles' growth and rise to the surface.

Prentice-Hall (p. 96) identifies ideal behaviour of a gas as being possible only in the absence of intermolecular force. Gases with relatively low molar volume compared with 22.414 litres at STP, will deviate most from ideal behaviour, since intermolecular attraction will be greater and therefore tendency to liquefy will be greater.

At the end of Chapter 5, Freeman provides 32 questions and problems on condensed phases. Raytheon, Chapter 5, gives 30 questions, 10 of which are from Freeman, and Chapter 6 ends with 38 questions, 18 of which are from Freeman. Houghton Mifflin has corresponding problems scattered among its Chapters 5, 10, 14 and 15. Prentice-Hall supplies 23 questions, of which 17 are from Freeman.

The laboratory work in all four versions contains an experiment investigating a precipitation reaction between sodium iodide solution and lead (II) nitrate solution, both 0.5 molar. From the weights of precipitate produced when these reactants are mixed in various proportions by volume, the student can determine the formula of the precipitate.

Each version contains an experiment consisting of several ionic reactions requiring the student to distinguish between reacting species and spectators, so that net-ionic equations can be written.

Raytheon provides three additional experiments. These include a determination of the molar heat of fusion of ice, determination of the depression of freezing point caused by 0.0025 mole of solute in 5 grams of acetamide, and a qualitative study of energy of crystallization of sodium thiosulfate pentahydrate. The student is directed to devise a procedure for measuring the heat released when crystallization occurs.

Another experiment, provided by Prentice-Hall, examines the effect of pressure on the volume of solids and liquids and measures solubility of carbon dioxide gas in water, using a syringe method.

Summary

Table 9. Comparison of Chapter 5 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated: Vapour pressure	Topics treated: Additional	Chapter-end exercises
Freeman	authoritarian presentation		32
Raytheon	in molecular terms	P.E. and K.E. model; freezing of salt solutions; molecular interpretation of condensation, vaporization, and melting	Ch. 5:30(33% from Freeman) Ch. 6:38(71% from Freeman)
Houghton Mifflin	authoritarian presentation	solute lowers freezing point (quantitative)	scattered in H.M. Chs. 5, 10, 14, 15
Prentice-Hall	in molecular terms	boiling: vapour pressure > atm.p.; least ideal gas has lowest molar volume	Ch. 5:23(74% from Freeman)

Table 10. Comparison of Experiments in the Four Versions, Relevant to Chapter 5 of the Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Precipitation reaction, $NaI + Pb(NO_3)_2$	10	16	S-2	12
Ionic reactions	11	17	S-3	15
Heat of fusion of ice		13		
Energy of crystallization		14		
Effect of solute on freezing point		15		
Compressibility and solubility				11

Structure of the Atom and the Periodic Table

The periodic table is identified as the "most important single correlation of chemistry" (Freeman textbook, p. 104). Chapter 6 in Freeman begins with a study of atomic structure, which provides the explanation for similarity in chemical properties of elements, and thus, for the design of the periodic table.

Houghton Mifflin and Raytheon provide the most thorough historical accounts of the periodic table. Raytheon (p. 109) states that Mendeleev arranged the elements known in 1871 in the order of increasing molar mass. An element was placed in the same vertical column as other elements that have similar chemical and physical properties. Gaps which appeared in this arrangement motivated Mendeleev to predict the existence and properties of elements with molar mass near the values 44, 68, and 72 grams. These elements were discovered after 1876 and were found to have molar masses of 43.7, 69.4, and 71.9 grams respectively. Raytheon (p. 104) lists several of Mendeleev's predictions in Table 7-3 beside the observed properties of the three elements.

The grouping of elements into families is justified in Prentice-Hall (textbook, pp. 165-168) from the vantage point of modern knowledge. First ionization energies show a cyclic pattern when plotted against atomic number on a graph. The contrast between first and second ionization energies is examined in order to show family likenesses of the alkali elements. The element having the highest ionization energy in a cycle is a noble gas. Houghton Mifflin (pp. 115-116) gives a clear summary of trends present in the periodic table. Across each row, there is a range from metallic elements on the left to non-metallic elements on the right. Eleven elements, at the right and upper-right side, are gases at standard conditions. Mercury and bromine are the only elements in the liquid state at standard conditions.

The model of the atom has been revised slightly in two of the revisions and omitted in the other. Freeman (p. 88) represents the whole atom as being the size of Yankee Stadium. If this were a hydrogen atom, the nucleus (1 proton) would be the size of a flea at the centre of the stadium and the electron would wander through all the rest of the stadium. This would have been a better model if the electron had been represented macroscopically, along with the other structures. Houghton Mifflin substitutes an ant for the flea and omits the electron, since the analogy here is just meant to indicate relative sizes of nucleus and atom. Prentice-Hall (p. 42) considers that the nucleus of a chlorine atom is as a spot one centimetre in diameter at the centre of the University of Michigan Football Stadium and the electrons are as birds, flying freely within the stadium. This model is consistently macroscopic and the mobility of electrons is represented by a universally recognized model. (The "electrons", however, are only capable of moving above ground, which represents half of the total "orbital space".)

Freeman refers to the rare gases as inert gases although reference is made to the Bartlett experiment. The three revisions refer to these gases as "noble". Houghton Mifflin (p. 117) justifies its choice of adjective with the statement that "...it appears desirable to describe these as the "noble" gases just as metals such as gold and platinum which form compounds but do not react readily are called "noble metals". Raytheon (p. 111) provides a table of five noble gas compounds with a list of their chemical and physical properties and Houghton Mifflin (pp. 118-119) outlines the present-day uses of noble gases. A quotation from Bartlett, describing his historical synthesis of xenon hexafluoroplatinate in 1962, appears in Prentice-Hall (p. 170) with coloured pictures of the reactants and product (p. 171).

Both Freeman (p. 92) and Houghton Mifflin (p. 118) interpret the increase in boiling point with increasing atomic number of noble gases. The increase in boiling point is considered to be the result of an increase in attractive force between atoms. Prentice-Hall (p. 169) links this interpretation with the observation that ionization energy tends to decrease as atomic number increases among the noble gases. Thus, interactions become stronger as ionization energy decreases. The limits of this relationship need to be defined if it is to be a valid association for student reasoning, since one can observe that for alkali metals, boiling point decreases as ionization energy decreases and atomic number increases. Raytheon (p. 109) gives the most conservative explanation, stating that "... as molar mass increases, the boiling temperature increases. We interpret a higher boiling temperature to mean that more energy must be supplied to allow a molecule to leave the liquid state".

All versions except Raytheon describe the use of silver nitrate solution to test for the presence of halide ions. Properties and uses of halogens are outlined in Houghton Mifflin (p. 128).

Freeman and Houghton Mifflin describe trends in physical and chemical properties across the third row of elements in the periodic table. Prentice-Hall examines the second-row elements. Structural characteristics that correspond with metallic, network, and molecular properties are emphasized. Prentice-Hall (p. 184) accounts for the difference in reactivity of oxygen and nitrogen gases in terms of heat of formation of the molecule.

At the end of Chapter 6 in Freeman, 31 questions and problems are provided to investigate and reinforce the student's knowledge of the periodic table and atomic structure. Raytheon, Chapter 7, supplies 15 exercises, 8 of which are from Freeman; and Houghton Mifflin, Chapter 6, provides 28 exercises, 16 of which are from Freeman. There are 28 exercises at the end of Chapter 8 in Prentice-Hall, 19 of which are from Freeman.

Raytheon is the only version which has experiments that should be performed to accompany the study of the periodic table. Since the Raytheon textbook does not have a section on alkaline earth elements to correspond with Freeman's Chapter 21, three experiments relevant to Chapter 21 of Freeman are associated with study of the periodic table in Raytheon.

One of these experiments is an introduction to qualitative analysis and develops a scheme whereby an unknown solution may be identified. Another experiment makes use of slight differences in solubility of some compounds of second-column metallic elements to devise a qualitative-analysis scheme to test for calcium, barium, strontium, and magnesium ions in an unknown solution. Flame tests are performed for additional confirmation. The final experiment of the set enables the student to develop a scheme of qualitative analysis for Ag^{+}, Hg_2^{2+} and Pb^{2+} ions.

Summary

Table 11. Comparison of Chapter 6 of Freeman Textbook with Corresponding Material in the Three Revisions

	Topics treated					
Version	Periodic table	Trends in rows	Atomic model	Rare gases	Additional	Chapter-end exercises
Freeman	from chem. and phys. properties	row-3	flea, stadium, electron	inert	halide tests; no experiments	31
Raytheon	from chem. and phys. properties; Mendeleev's predictions			noble; table of compounds	3 experiments, qual. anal. #19, 20, 22	15 (53% from Freeman)
Houghton Mifflin	historical development	row-3	ant, stadium	noble; present uses	halide tests; no experiments	28 (57% from Freeman)
Prentice-Hall	from ionization energies	row-2	1-cm spot, birds, stadium	noble; Bartlett quote and pictures	halide tests; no experiments	28 (68% from Freeman)

CHAPTER IV

DETAILED COMPARISON OF FREEMAN VERSION WITH THE THREE REVISIONS: CHEMICAL PRINCIPLES

Principles of chemical reactions are extracted from the laboratory experiments that are co-ordinated with Chapters 7 through 17 of the Freeman textbook. Chemical principles of two types are investigated. Principles of chemical reactions are covered in Chapters 7 to 13, and principles of chemical bonding in Chapters 14 to 17.

Energy Effects in Chemical Reactions

Before he reads Chapter 7 in the Freeman textbook, the student should perform an experiment which permits him to develop by induction Hess's Law of Additivity of Reaction Heats. Chapter 7 in Freeman examines the energy effects caused by chemical reactions and applies the law of additivity to several reactions. Types of molecular energy and macroscopic effects of warming matter are described, ending with nuclear fusion which occurs at temperatures of several million degrees absolute. The accounts of energy effects in Freeman and Houghton Mifflin are almost identical, but Raytheon and Prentice-Hall introduce additional information that is significant.

The clearest general analysis of energy effects in chemical reactions is presented in Raytheon (p. 192) as follows:

> When a chemical reaction occurs, some bonds in molecules are broken and new bonds form. Energy is required to break a chemical bond. However, energy is released when new chemical bonds form. Almost all of the energy effects in a chemical reaction are the result of bond-breaking and bond-forming events.

Those basic concepts are required for a meaningful approach to calculations of heat of reaction. A partial equation must be selected for each reactant compound in which bonds are broken, showing the breakdown into separate elements. Also, a partial equation for the formation from its elements, of each product compound must be used in determining the heat of the overall reaction.

Before specific quantitative detail is presented, Prentice-Hall (p. 191) summarizes the general qualitative observations for the preparation of water gas. Qualitatively, energy is absorbed when water vapour combines with hot coke to form water gas, and energy is liberated when coke burns in oxygen (to produce heat for the reaction of hot coke with water vapour). With those generalities established, the relevance of the quantitative details can be clearly perceived by the student while the details are being presented. Freeman does not isolate the generalities first, but proceeds directly into specific quantitative description.

The table of energy changes involved in the manufacture and use of water gas is more self-contained in Prentice-Hall (p. 193) and Raytheon (p. 194) since the equations for the four reactions are given in the table. Freeman (p. 109) and Houghton Mifflin (p. 282) represent each equation by a number so that the reader must look back through the textual description to find each equation. This is a more confused and less satisfying presentation.

The photosynthesis reaction is described in Raytheon (p. 195) in terms of energy effects. This reaction provides an excellent opportunity to correlate biology and chemistry. For example, the student could determine the net energy effect of photosynthesis in kilocalories per mole of glucose, if the heat of formation of glucose were given. Prentice-Hall is the only version that uses the term enthalpy to represent the energy stored in a substance during its formation. The other versions identify this energy as heat content of the substance.

There is an error in labelling of diagrams in Houghton Mifflin (p. 297). The caption for the upper diagram, which shows the molecule moving from place to place, should be "translational motion". The lower centre and lower right diagrams both illustrate vibrational motion, since the atoms are moving alternately toward and away from the molecular centre of mass. In the textbook, the upper diagram is not identified, and the lower right diagram is described as translational motion. These errors could certainly confuse the students.

Raytheon (p. 203) provides a very informative table which compares energy changes that occur within the temperature range from absolute zero to 1×10^8 $^oK.$, in terms of source of energy, absolute temperature, process occurring, state of atoms and molecules, and molecular process. Raytheon is the only version in which the formation of plasma (by ionization of atoms at about 10^6 $^oK.$) and nuclear fusion reactions in stars (at about 10^7 $^oK.$) are discussed.

Although all versions discuss nuclear fission of uranium-235, Prentice-Hall (p. 204) gives the most information, describing the operation of a nuclear reactor, including selection of critical mass of fissionable material and control of fission rate by cadmium rods. Nuclear power is related to student experience in the statement that one-half pound (235 g) of uranium-235 releases the same amount of energy as 140,000 gallons of gasoline (approximately 4.5 X 10^9 kcal per mole of uranium-235.

Freeman provides 23 questions and problems at the end of Chapter 7, to examine the students' knowledge of energy effects in chemical reactions. Raytheon supplies 32 questions at the end of Chapter 11, 19 of which are from Freeman, and Houghton Mifflin has taken 11 of its 15 questions from Freeman, as well as 10 of its 14 problems. In Prentice-Hall, Chapter 9 ends with 25 questions, 23 of which are from Freeman.

The experimental work includes a study of reactions, consisting of observation of evidence of chemical change and observation of rates of reaction, factors affecting rate of reaction, and completeness of reaction.

The heat of reaction of sodium hydroxide solution with hydrochloric acid is determined and compared with the total heat from the equivalent sequence of reactions. The data from this experiment justify the formulation of the law of additivity of reaction heats. Raytheon and Prentice-Hall direct that styrofoam cups should be used as calorimeters, as they reduce heat loss more effectively than Erlenmeyer flasks do.

Raytheon provides an additional experiment that combines a sequence of three reactions for the determination of heat of combustion of magnesium to magnesium oxide.

Summary

Table 12. Comparison of Chapter 7 of Freeman Textbook with Corresponding Material in the Three Revisions

	Topics treated		
Version	Energy effects	Energy changes	Chapter-end exercises
Freeman			23
Raytheon	clear general analysis; photosynthesis	table, $0^{o}K$ to 10^{8} ^{o}K; plasma formation; fusion in stars	32 (59% from Freeman)
Houghton Mifflin	caption error		15 (73% from Freeman) 14 (71% from Freeman)
Prentice-Hall	general to specific; enthalpy	nuclear reactor	25 (92% from Freeman)

Table 13. Comparison of Experiments in the Four Versions, Relevant to Chapter 7 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Study of reactions	12	24	10	16
Heat of reaction (NaOH + HCl)	13	26	13	17
Heat of reaction ($Mg + \frac{1}{2}O_2$)		27		

Rates of Chemical Reactions

Reaction rate is explained by the activated complex theory in Chapter 8 of the Freeman version. Changes in reaction rate produced by variation of concentration or temperature and by addition of a catalyst are recognized as being consistent with the kinetic theory of molecular motion and the activated complex theory. In presenting these topics, Raytheon and Prentice-Hall have clarified and developed some of the concepts more fully than Freeman and Houghton Mifflin.

In defining "rate of reaction", all versions except Raytheon refer to the reaction

$$CO + NO_2 \longrightarrow CO_2 + NO.$$

Since NO_2 is a brown gas and the other substances are colourless gases, the brown colour will gradually disappear as the forward reaction proceeds. Both Freeman and Houghton Mifflin define the rate of reaction as (quantity of NO_2 consumed)/(time interval). Raytheon and Prentice-Hall are in agreement that the rate is (change in concentration of NO_2)/(time interval). To examine the implications of these two definitions, consider two vessels containing different volumes but the same concentration of nitrogen dioxide gas. If in each vessel the same number of moles of nitrogen dioxide react per minute, the rate of reaction is greatest in the smaller (and warmer) vessel (where the brown colour is fading faster) by the Prentice-Hall definition. Both rates are the same according to the Freeman definition. The definition in Freeman is not well chosen and does not agree with the verbal context in which it is placed in Freeman (pp 124, 125).

Raytheon does not express rate of reaction mathematically as proportional to the product of concentrations of reactant gases or to the product of partial pressures of the reactant gases in the reaction vessel. Since the equations developed in the other versions to express this relationship are not used, their omission from Raytheon is not harmful and may even increase the coherence of the course.

Raytheon (p. 215) is the only version which describes the mechanism for the decomposition of hydrogen iodide, HI, into its elements. Five stages are represented with diagrams of molecular models that correspond with potential energy as indicated by dots shown on the potential energy curve. Captions interpret each stage in terms of molecular behaviour.

An experimental determination of the distribution of velocities of tin vapour molecules at constant temperature is outlined in all versions. Prentice-Hall (p. 221) presents a method of calculating velocities from the experimental data.

Raytheon describes the alteration in the molecular kinetic energy distribution curve as temperature changes. As the temperature rises, the curve flattens and spreads out. This is a useful generalization. Since average speed of molecules is greater at the higher temperature, many more collisions involve energy greater than threshold energy.

Each textbook has a different model for the formation of an activated complex. In the Freeman version, the activation energy barrier is represented by a mountain pass at an altitude of 4,200 feet. Instability of a vehicle at the summit of the pass represents instability of the activated complex. This instability may result in a return to the starting point(reactants) or progress toward the destination (products). The catalyzed-reaction pathway is analogous to a mountain pass of altitude 900 feet instead of 4,200 feet. For the catalyzed reaction, there is a different activated complex and a lower activation energy. Houghton Mifflin uses the mountain pass analogy, with specific reference to south-north travel in the United States rather than west-east travel.

Prentice-Hall represents activation energy as the minimum energy required for a pole vaulter to pass over the bar (with the best geometric arrangement of his body). He starts from the level of the runway (reactants) and lands at the lower level of the pit (products). This model is very fitting for exothermic reactions in particular. The coach may act as a catalyst by lowering the bar, enabling more people to get over it.

Raytheon represents the activation energy barrier by a very steep hill over which someone tries to roll a bowling ball. Only occasionally the bowler provides enough energy to get the ball over the hill. Raytheon (p. 213) shows most clearly that the potential energy of the activated complex is equal to the threshold kinetic energy, by representing these energies at the same level on two adjacent graphs. The graph of kinetic energy distributions at constant temperature has been rotated counterclockwise through ninety degrees so that the threshold energy line is level with the energy of the activated complex on the potential energy graph. The provision of a mechanism for the catalyzed reaction is represented by the washing away of the hilltop so that it is easier for the bowler to roll the ball over.

Raytheon (pp. 218-222) describes the reaction mechanisms of molecular inversion, chain reaction, and several forms of catalysis. For the mechanism of inversion of ammonia, the diagram (Raytheon, p. 219) is incorrect as all three hydrogen atoms should be bonded to the nitrogen atom directly and a hydrogen atom does not participate in the formation of two covalent bonds. The description of surface catalysts (p. 222) contains the information that bonds form between the catalyst and the adsorbed reactant, releasing more energy than is needed to break the bonds in the reactant, and thus reducing the energy which the second reactant must bring to the reaction.

In describing acid catalysis, Prentice-Hall (pp. 228, 229) is the only version which represents the acid catalyst as H_3O^+ rather than H^+. A book published in 1969 under the auspices of CHEM Study indicates that there is no firm evidence for the existence of the hydronium ion (Merrill and Ridgway, p. 137). This explains the absence of H_3O^+ from the Freeman version.

Raytheon (p. 424) compares the mechanisms of chemical and nuclear reactions in terms of form and stability of activated complex and in terms of energy of reaction. Temperature change of 500°C does not alter the rate of nuclear reaction perceptibly because the energy terms associated with a nuclear reaction are millions of times larger than energy terms associated with a chemical process (Prentice-Hall, p. 231).

Freeman provides 22 questions at the end of Chapter 8 to examine student knowledge of reaction rates. Raytheon supplies 30 questions, of which 19 are from Freeman, and Houghton Mifflin has taken 16 of its 27 questions from Freeman. Prentice-Hall has 24 questions at the end of Chapter 10, 20 of which are from Freeman.

Laboratory work in all versions except Raytheon includes a "clock" reaction to show the influence of temperature and concentration on time required for a reaction to occur. Iodate ion reacts with hydrogen sulfite ion to produce iodide ion. Iodide ions react with the remaining iodate ions to form free iodine which turns the starch blue.

An experiment in Freeman and Prentice-Hall is designed to investidate the rate of decomposition of aqueous sodium hypochlorite, NaClO. The reaction is catalyzed by an oxide of cobalt. Effects of temperature and concentration on the reaction rate are judged by the rate of production of oxygen gas.

The "clock" reaction in Raytheon is designed to determine the influence of temperature, concentration, and catalysis on the time required for a reaction to occur. The reactants are iodide ion, peroxydisulfate ion, thiosulfate ion, and starch. Copper sulfate solution is the catalyst. This experiment has the advantage of indicating the quantitative effect of catalysis on reaction rate.

Summary

Table 14. Comparison of Chapter 8 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated: Reaction rate	Topics treated: Activated complex model	Topics treated: Additional	Chapter-end exercises
Freeman	quant. change/time	mountain pass		22
Raytheon	conc. change/time	hill, bowler	threshold=activation energy; curves; mechanisms	30 (63% from Freeman)
Houghton Mifflin	quant. change/time	mountain pass		27 (59% from Freeman)
Prentice-Hall	conc. change/time	pole vaulting	H_3O^+ catalyst; nuclear reaction rate	24 (83% from Freeman)

Table 15. Comparison of Experiments in the Four Versions, Relevant to Chapter 8 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Clock reaction, $IO_3^- + HSO_3^-$	14		14	18
Decomposition rate, NaClO	14a			S-5
Clock reaction, $I^- + S_2O_8^{2-} + S_2O_3^{2-}$		28		

Equilibrium in Chemical Reactions

The dynamic nature of chemical equilibrium is stressed in Chapter 9 of the Freeman version. Effects of various changes on equilibrium conditions are predicted using Le Chatelier's Principle. Equilibrium constants are determined and interpreted. Houghton Mifflin is the only revision that does not make any appreciable changes from the Freeman presentation of equilibrium in reactions.

Raytheon (pp. 227-229) describes three separate examples of equilibrium and abstracts factors common to all three. These factors are uniform temperature, a closed system, and a measurable property which has changed with time and has reached a constant value. These factors are incorporated into a generalization, "For a closed system at a uniform temperature, equilibrium is recognized by the constant properties of the system". Additional observations lead to the generalization that equality between rates of forward and reverse reactions maintains the constancy of properties. Freeman proceeds from specific observations of two systems at equilibrium to the definition, "Equilibrium is characterized by constancy of macroscopic properties" (p. 143). In Raytheon, the concept of equilibrium has been more methodically integrated with laboratory experiences and should therefore be more meaningful and more readily retained by students.

All versions except Raytheon describe the type of system exemplified by the laboratory burner flame, which displays constant properties but cannot be called an equilibrium condition. The flame is a "steady state", since it functions as an open system, with matter entering and leaving at all times. Classification of such negative examples (examples of what a concept is not) strengthens the concept of equilibrium. According to De Cecco (pp. 408, 409) several studies have shown that presentation of negative examples discourages snap judgments and facilitates making proper discriminations so that valid conclusions will be reached.

Proof that equilibrium is dynamic is provided only by Houghton Mifflin (p. 335), using isotopic tracers. A liquid-vapour equilibrium, developed using liquid water containing the isotope, ^{17}O, has reached equilibrium at the same temperature as another liquid-vapour system that contains no tracer in the water. Vapour is allowed to move back and forth between these two systems. When equilibrium has been reached, the isotopic species, ^{17}O, is found at the same concentration in the liquid of both vessels. This result indicates that molecules were continuously passing from the liquid to the gas phase and vice-versa, even though equilibrium had been achieved.

Prentice-Hall (pp. 240-242) emphasizes with reference to the $CaCO_3$ - CO_2 equilibrium that one of the best ways to ensure that we have a true equilibrium condition is by reaching the same equilibrium point whether products or reactants are the initial content of the closed system. Regardless of whether limestone or calcium oxide and carbon dioxide is the initial content of the closed system, if the temperature is brought to 800°C and held constant, the pressure will become steady at 190 mm.

Circle graphs divided into appropriate sectors indicate the composition of the N_2O_4 - NO_2 system at equilibrium at 0°C, 25°C, and

100^{o}C (Raytheon, pp. 231, 232). Since the information of NO_2 is endothermic, the graph for the equilibrium at 100^{o}C shows the largest NO_2 sector of the three graphs. The circle for 100^{o}C conditions is completed by an N_2O_4 sector whose angle is about ten degrees. These graphs are a useful teaching aid which clarifies thinking.

An equation does not give quantitative information about conditions at equilibrium. Just as the number of boys and number of girls (reactants) at the first school dance of the year does not indicate the number of dancing couples (products), a chemical equation does not indicate the relative concentrations of reactants and products at equilibrium (Prentice-Hall, p. 243). This analogy is effective since it makes use of experiences familiar to the high school student.

Le Chatelier's Principle is most thoroughly interpreted in the Prentice-Hall version (pp. 246-250). For instance, the effect of decrease in temperature on an equilibrium is described as well as the effect of a rise in temperature. A summary table of some changes to which an equilibrium system may be subjected, processes that tend to counteract the change, and final results, is provided in Raytheon (p. 236). However, students should know and be able to apply Le Chatelier's Principle without using any table as a crutch.

Raytheon (p. 235) provides a discussion of the effect of pressure change on the equilibrium system:

$$N_2O_4 + 14.1 \text{ kcal} \longrightarrow 2NO_2$$

Explanation is given for the brown colour due to NO_2 becoming darker, then lighter as pressure on the system is suddenly doubled.[1]

The model of golf balls rolling to the lower level in the back of a station-wagon is used in all versions except Prentice-Hall to represent the tendency of systems to move toward a state of minimum potential energy. Prentice-Hall draws attention to this tendency in skiing and in water running downhill. The tendency for maximum randomness is illustrated by the diffusion of methyl violet when a few drops of it are added to water in a test tube (Prentice-Hall, p. 259) and by the jostling of golf balls between higher and lower levels as a station-wagon passes over bumpy roads (Freeman, p. 157).

Prentice-Hall (pp. 260, 261) identifies the equilibrium state as a compromise between minimum enthalpy and maximum entropy. Both tendencies can be observed in the behaviour of water in a blender. When the blender is turned off, water is at its lowest position, corresponding with temperature of absolute zero and minimum potential energy of molecules. With the water running at high speed, water is distributed in more space, corresponding with the gain in kinetic energy and the increased randomness which results from temperature increase.

Raytheon is the only version that introduces the equation:

$$\Delta G = \Delta H - T\Delta S$$

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[1]These changes can be observed by students, using a ten-cent plastic syringe which can be filled with NO_2 gas from a bottle sealed with a serum cap. The needle can then be inserted into a rubber stopper to seal the syringe. Pressure can be doubled by suddenly pushing in the plunger to halve the volume of gas. (Nitrogen dioxide should later be forced out as it will damage the syringe). (In-service training for teachers given by Irwin Talesnick, Professor at McArthur College of Education, in Kingston, 1969).

where ΔG is net driving force for the reaction, ΔS is entropy change and T is absolute temperature.

Freeman has 26 questions at the end of Chapter 9 that examine the student's knowledge of equilibrium in chemical reactions. There are 36 questions at the end of Chapter 13 in Raytheon, of which 33 are from Freeman, and 24 of the 30 questions in Houghton Mifflin are from Freeman. In Prentice-Hall, 26 of the 28 questions are taken from Freeman.

Laboratory work for all four versions contains a procedure for determining an equilibrium constant for the formation of the red ion, $FeSCN^{2+}$ in aqueous solution, from Fe^{3+} and SCN^-. (In all versions, this experiment is preceded by demonstrations to give a qualitative introduction to the reaction and to show that intensity of colour of a solution depends on depth and concentration of the solution). The teachers' guides published by Raytheon and Prentice-Hall are particularly useful for checking student results and calculations as they contain tables of depth ratios of liquids and values of the three potential equilibrium constants that correspond with each depth ratio. The Raytheon teacher's guide provides data sheets and calculation sheets which could be duplicated for individual students to record their results. A Fortran IV Computer programme for use of the experimental data to compute equilibrium constant expressions, is given by Raytheon and may be used in schools where a class has access to a suitable computer.

Summary

Table 16. Comparison of Chapter 9 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated: Equilibrium	Le Chatelier	Additional	Chapter-end exercises
Freeman	golf ball model		steady state	26
Raytheon	defined by induction; circle graph, concs.; golf ball model	table of results, N_2O_4 - NO_2	ΔG equation	36 (92% from Freeman)
Houghton Mifflin	golf ball model		steady state; isotopic tracer	30 (80% from Freeman)
Prentice-Hall	true test; dance analogy; blender model	thorough interp.	steady state	28 (93% from Freeman)

Table 17. Comparison of Experiments in the Four Versions, Relevant to Chapter 9 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Chemical equilibrium ($FeSCN^{2+}$)	15	29	15	19

Solubility Equilibria

A general survey of ionic reactions is provided in Chapter 10 of Freeman. The equilibrium constant is applied to chemical reactions and comparison of the established solubility constant with a trial ion product indicates whether a precipitate will form under the trial conditions. The variation in solubility of a solid in different solvents and of two gases in water is explained as resulting from opposing effects of tendencies toward maximum randomness and minimum energy. In dealing with these topics, the Raytheon version has omitted certain topics that were included in the other versions, and Prentice-Hall has added some useful information.

Raytheon (p. 97) and Freeman (p. 171) have omitted three items from their table of solubility of common compounds in water. The chloride, bromide, and iodide of thallium have low solubility. Radium sulfide, radium hydroxide, and thallium hydroxide are soluble. The periodic table in Prentice-Hall (p. 277) describing halides of thallium as soluble contradicts Table 12-1 (Prentice-Hall, p. 279) where the chloride, bromide and iodide of thallium are listed as having low solubility. The solubility constants (Prentice-Hall, p. 280) indicate that these halides of thallium have low solubility.

The Raytheon version does not contain the six separate periodic tables with elements shaded in if they form compounds of low solubility with certain anions. The summarized table of solubilities of common compounds is not given in the Houghton Mifflin version.

The theory of solubility equilibria is not dealt with as thoroughly in Raytheon as in Freeman. Raytheon identifies equilibrium as a compromise between maximum randomness and minimum energy, without examining specific reactions. Freeman explains relative solubility of solids in liquids as resulting from heat effects and the effect of randomness. For example, Freeman (p. 166) indicates that 5.8 kcal of heat must be supplied to dissolve 1 mole of iodine in carbon tetrachloride, but only 1.6 kcal is needed to dissolve 1 mole iodine in alcohol. Thus, the energy factor (favoring the crystal) is much larger for carbon tetrachloride and therefore iodine is less soluble in it than in alcohol. Increase in randomness favours the dissolving of solid in liquid.

Changes in randomness of iodine molecules are described in Prentice-Hall (p. 271) from the crystalline form at $0^{o}K$ where translational kinetic energy is zero, through rise in temperature and dissolving in liquid to form a dilute solution.

Equation 30 in Prentice-Hall (p. 281) which reads as follows:

"$[Cu^{+}] = [Cl^{-}]$ = s moles/litre = s moles/litre CuCl dissolved" is not well phrased. The student may wonder whether 1 litre of CuCl is involved. Freeman's expression is better:

$[Cu^{+}] = [Cl^{-}]$ = s moles/litre = moles CuCl dissolved.

In calculation of solubility from K_{sp}, Prentice-Hall represents the solubility, s, in moles/litre, so that s^2 is in $moles^2/litre^2$. Freeman omits the units in the equation expressing K_{sp} as a product of solubilities.

The principles of precipitate-formation and equilibrium are related to nature and industry in Prentice-Hall (p. 283). Oysters and corals adjust conditions in their own local area so that the concentration of carbonate ion is large enough to cause precipitation of more calcium carbonate shell material from the water. Precipitation equilibrium is similarly involved in formation of limestone caves and in industrial preparation of pigments, such as yellow lead chromate and "cadmium reds".

Prentice-Hall (p. 284) outlines the use of precipitation for separation of Cu^{2+}, Ag^{+}, and Mg^{2+} ions in aqueous solution.

There are 27 questions at the end of Chapter 10 in Freeman, which require knowledge of solubility equilibria. Raytheon has 20 of those questions from Freeman scattered through Chapters 6 and 13. In Houghton Mifflin, Chapter 15, 12 out of 13 problems and 14 out of 22 questions are from Freeman. Prentice-Hall provides 30 questions, 22 of which are from Freeman.

All versions except Raytheon contain an experiment to determine the solubility product constant of silver acetate. An experiment in Raytheon is designed to study saturated, unsaturated, and over-saturated solutions and the heat effects of dissolving and crystallization, using hypo crystals or sodium acetate trihydrate in water.

Summary

Table 18. Comparison of Chapter 10 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated: Solubility	Topics treated: Additional	Chapter-end exercises
Freeman			27
Raytheon	no periodic tables; briefly on heat effects		20 (in Chapters 6 and 13)
Houghton Mifflin	no summary table of solubilities		13 (92% from Freeman) 22 (64% from Freeman)
Prentice-Hall	error p. 277 table; randomness, I_2	pptn:oysters, corals, pigments, ion separations	30 (73% from Freeman)

Table 19. Comparison of Experiments in the Four Versions, Relevant to Chapter 10 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
K_{sp}, $AgC_2H_3O_2$	16		16	21
Types of solutions		18		

Aqueous Acids and Bases

Principles of equilibrium are applied to acids and bases in Chapter 11 of the Freeman version. The relationship of $H^+(aq)$ and $OH^-(aq)$ is examined and the equilibrium constant of an acid, K_a, is interpreted as a quantitative measure of acid strength. Properties of acids and bases are described in terms of the Brønsted Theory. The authors of the Raytheon and Prentice-Hall revisions have presented this section of the course more thoroughly than Freeman.

Raytheon (p. 260) shows, in Figure 14-3, by changes in the size of letter symbols that OH^- ion tends to increase in concentration as H^+ ion decreases in concentration. On the same page, the hydrogen ion concentration from water in a solution formed by dissolving 0.1 mole of hydrogen chloride in 1 litre of water is identified. Le Chatelier's Principle would suggest that the addition of hydrogen chloride would cause a shift in the dissociation constant of water such that less than 10^{-7} moles of H^+ ion is contributed by water per litre. This is negligible compared with the 10^{-1} moles of H^+ ion supplied by hydrogen chloride per litre of solution. Thus, the effective H^+ ion concentration is 10^{-1} $\underline{M}$ and OH^- ion concentration is 10^{-13} $\underline{M}$.

Indicators are defined by Raytheon (p. 263) as weak acids or bases which have one colour in acid solution and another colour in basic solution. An indicator acting as a base, forms a bond with hydrogen ion in acid solution, resulting in one colour. The bond is broken as the indicator donates the H^+ ion, if the solution is made alkaline, and a different colour is produced.

A colour plate showing colours of seven indicators in pH range 1 to 13 is provided in Freeman (opposite p. 211) and in Houghton Mifflin (p. 393). The colours of six different indicators in the pH range 1 to 11 are shown in Prentice-Hall (p. 306). The three indicators which are common to all three plates are phenolphthalein, bromthymol blue, and methyl orange. Raytheon does not supply a colour chart.

In Prentice-Hall's section on electrolytes (p. 291), the high fusion temperature of lithium chloride is explained as due to Li^+ ions and Cl^- ions being

> ...held together in a rigid lattice by electrostatic forces of attraction. If we heat this solid to a sufficiently high temperature, 613°C, the kinetic energy of the ions is large enough to overcome the attraction of the positively and negatively charged particles.... These ions can then carry current through the molten mass.

Freeman (p. 186) is more vague, stating that the high melting point of lithium chloride "shows that the crystal is very stable".

Prentice-Hall (p. 293) indicates that the polarity of the water molecule is responsible for the small amount of energy used in dissolving lithium chloride in water. Energy is released when the chloride ion reacts with the positive end of the water molecule and this "energy of hydration" causes the breakup of the lattice of lithium and chloride ions, even at room temperature. Such a specific analysis is not presented in Freeman (p. 186) which again limits its explanation to a general statement on stability.

> The high solubility of lithium chloride in water can be explained only by saying that $Li^+(aq)$ and $Cl^-(aq)$ must also be very stable. This means that water must interact strongly with these ions.

A salt is defined in Houghton Mifflin (pp. 398-399) as a compound containing the positive ion from a base and the negative ion from an acid.

For example, calcium sulfate is a salt. Salt and water are given as the products of "neutralization" in Raytheon (pp. 96, 258) as well as in Houghton Mifflin. This is the more traditional Arrhenius approach which precedes the Brønsted interpretation. Brønsted defines a base as a substance that combines with $H^+(aq)$, and may or may not produce $OH^-(aq)$ ion in solution. Freeman restricts description of acids and bases to the Brønsted interpretation. The word "neutralization" is omitted, as explained in a footnote (Freeman, p. 189), to avoid confusion with the concept of electrical neutrality. Any aqueous solution is electrically neutral, whether or not the number of hydroxide ions equals the number of hydrogen ions present in the solution.

All versions except Raytheon provide general theory for deciding whether an acid-base reaction favours the formation of reactants or products, but no specific problem is solved. A structure is provided by Raytheon (pp. 267-268) for the process of determining whether reactants or products are favoured in the reaction between sodium carbonate and hydrogen fluoride, using the K_a values for HCO_3^- and HF. The majority of chemistry students need some structuring to equip them to solve such problems at the end of Chapter 11 in Freeman, as the K_a notation is a new concept at this point in the course and must be manipulated.

The method of calculating an equilibrium constant for the reaction between a Brønsted acid and Brønsted base using the K_a values for the acid reactant and acid product is indicated in Raytheon (pp. 268, 269). Interpretation of this new constant for the total reaction would provide another means of deciding whether reactants or products are favoured in the total reaction.

The equilibrium constant, K_a, of HF is calculated using an accounting table where initial concentrations and equilibrium concentrations are listed (Raytheon, p. 270). The structure is similar to one provided in Freeman (p. 147) for organizing data to determine the equilibrium constant for a chemical reaction.

In determining the K_a of benzoic acid, Prentice-Hall (p. 309) subtracts the number of moles of benzoic acid that ionized in each litre of solution from the original molar concentration of benzoic acid, to obtain the denominator for the K_a expression. The other three versions do not include the subtraction as they state that the change in concentration of acid molecules is negligible. The Prentice-Hall approach to such problems should give the student a more secure understanding, since it provides the technique for solving problems where the change in molecular concentration is significant.

The Freeman version (p. 182) makes the claim that "...the concentrations of hydrogen and hydroxide ions give us tremendous leverage in controlling the chemistry of aqueous solutions". In all versions except Prentice-Hall, the usefulness of such control is related only to the effect on decomposition of formic acid, which is not of vital interest to the student. The effect of hydrogen-ion concentration is related to two biological processes in Prentice-Hall (pp. 296, 297). In human blood H^+ must be close to 6.0×10^{-8} M or death may result. The juice of red cabbage changes in colour as acid is added.

Raytheon explains that acidic or basic properties may be displayed by a hydroxide of a third-row element depending on the tendency of that element to release electrons. The amphiprotic property of aluminum hydroxide (capacity to either donate or accept a proton) is related to the intermediate size of ionization energy of aluminum.

The Lewis concept of acids as electron-pair acceptors and bases as electron-pair donors, is introduced only in Prentice-Hall.

Freeman provides 24 questions on acids and bases at the end of Chapter 11. On the same block of knowledge, 23 out of 29 questions in Raytheon, 18 out of 36 items in Houghton Mifflin, and 22 out of 30 questions in Prentice-Hall are taken from Freeman.

Laboratory work in all versions except Houghton Mifflin contains a determination of the heats of six different acid-base reactions, to establish the exothermic character of the reaction between hydrogen ion and hydroxide ion.

All four versions include an experiment that involves determination of hydrogen-ion concentration of an unknown aqueous solution by comparison with colours recorded from indicator-tests on standard solutions. Hydrogen-ion concentration is determined for a solution of weak acid, acetic acid, of known molarity. Volumes of basic solution required to neutralize equal volumes of 0.1 $\underline{M}$ HCl and 0.1 $\underline{M}$ CH_3COOH are compared. All versions except Houghton Mifflin provide an experiment requiring application of Le Chatelier's Principle to some reversible reactions. The effects of hydrogen-ion concentration on the chromate ion-dichromate ion equilibrium and on the equilibrium of solid barium chromate with a saturated solution of its ions are examined.

Summary

Table 20. Comparison of Chapter 11 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated: H^+ - ion concentration	Topics treated: Additional	Chapter-end exercises
Freeman	indicator colour chart		24
Raytheon	$[H^+]$ in 0.1 M HCl; $[H^+][OH^-]$ pattern; indicator mechanism; 3rd-row hydroxides	salt, neutralization; structure for K_a comparisons; accounting table	29 (79% from Freeman)
Houghton Mifflin	indicator colour chart	salt, neutralization	16 (31% from Freeman) 20 (65% from Freeman)
Prentice-Hall	indicator colour chart; $[H^+]$ in biology	detail on fusion + dissolving of KCl; detail for K_a, benzoic acid; Lewis acids, bases	30 (73% from Freeman)

Table 21. Comparison of Experiments in the Four Versions, Relevant to Chapter 11 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Heat of acid-base reactions	17	31		25
H^{+} ion conc., indicators	18	33	18	24
Le Chatelier's Principle	19	30		22

Oxidation-Reduction Reactions

The chemistry of an electrochemical cell is investigated in Chapter 12 of the Freeman version. A reduction half-reaction occurs at the cathode of the cell and an oxidation half-reaction occurs at the anode. The voltage of a cell measures the tendency for a cell reaction to occur. An oxidation-reduction equation may be balanced using the half-cell method or the oxidation-number method.

The importance of the electrochemical cell in industry was neglected in the Freeman version but has been given a great deal of attention in Raytheon and some attention in Houghton Mifflin. Prentice-Hall is the only version that explains reduction potentials. All other versions deal with oxidation potentials.

The origin of the word "reduction" is provided in Raytheon (p. 281) by noting that early metallurgists "reduced" large piles of ore to small piles of metal. Prentice-Hall (pp. 342, 343) explains why oxidation is identified with a loss of electrons. A metal, such as magnesium, reacts with oxygen to form an oxide of the metal. Since the metal (magnesium) atom loses two electrons in order to bond onto an oxygen atom, oxidation has come to mean a loss of electrons. Thus, magnesium is oxidized when it forms bonds with chlorine to produce magnesium chloride, since the magnesium loses electrons.

For the reaction:

$$Cu^{o} + 2Ag^{+} \longrightarrow Cu^{2+} + 2Ag^{o},$$

Prentice-Hall gives a more rigorous explanation than Freeman. According to Freeman (p. 205), randomness favours neither reactants nor products.

Prentice-Hall (p. 326) observes that the number of particles is the same on both sides of the equation, but the randomness factor favours reactants since ions distributed randomly are more disordered than atoms in an ordered metal lattice. However, both versions agree that since the equilibrium favours products, the energy term must favour products.

Units for amount of flow, rate of flow, and pressure in the fireman's water system are compared with units for the electrochemical cell. Raytheon (pp. 287, 288) defines the units clearly by means of a table, diagrams, and textual description. The comparison will be particularly helpful to students who have little knowledge of physics.

A procedure is shown in Raytheon (pp. 289-291) for determining the electrode potential of a half-cell by comparing it with the hydrogen reference half-cell. If the two half-cells are joined by a salt bridge and connected to a voltmeter, the electrode toward which the voltmeter needle is deflected has the lower oxidation potential. Since the hydrogen reference half-cell is conventionally assigned an electrode potential of 0.00 volts, the sign and magnitude of the electrode potential of the other half-cell can be read from the voltmeter. Raytheon lists oxidation potentials of elements in order of decreasing tendency to donate electrons.

A technique similar to Raytheon's is described in Prentice-Hall (pp. 328-331). A Cu-Cu^{2+} reference half-cell is connected to four different half-cells in turn. The voltage is tabulated for each half-cell, with the Cu-Cu^{2+} half-cell assigned a potential of 0.00 volts. The half-cell toward which the voltmeter needle swings is given the more positive reduction potential since it has the greatest tendency to be reduced. The same procedure is outlined using a $Ni-Ni^{2+}$ reference half-cell. The tabulated voltages indicate that for any given half-cell, the reduction potential is 0.6 volts lower using a copper reference half-cell than with a nickel reference half-cell. Such uniformity indicates that any half-cell could serve as a reference and that the choice of the $H^+ - H_2$ half-cell as a standard was an arbitrary choice. Prentice-Hall is the only version that arranges the elements in order of decreasing ability of the ions to attract electrons. Thus, reduction potentials are provided in Prentice-Hall whereas the other versions provide oxidation potentials. The Handbook of Chemistry and Physics (p. D-86), lists reduction potentials in accordance with the Stockholm Convention (IUPAC, 1935).

Freeman and Houghton Mifflin introduce electrode potentials by describing the experimental determination of the voltage of the Zn - Ni cell, the Zn - Ag cell, the Zn - Ni and Zn - Ag cells connected in opposition, and the Ni - Ag cell. The data produced suggest that the voltage of any cell can be calculated from the voltages of the two component half-cells.

Both Freeman (p. 214) and Prentice-Hall (p. 338) mention that if the electrode potential for the overall oxidation-reduction reaction is only 0.1 or 0.2 volts (positive or negative), even small deviations from standard conditions may invalidate predictions that do not consider these concentration or temperature changes.

A diagram and description of the composition of a dry cell are given in Raytheon (p. 294) with equations for the half-reactions that occur. For the lead storage battery, half reactions and their E^o values are given. Houghton Mifflin (p. 422) describes the dry cell and lead storage battery, providing half-reactions but no diagrams. The AgO -Cd cell used in satellites and the CH_4 - O_2 fuel cell which has 70% efficiency in producing electrical energy, are described in Raytheon.

The corrosion of iron is described by Raytheon (p. 296) as an oxidation-reduction reaction. Iron acts as an anode in water, releasing electrons which unite with hydrogen ions of water to form neutral hydrogen atoms. Hydrogen atoms react with oxygen of the air to form water. The positive iron ions react with oxygen of the air to form rust. Suggestions are given for minimizing corrosion of iron by breaking the circuit. Oxygen can be excluded by coating the iron with grease, paint, or a weak reducing agent like tin. A stronger reducing agent than iron can be brought into the system, forcing iron to act as a cathode. A block of magnesium is bolted onto the steel of a ship's hull because it tends to release electrons more readily than iron.

Copper plating is described in both Houghton Mifflin and Raytheon as an illustration of electrolysis. Chrome-plating, involving a conversion of chromate ions in solution to chromium metal at the cathode, is described in Houghton Mifflin (p. 435). It is probably more relevant to the interests of an adolescent reader than the electrolysis of halides described in Freeman and Prentice-Hall.

Raytheon (p. 299) outlines a procedure for determining the quantity of electrolytic product formed by passage of a current of known strength through an electrolytic system for a known interval of time.

The use of oxidation numbers to balance oxidation-reduction reactions is explained more thoroughly in Freeman and Houghton Mifflin than in Prentice-Hall. Raytheon does not use oxidation numbers, but relies completely on half-reactions, for balancing oxidation-reduction equations. In this version, oxidation numbers are used in naming compounds of an element that has two different oxidation numbers.

Freeman provides 24 questions at the end of Chapter 12 that require a knowledge of oxidation-reduction. In the revisions, Raytheon has taken 18 out of 36 questions, Houghton Mifflin has taken 25 out of 28 questions, and Prentice-Hall has taken 22 out of 26 questions from Freeman.

Laboratory work in all versions except Houghton Mifflin includes a determination of the relative electron-losing tendency of three metals and relative electron-gaining tendency of three halogens. Raytheon makes the experiment safer by substituting trichlorotrifluoroethane (TTE) as a solvent, instead of carbon tetrachloride. Halogen solutes take on the same colours in both solvents. The threshold limit values (safe for 8-hour continuous exposure) are: for TTE, 7600 mg/m^3 air; for CCl_4, 65mg/m^3 air.

All versions except Raytheon contain an experiment involving construction and determination of voltage readings of several electrochemical cells. An additional procedure in Houghton Mifflin consists of the setting up and operation of a silver-copper cell. After reaction is stopped, the weight lost by the copper strip is determined and converted to moles and the increase in weight of silver is converted to moles.

Summary

Table 22. Comparison of Chapter 12 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated: Redox	Electrochemical cell	Additional	Chapter-end exercises
Freeman		oxidation potentials; E^o validity		24
Raytheon	reduction origin; corrosion of Fe; Cu plating; no O.N. to balance equations	water system analogy; oxidation potentials; dry cell, Pb storage + other cells	nomenclature for compounds	36 (50% from Freeman)
Houghton Mifflin	Cu, Cr plating	oxidation potentials; dry cell, Pb storage		10 (70% from Freeman) 18 (100% from Freeman)
Prentice-Hall	oxidation origin	reduction potentials; arbitrary choice of std. half-cell; E^o validity		26 (85% from Freeman)

Table 23. Comparison of Experiments in the Four Versions, Relevant to Chapter 12 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Intro. to redox	20	34 (safest)		26
Electrochemical cell, voltage, wts. of products			20	
Electrochemical cells, construction, voltage	21		S-4	27

Chemical Calculations

Chemical equations are interpreted quantitatively in Chapter 13 of Freeman. A pattern called the mole method is provided for solving stoichiometric problems. The manufacture of sulfuric acid is described, with diagrams, to provide the theory relevant to problems on sulfuric acid synthesis.

All versions use the mole method for solving stoichiometric problems involving the determination of how much of substance B will be produced from (or react with) a measured quantity of substance A. Freeman (p. 225) deals with such problems in 3 steps. The amount of A in measured units is converted to moles of A. The number of moles of B, involved with the determined moles of A, is calculated. The moles of B are converted to amount of B in desired units. Prentice-Hall (pp. 59, 60) incorporates simple unit analysis into the mole method, whereas the other versions rely on parallel statements in structuring problems.

Raytheon and Prentice-Hall do not describe the synthesis of sulfuric acid, whereas Freeman and Houghton Mifflin provide illustrations of both the lead chamber process and the contact process, which make the problems based on these processes more meaningful.

Authors of the Freeman edition decided not to use the noun "valence", as it can have too many meanings. They do use "valence" as an adjective in the term "valence electrons". The noun "valence" appears only in Houghton Mifflin (pp. 253, 254) where it is the number of electrons an atom loses, gains, or shares when it forms chemical bonds with other atoms.

Valences of elements and of some radicals are given in charts. A set of five rules is given for using valences in writing formulas. Nomenclature of binary compounds is briefly and clearly explained in Chapter 11. The topics of writing formulas and naming need to be supplemented with drill geared to student capabilities in the particular class, if these skills are to be mastered.

Freeman provides 23 questions that involve stoichiometry, at the end of Chapter 13. Questions involving the same principles are supplied in Chapters 3 and 4 of Raytheon and Prentice-Hall. In Chapter 11, Houghton Mifflin gives 12 questions, of which 5 are from Freeman, and 20 problems, of which 16 are from Freeman.

The laboratory work in all versions except Houghton Mifflin contains a study of reactions between ions in solution, involving solubility equilibria, oxidation-reduction reactions, and acid-base reactions. Raytheon's method is safest, as TTE is used instead of carbon tetrachloride.

Quantitative titrations give experience in acid-base titration and additional experiences in quantitative analysis. The weight of a mole of an unknown solid acid is determined by titration with a standardized base, given that one mole of base reacts with one mole of the acid.

Summary

Table 24. Comparison of Chapter 13 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated: Stoichiom. problems	Topics treated: Additional	Chapter-end exercises
Freeman	mole method	H_2SO_4 synthesis	23
Raytheon	mole method	—	Scattered in Ch. 3, 4, (See Appendix B)
Houghton Mifflin	mole method	H_2SO_4 synthesis; valences $\rightarrow$ formulas; nomenclature	12 (42% from Freeman) 20 (75% from Freeman)
Prentice-Hall	mole method-simple unit analysis		Scattered in Ch. 3, 4, (rel. to Ch. 3, 4 of Freeman)

Table 25. Comparison of Experiments in the Four Versions, Relevant to Chapter 13 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Reactions betw. ions	22	37 (safest)		30
Quantitative titration	23	32	19	23

Why We Believe in Atoms

Experiments that provide the basis for the atomic theory and for currently accepted details of atomic structure are described in Chapter 14 of Freeman's textbook. The experimental results are provided and their significance is explained. Raytheon gives more historical information than the other versions. The Prentice-Hall and Raytheon textbooks are more thorough than the other versions in describing modern methods of determining the structure of unknown substances. They also present analogies and relevant facts that should interest the student and make chemistry more understandable to him.

Chemical regularities such as definite composition of compounds and combining volumes of gases are identified as laws in all versions except Raytheon (pp. 23-25). Scientists increasingly avoid the word "law" because observations that a scientist can make often show that original generalizations apply only over a limited range of experimental conditions. The authors of the Raytheon version feel that changing a generalization is less drastic than changing a law.

All atoms in the gas phase emit light when they are heated to a high temperature or when an electric discharge passes through them. Raytheon and Prentice-Hall explain light waves in terms of water waves, with schematic diagrams and textual definitions for frequency and wavelength. An equation for determination of frequency of light emitted by the excited hydrogen atom as its electron moves to the energy level of principal quantum number 2 is provided in Raytheon (p. 126). Prentice-Hall (pp. 370, 372) gives the general form of the same equation in which the final position of the electron does not have to be the second energy level. Students following the Freeman or Houghton Mifflin texts to determine frequency of light emitted as electrons dropped from one energy level to another level in hydrogen atoms would go through three steps to determine energy released and then solve an equation to determine frequency of the light energy emitted.

The Freeman version supplies a mathematical analysis for determination of the charge to mass ratio (e/m) for an electron. An experiment which supplies the required data is described, involving deflection of an electron beam in a cathode ray tube by a uniform magnetic field of known strength. Labelled diagrams of the apparatus are shown (Freeman, pp. 239, 240). Raytheon (pp. 127-129) describes Thomson's experiment to determine the e/m ratio for an electron. The effects on the path of cathode rays produced by an electromagnet and by a pair of electrodes are combined so that cathode rays strike the fluorescent screen at the same position as when neither field is present. Prentice-Hall (pp. 589-592) provides a description of the same Thomson experiment with the mathematical development of the e/m value. Houghton Mifflin is the only version that provides photographs instead of labelled diagrams of apparatus for the experiment. Educational psychologists have found that

> drawings or animated moving pictures which show only important attributes of the concept are considerably more effective than direct experience.... Possibly realistic situations present us with more information than we can easily handle (De Cecco, p. 411).

A diagram is provided in Raytheon showing four atomic models accepted by scientists from 1807 to 1913, as well as a flow chart of discoveries leading to the Rutherford model. Present knowledge of atomic structure is summarized in Prentice-Hall (p. 146). Mathematical calculations and the method for Millikan's oil-drop experiment to determine charge on the electron are given in Prentice-Hall (p. 149).

Roentgen's observations of green fluorescence of a gas discharge tube and ionization of air by X-rays are described in Raytheon. X-rays are now known to be light of very short wave length. Since they are absorbed more by materials of high density than by materials of low density, they are useful to detect broken bone and cracks in steel. Becquerel's discovery of radioactivity of uranium compounds is described in Raytheon and explained as a spontaneous release of energy from certain atoms in the form of gamma rays, beta rays, or alpha particles.

Errors appear in the photographic plate in the mass spectrograph diagram (Prentice-Hall, pp. 151, 593). Since Ne^{2+} ions have greater charge, their path will have a smaller radius of curvature than Ne^{+} ions. The mass spectrometer is described only in Prentice-Hall (p. 594).

Before Rutherford's scattering experiment is presented, Prentice-Hall provides the following analogy to the determination of structure of the atom. Consider a field covered with a large tent containing only a non-living object of unknown shape, size and composition near the centre of the tent. A person at the edge of the field can investigate the object only by firing bullets into the tent from a rifle. Shape and size of the object are indicated by the area from which bullets are deflected and hardness or softness is indicated by the degree of deflection. In Rutherford's experiment, the scattering of alpha particles by gold foil was interpreted to reveal structure of the atom.

Houghton Mifflin (p. 153) provides a photograph of tracks of alpha particles as observed in a cloud chamber and a corresponding diagram that indicates the effect of nucleus-alpha particle repulsion on the path of the alpha particle.

Raytheon compares interaction of light with chemical compounds to travel of a car along a road. If the road has many deep ruts, much of the car's energy is scattered or absorbed by the road as the ruts are made deeper, whereas very little energy is absorbed by a smooth road. Similarly, a chemical substance will absorb some wavelengths of light and transmit others. Water does not absorb much of the energy that a television station sends out since the television set operates normally during a rainstorm. However, water vapour in the air does absorb infrared radiation from the sun so that much infrared radiation never reaches the earth.

Spectroscopic and diffraction methods to determine molecular structure are compared in Raytheon. X-ray diffraction and spectroscopic methods are described in all versions except Houghton Mifflin. Neutron diffraction is mentioned in Raytheon. Prentice-Hall and Raytheon refer briefly to electron diffraction. A summary table on spectroscopic measurements is provided in Raytheon along with interpretation of infra-red spectra of the isomers ethyl alcohol and dimethyl ether.

Nuclear magnetic resonance (NMR) is described only in Prentice-Hall and Raytheon. When a compound is placed in a magnetic field, information about specific bonds can be quickly obtained using NMR.

Nineteen questions test students' knowledge of atomic and mole-cular structure at the end of Chapter 14 in Freeman. Raytheon provides

21 questions, of which 9 are from Freeman. In Houghton Mifflin, 13 out of 20 questions are from Freeman, and Prentice-Hall has taken 34 out of 49 questions from Freeman.

Laboratory work in all versions except Houghton Mifflin contains an experiment to give practice in constructing a model of an unseen object contained in a sealed box. An experiment to demonstrate the quantitative relationship between the number of electrons and atoms deposited during electrolysis is included in all four versions. Copper is plated at the cathode and silver at the anode, using a current of 1 ampere through the cell for 30 minutes. The Raytheon manual suggests that contact between anode and cathode can be prevented by housing the anode in a cylinder made of plastic window screen.

Summary

Table 26. Comparison of Chapter 14 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated: Atomic particles	Topics treated: Analytical	Topics treated: Additional	Chapter-end exercises
Freeman	e/m calc. for e^-			19
Raytheon	Thomson expt. e/m; historical models diagram; flow chart of discoveries	Roentgen, X-rays; radioactivity; absorpt. road analogy; neutron diffraction; electron diffraction; NMR; spectroscopy summary	avoids "laws"; light waves:water waves; frequency equations	21 (43% from Freeman)
Houghton Mifflin		no X-ray diffraction; no spectroscopy	photograph vs. diagrams; alpha-particle tracks	20 (65% from Freeman)
Prentice-Hall	e/m calc. for e^-; summary, at. structure	electron diffraction; NMR	light waves:water waves; frequency equation; error, spectrograph; mass spectrometer; scattering expt. - tent analogy	27 (67% from Freeman) 22 (73% from Freeman)

Table 27. Comparison of Experiments in the Four Versions, Relevant to Chapter 14 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Sealed box (inferential thinking)	24	21		14
Electrodeposition	25	36 (hint)	S-5	13

Electrons and the Periodic Table

The periodic table is explained in terms of the hydrogen-atom spectrum in Chapter 15 of Freeman. Our present concept of electron distribution in an atom is described, displacing the impressions that any atom has boundary surfaces and that the electron has a planetary trajectory. Ionization energy is treated as the experimental basis for understanding chemical trends across the periodic table. The presentation of material in Houghton Mifflin makes few departures from Freeman. Raytheon, to some extent, and Prentice-Hall, especially, attempt to integrate the material in this section of the course with experiences familiar to all students.

Prentice-Hall introduced the relationship between light and colour by reminding the reader of familiar phenomena such as the blue-green colour of cupric chloride in aqueous solution and the green colour from barium chloride exposed to a flame. Bohr assumed that when electrons in a high energy state move to a lower energy level, spectral lines appear. Energies corresponding with lines on the spectrum of the hydrogen atom indicate that there are intermediate energy stages for the hydrogen atom between the ground state and the ionized state (Raytheon, p. 142). The relationship of the visible hydrogen spectrum to the full electromagnetic spectrum in terms of wavelength spans is shown in a colour plate in Houghton Mifflin and Prentice-Hall. For each of the four lines in the visible spectrum of hydrogen, Houghton Mifflin indicates the energy of the photons, frequency and wavelength. Freeman and

Raytheon show only the visible hydrogen spectrum on their colour plate, giving energy of photons for each line. Three models are provided for energy levels in the hydrogen atom. Freeman and Houghton Mifflin represent energy levels for the electron as irregularly spaced notches on the beam of a triple beam balance. Raytheon compares the energy states of the hydrogen atom to a staircase. Each step represents a different energy state. If the child climbs higher, his potential energy increases as he does work to go up. If the child jumps down, his potential energy is converted to energy of motion and then to heat and sound as he lands. His position always changes by an integral number of steps. There is no way to move up or down by one-half or one-third of a level. The steps get smaller the higher up this staircase he goes.

Prentice-Hall's model consists of a modernistic bookcase with a large paperweight on the bottom shelf, corresponding with the system at its lowest energy state or "ground state". If the paperweight is picked up and moved from shelf 1 to shelf 2, work must be done to lift the weight. If the paperweight falls from shelf 2 to shelf 1, energy will be released. There are no intermediate levels between the shelves. If a weight were to fall from shelf 3 to shelf 1, more potential energy would be converted to kinetic energy and then to heat. Thus, heat release as the weight drops to a lower level corresponds to energy released as the electron in an excited atom drops to a lower level of energy. It is mentioned that the bookcase model is imperfect since energy of a paperweight on a bookshelf is all potential energy whereas energy of an electron in level 1 or 3 of the hydrogen atom consists of both potential and kinetic energy. This criticism could be applied to the energy-level models in all four versions. However, the stair and bookshelf models are more representative of energy levels in the hydrogen atom than are notches on a horizontal beam since input of energy is required for translation of particles in one direction and output in the opposite direction.

Schrödinger's quantum-mechanical equation, which describes how the probability of finding an electron changes from place to place, is given in Raytheon. A six-point summary of the modern concept of atomic structure is provided in the same version, with the authority for each statement.

The electron cloud in an atomic orbital is represented in all versions except Prentice-Hall as resembling the holes in a dartboard. The probability of finding a hole increases as one approaches the bull's eye, just as probability of finding an electron at a particular distance from the nucleus can be determined from properties of the orbital that contains the electron. Prentice-Hall compares the atomic orbital with the area around a bird-feeding station in a large, snow-covered park in the dead of winter, where there is only one bird. The park and bird are photographed every 5 minutes throughout the day. Then, negatives are super-imposed on each other with the feeding station always at the same point. The darkest areas occur where the bird spends most time, which is around the feeding station for a normal bird. The bird's motion is more representative of the degree of randomness and continuity in electron-motion than is the movement of a dart.

Prentice-Hall is the only version which gives an explanation of the nature of light waves, beginning with fundamental observations of a rotating magnet that produces wave-like motion of a compass needle, and of a moving charged plate that causes a charged metallized styrofoam ball to swing. The motion of a charged body generates a magnetic field as well as an electrical field as exemplified in an electric motor. It was correctly predicted in the latter part of the nineteenth century that if a charged body is speeded up or slowed down, oscillating electrical and magnetic fields radiate from the charged particle at a velocity of 3×10^{10} cm/sec. The function of television and radio transmitting stations is to pump electrons up and down an antenna at changing rates, causing electromagnetic waves to break away and travel through space in all directions. A radio or television set can convert the waves to sound or pictures. Prentice-Hall describes the colour of compounds as resulting from movement of electrons between levels of different energies, producing electromagnetic waves.

Prentice-Hall is the only version which mentions that two electrons in a given orbital spin in opposite directions. Diagrams of energy levels in both Raytheon (pp. 152-154) and Prentice-Hall (p. 397) indicate that as atomic number goes up, electrons enter higher energy orbitals, and energy of the 1s or 2s level decreases consistently from hydrogen to neon as all electrons are pulled closer to the nucleus.

Freeman provides 16 questions examining students' knowledge of electron properties. In Raytheon, Houghton Mifflin and Prentice-Hall, respectively, 11 out of 18 questions, 16 out of 32 questions, and 17 out of 22 questions are taken from the Freeman version.

The practical work on analysis for anions can be done along with Chapter 9 of the Raytheon textbook. Reactions of sulfate, carbonate, chloride, and iodide ions are included in the experiment.

Summary

Table 28. Comparison of Chapter 15 of Freeman Textbook with Corresponding Material in the Three Revisions

	Topics treated			
Version	Energy levels	Orbitals	Additional	Chapter-end exercises
Freeman	notched beam model	dartboard model		16
Raytheon	staircase model; effect of incr. at. no.	Schrödinger eqn.; at. struct. summary; dartboard model	expt. #23 (anion analysis)	18 (61% from Freeman)
Houghton Mifflin	electromag. spectrum, detailed diagram; notched beam model	dartboard model		32 (50% from Freeman)
Prentice-Hall	bookcase model; effect of incr. at. no.	bird model; electron spin	nature of light waves, TV, radio, coloured cpds	22 (77% from Freeman)

Molecules in the Gas Phase

All chemical bonds result from the simultaneous attraction of electrons to two nuclei, according to Chapter 16 of the Freeman version. Directions are given for prediction of the number of bonds that can be formed by an atom in the first three rows of the periodic table. Prediction of bond angles and bond character are explained. Prentice-Hall's presentation of these topics is most meaningful, particularly in its inclusion of the valence-shell electron-pair repulsion theory to explain relative sizes of bond angles.

Diagrams of attractive and repulsive forces operating within and between two hydrogen atoms that approach each other, are provided with no attention given to magnitudes in Houghton Mifflin and Freeman. Raytheon describes crystal growth in terms of total attractive forces exceeding total repulsive forces among the ions present, but provides no Freeman-type diagram. Prentice-Hall (p. 404) does not compare numbers of attractions and repulsions between two hydrogen atoms in specific numerical terms but states that "experiment shows that the attraction terms are greater -- a stable chemical bond is formed". Thus, the Prentice-Hall authors have not overdone their emphasis on the "discovery" approach.

Bond formation by the overlap of two orbitals containing a total of one electron is described in Houghton Mifflin as weak bonding resulting in a reactive molecule. An example of this type of reaction is the union of a hydrogen atom and hydrogen ion to form a H_2^+ ion. Freeman (p. 290) provides specific values of bond energies to show that a bond formed between two atoms that have very different ionization energies tends to be stronger than a bond between atoms that have similar ionization energies. Raytheon is the only version that does not supply a chart showing variation in bond type with difference between ionization energies of atoms present in a molecule. It is simply stated that ionic bonding results from loss or gain of electron(s) by an atom to attain electron configuration of an inert gas (Raytheon, p. 170).

Covalent bonding occurs between two atoms whose ionization energies are of similar magnitude, and whose orbitals are partially filled (Freeman, pp. 279, 289). A diagram showing the drop in potential energy as two hydrogen atoms approach each other, with potential energy reaching a minimum when the atoms are the bond length apart and the covalent molecule forms, is shown in Raytheon (p. 172). The latter is the only version which does not explain the promotion of a 2s electron to a 2p orbital in the carbon atom in order that stability can be maximized in formation of covalent compounds.

Electron dot models of bonded atoms are clearly shown in Prentice-Hall (p. 410) with electrons of one atom as green dots and with black dots for electrons of an atom bonded to it. Freeman shows them all as black dots.

Evidence is presented in Raytheon (p. 184) for the existence of a double bond in the oxygen molecule. It is mentioned that other experimental measurements indicate that there are two unpaired electrons in the oxygen molecule. A complex model has been devised to explain the properties of oxygen.

Prentice-Hall (p. 410) defines a "free radical" as a molecular species with a half-filled valence orbital. For example, the HO unit is the hydroxyl radical and has no electrical charge, whereas OH^- has no unpaired electrons and is classed as an ion since it is charged. Houghton Mifflin (pp. 255, 647) identifies a radical as a group of atoms that acts as a single atom and indicates that radicals may have electrical charge. By the Houghton Mifflin definition, OH^- may be called an ion or a radical. Thus, the interpretations of the word "radical" given in Prentice-Hall and Houghton Mifflin are contradictory. The activity of the radical, BF_3, with ammonia and with fluoride ion is described in Prentice-Hall (pp. 414, 605).

Shapes of second-row fluoride molecules, such as NF_3, are described in Raytheon (p. 339). Since the bonding is the p^3 type, one might expect the bond angles to be 90^o each. Experimental measurement indicates an angle of 102^o and no reason is given for the deviation. Prentice-Hall (p. 418) is the only version which presents an explanation, in the theory that "the arrangement of atoms around any given central atom is determined primarily by the repulsive interactions between electron pairs in the valence shell of that atom". For example, the electron pairs in the C-H bonds in CH_4 move as far apart as possible and the tetrahedron results. Freeman (p. 292) states that "sp^3 bonding (of carbon) always gives bond angles which are exactly or very close to tetrahedral angles", without explaining why.

Prentice-Hall also describes hybrid orbitals. For example, in the oxide ion, one 2s orbital and three 2p orbitals have hybridized to form four identical orbitals such that the central axis of each orbital makes an angle of 109^o 28' with the central axis of every other orbital to achieve maximum distance between the electron clouds. When a proton approaches an orbital of the oxide ion, the electron cloud which results from the bond that forms is shrunk in diameter (becoming longer and narrower). To form water, two protons bond to separate orbitals of the oxide ion forming two shrunken orbitals which are forced closer together by the spreading out of the free electron clouds. Thus, the H-O-H bond angle in water is 104^{o} 30'.

In F_2O, the F-O-F angle of 103^{o} results from the stronger attraction of electrons to F than to H^+. The electron cloud in the bonding orbital stretches out and shrinks in diameter even more than in the water molecule, thus allowing the expanding clouds of free electron pairs to push the bonding orbitals closer together. Directions are given for prediction of molecular geometry (Prentice-Hall, p. 422). Triple bonds are described in all versions except Freeman.

At the end of Chapter 16, Freeman provides 21 questions examining student knowledge of gaseous molecules. In the revisions, 10 out of 25, 20 out of 26, and 19 out of 24 questions are taken from Freeman for the Raytheon, Houghton Mifflin, and Prentice-Hall versions, respectively.

The Freeman and Prentice-Hall versions contain one experiment that is scheduled with Chapter 16 of Freeman - an investigation of some properties of a pair of cis-trans isomers.

Summary

Table 29. Comparison of Chapter 16 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated: Bonding	Topics treated: Additional	Chapter-end exercises
Freeman	force diagrams; bond energies	isomers expt. (#26)	21
Raytheon	no ioniz-energy diff.: bond-type correlation; P.E. diag. for bond formation	omits electron promotion in carbon; O_2^- molecule structure	25 (40% from Freeman)
Houghton Mifflin	force diagrams	"radical" defn.	26 (77% from Freeman)
Prentice-Hall	activity of BF_3; electron-pair repulsion theory; hybrid orbitals; bond angles	isomers expt. (#S-9); "free radical" defn. contradicts H.M.	24 (79% from Freeman)

Bonding in Solids and Liquids

The roles of van der Waals forces, hydrogen bonding, covalent bonding, and metallic bonding in the condensed phases of matter are explained by Chapter 17 of the Freeman version. Properties of ionic solids are investigated. Each of the revisions makes valuable additions to the material found in the Freeman version on the topic of condensed phases. Raytheon provides the description of alloys that is most relevant to modern living. Both Prentice-Hall and Raytheon contain thorough descriptions of crystal-structure types. The Prentice-Hall version gives the most information about boron and graphite. Houghton Mifflin supplies valuable information on the properties of salts.

Van der Waals forces become effective in noble gases that are greatly cooled or compressed, when the electron distribution changes from symmetrical to non-symmetrical, producing a momentary electrical dipole (Raytheon, p. 334). Attractive forces between atoms arise from interaction of the dipoles and cause liquefaction and solidification.

Paraffin and glass are described as very viscous liquids in the Houghton Mifflin version. Glass lacks the regular pattern of a solid and has the capacity to flow, as revealed by window panes which have become thicker at the bottom and thinner at the top in response to gravity.

Raytheon (p. 337) describes molecular solids such as argon, chlorine, and yellow phosphorus, as containing directional bonds, with valence electrons closely associated with a particular molecule, resulting in poor electrical conductivity. Crystals of molecular solids are soft because the inter-molecular forces are weak.

In all versions except Prentice-Hall, network silicates of the 1-, 2-, and 3- dimensional types are described. Prentice-Hall does provide the fullest description of graphite, a layered network solid composed of carbon. The orbitals that are used for bonding form a double bond and two single bonds to each carbon atom. Electrical conductivity along layers of graphite is attributed to delocalization of electrons in the double bond, so that they are free to move between atoms in the sheet. There is another theory that the p_z orbitals on adjacent carbon atoms overlap to make giant orbitals called π-orbitals, extending over the whole sheet. Electrons can move freely over the sheet in π-orbitals.

Atom-packing in solids is described in greatest detail in Prentice-Hall and Raytheon versions. Minimum energy is achieved in a solid where all atoms are identical, by closest packing. The body-centred-cubic geometry of alkali metal crystals is described and shown in diagrams as well as the hexagonal close-packed arrangement displayed by some alkaline earth elements. The structure of aluminum crystals, known as close-packed cubic, is also represented.

Freeman and Raytheon provide the most information about alloys. A table of the composition and use of seven common alloys, including nichrome, bronze, and stainless steel, is supplied by Raytheon. A chart of copper alloys showing the per cent composition and the conductivity of each one, is given in Freeman.

Raytheon accounts for the electrical conductivity of molten salts being lower than for a typical metal. In a metal, electrons are responsible for transport of electrical charge. They have much smaller mass and therefore move at higher velocity than the ions that must move to carry the charge in molten salt.

Structures such as NO_3^- and CO_3^{2-} are classed as polyatomic ions in Houghton Mifflin (pp. 235, 236). Their stability results from a noble-gas electron configuration. The structure of the nitrate ion is described in detail.

Houghton Mifflin contrasts the behaviour of metals and ionic solids subjected to stress. In a mass of metal, one layer of atoms can slide past another and the mobile sea of electrons flows to maintain cohesive force between the layers. When layers of an ionic solid slide over each other so that the positive ions of one layer reach a position directly opposite the positive ions in another layer, negative ions are against negative ions. The tremendous forces of repulsion cause the crystal to crack along the plane between the two layers.

The lowering of freezing point by a solid dissolved in water, the depression being proportional to the number of dissolved particles in a given weight of water, is described quantitatively in Houghton Mifflin (p. 241). The freezing point of water is lowered 1.86C° for each mole of solute particles in solution in 1 kg of water. This regularity is applied for determination of molecular weight and for determination of how many ions are formed by each formula unit of an ionic compound when it dissolves.

In accounting for solubility of solid sodium chloride in water, Prentice-Hall (p. 453) considers the factors of minimum energy and maximum randomness. The dissolving process is endothermic, with a ΔH value of +0.9 kcal/mole. The increase in randomness, expressed in energy terms, amounts to -8.4 kcal/mole. Thus, the net energy value favours solution.

Boron is described in Prentice-Hall (p. 448) as an element that has not enough valence electrons to form network solids as carbon does, and not enough empty orbitals and easily available electrons to bond like a metal. The structural unit in all forms of boron is a cluster of 12 atoms called an icosahedron. Within each cluster, electrons are delocalized but between clusters there are normal covalent bonds. Thus, boron is neither a metal nor a non-metal. The formation of boron hydrides is described.

Freeman provides 16 questions to examine student knowledge of condensed phases. In Raytheon, Houghton Mifflin, and Prentice-Hall versions, respectively, 18 out of 23, 15 out of 20, and 16 out of 20 questions are taken from the Freeman version.

Experimental work in all versions includes a study of the packing of atoms or ions in crystals, involving construction of styrofoam models.

Summary

Table 30. Comparison of Chapter 17 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated: Bonds and forces	Topics treated: Additional	Chapter-end exercises
Freeman		alloys	16
Raytheon	dipole in rare gases; molecular-solid properties	crystal structure; alloys; conductivity, molten salts vs. metals	23 (78% from Freeman)
Houghton Mifflin	properties of glass; effect of stress, metals vs. ionic solids	polyatomic ions; freezing point depression	20 (75% from Freeman)
Prentice-Hall	no network silicates; graphite in detail; boron structure	crystal structure; NaCl solubility	20 (80% from Freeman)

Table 31. Comparison of Experiments in the Four Versions, Relevant to Chapter 17 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Packing of atoms or ions	27	38	9	31

CHAPTER V

DETAILED COMPARISON OF FREEMAN VERSION WITH THE THREE REVISIONS: DESCRIPTIVE CHEMISTRY

The last eight chapters of the Freeman version are devoted to descriptive chemistry. CHEM Study philosophy minimizes attention to purely descriptive aspects such as the structures of common polymers and drugs. The emphasis is on applicability of chemical principles to the groups of elements and compounds studied.

Chemistry of Carbon Compounds

There are three main aims in the presentation of organic chemistry by the Freeman version. It should be shown that structure is important in determining chemical behaviour, that "functional" groups can be associated with general types of behaviour, and that certain patterns of breaking old bonds and formation of new bonds characterize organic compounds. The three revisions contain no major changes from the Freeman version, but they have included a few additional facts that may increase the reader's understanding of organic chemistry.

The addition of an odorous sulfur-containing compound to methane for cooking and heating is explained in Houghton Mifflin. Such an impurity is required by law for safety in commercial consumption since methane is colourless and odourless and does not support life.

Composition of modern gasolines is described in Houghton Mifflin. The main components are medium and lighter compounds produced from fractional distillation of crude oil. Tetraethyl lead is used to improve the burning qualities. Processes such as alkylation and catalytic cracking improve quality and yield of gasoline respectively.

Freeman and Prentice-Hall describe in detail the reaction between methyl bromide and the hydroxide ion, with molecular models and potential energy graphs to represent stages in the mechanism of the reaction.

Nuclear magnetic resonance (nmr) spectroscopy is a technique suggested in Prentice-Hall for determination of the structure of isomers. For example, ethanol is an isomer of dimethyl ether. The compound, CH_3CH_2OH, known as ethanol, has three different nmr frequencies, representing hydrogen atoms in three different positions. For dimethyl ether, CH_3OCH_3, only a single nmr frequency should be observed, since all six hydrogens are identical.

Tables displaying regularities in names of parent alkanes and their derived alcohols, amines, acids, amides, and methyl esters are in all versions, except Raytheon. (None of the four versions is explicit enough in pointing out the regularities.) Species containing one, two, three, four, and eight carbon atoms per molecule are included in the tables. There is a misrepresentation in Houghton Mifflin (p. 562) of molecular models of alcohols, aldehyde, ketone, and carboxylic acid. Four bonds should be shown associated with each carbon atom.

Quantitative data for the benzene ring structure are provided by Raytheon. The distance between adjacent carbon atoms in a benzene ring is 1.40 Angstroms, as compared with 1.54 Angstroms and 1.33 Angstroms between adjacent carbon atoms in ethane and ethylene respectively. This suggests that the carbon-to-carbon bond in benzene is intermediate between a single bond and a double bond. Raytheon represents benzene by a hexagon with an enclosed circle. All other versions make greater use of a hexagonal symbol with alternate bonds shown as double bonds. However, they do mention that experimental evidence shows that all six bonds are identical.

The "π cloud" of delocalized electrons located above and below the benzene ring's surface is described in Prentice-Hall. The electrons in the π cloud move all around the benzene ring. Aromatic compounds are defined as those compounds containing rings with delocalized electrons.

Raytheon describes the structure of the enzyme lysozyme, which increases the rate of decomposition of polysaccharides in bacterial walls. In 1966, lysozyme was found to consist of a chain of 129 amino acids, partly coiled and partly uncoiled, and containing 1,940 atoms per molecule.

At the end of Chapter 18, Freeman provides 22 questions to examine the student's knowledge of organic chemistry. In the corresponding chapters in Raytheon, Houghton Mifflin, and Prentice-Hall, respectively, 14 out of 25, 21 out of 33, and 22 out of 24 questions are taken from Freeman.

Experimental work in all versions includes a study of some reactions of hydrocarbons and of alcohols. Raytheon again directs that trichlorotrifluoroethane (TTE) should be used as a solvent instead of carbon tetrachloride, for safety reasons. Raytheon and Prentice-Hall provide structural formulas of alcohols and hydrocarbons used in the experiment, which gives their presentations greatest clarity. They also include a note of caution regarding the use of sodium.

Another experiment contains procedures for preparation of derivatives of organic acids. Preparation of ethyl acetate is outlined in all versions. Houghton Mifflin and Freeman give directions for preparing acetamide, and Raytheon describes preparation of methyl salicylate. All versions except Raytheon contain a procedure for preparing some polymers.

Summary

Table 32. Comparison of Chapter 18 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated: Aliphatic	Topics treated: Aromatic	Chapter-end exercises
Freeman	$CH_3Br + OH^-$		22
Raytheon	no tables of regularities in names; lysozyme	C_6H_6 bond lengths; symbol:circle in hexagon	25 (56% from Freeman)
Houghton Mifflin	CH_4 safety; gasoline composition; error p. 562 models		33 (64% from Freeman
Prentice-Hall	$CH_3Br + OH^-$; nmr to identify isomer	π cloud, delocalized e^-	24 (92% from Freeman)

Table 33. Comparison of Experiments in the Four Versions, Relevant to Chapter 18 of the Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Reactions, hydrocarbons + alcohols	28	39	27	32
Prep. org. acid derivatives	29 acetamide	40 Me salicylate	S-6 acetamide	33
Prep. of polymers	29a		28	S-10

Halogens

Similarities and systematic differences are displayed by the elements in column VII of the periodic table. Atomic structure and chemical properties of the halogens are described in Freeman and Houghton Mifflin, whereas Prentice-Hall deals almost exclusively with structure and dimensions of the atoms and ions. Commercial uses of halogens are explained more thoroughly in Raytheon than in the other versions.

The CHEM Study Steering Committee decided to omit the Bohr model of the atom from their textbook since that model is now of historical value only. However, the revision published by Houghton Mifflin (pp. 440,441) contains Bohr models for the four lightest halogen atoms. Possibly such a reversion to the traditional form will inhibit the student's learning of the modern model.

The influence of electron configuration on bonding behaviour is described only in Freeman and Houghton Mifflin. Two atoms of a given halogen bond together covalently but a halogen atom forms an ionic bond with an alkali metal.

Preparation of fluorine gas by electrolysis of KHF_2 is described in Raytheon. A copper reaction-vessel is suitable since a resistant layer of copper (II) fluoride forms and protects the underlying metal from rapid corrosion. Industrial preparation of bromine from sea water is explained only in Freeman.

Dissociation constants for conversion of halogen molecules at $1000^{\circ}C$ to uncombined halogen atoms are provided only by Freeman and

Houghton Mifflin. The constant is greater for iodine than for chlorine since iodine's bond energy is smaller. Bonding electrons are farther from the nucleus in the iodine atom, since it is a larger atom than chlorine. Electrical forces of attraction between the iodine nucleus and valence electron are small; therefore, bond energy in a covalent iodine molecule is low and dissociation occurs readily.

The use of iodide ion as a reducing agent and free iodine as an oxidizing agent for quantitative analyses is described only in Freeman and Houghton Mifflin. They are the only versions that deal with disproportionation and the effect of hydrogen-ion concentration on oxidation of halogens.

Prentice-Hall explains that differences in nuclear pull result in negative ions being larger than positive ions or neutral atoms that have the same number of electrons. The radius assigned to an atom is determined by the bonding situation in which the atom exists. Possible measurements include covalent radius, van der Waals radius, metallic radius, and ionic radius. Positive oxidation states of halogens and the properties of fluorine are described in all versions except Prentice-Hall.

Major uses of halogens are listed in a table in Raytheon (p. 389). The use of silver bromide for black and white photography is explained in detail. Photographic film is a sheet of transparent plastic covered with a thin layer of gelatin. Suspended in the gelatin are very fine crystals of silver bromide, a salt which on exposure to light decomposes to silver metal and free bromine. The four steps by which a finished print is produced from an unexposed film are exposure, development, fixation, and printing. Each step is clearly explained in Raytheon.

The carbon-fluorine bonds in teflon are so strong that the protective coating on cooking pans shows almost no tendency to react with other substances (Raytheon, p. 391). Valves and stopcocks of teflon are used extensively for handling corrosive chemicals.

Freeman provides 20 questions which examine the student's knowledge of halogens. In Raytheon, Houghton Mifflin, and Prentice-Hall, respectively, 20 out of 20, 7 out of 13, and 16 out of 20 of the questions about halogens are taken from Freeman.

Laboratory work includes electrolysis of aqueous potassium iodide. Again, Raytheon directs that TTE should be used as a solvent instead of carbon tetrachloride, since it is much safer. Some properties of iodide ion, iodate ion, and free iodine are examined in another experiment.

Summary

Table 34. Comparison of Chapter 19 of Freeman Textbook with Corresponding Material in the Three Revisions

	Topics treated			
Version	Bonding	Industrial	Additional	Chapter-end exercises
Freeman	e^- config. effects; dissoc. constants	Br_2 prep.	iodimetry; disproportionation	20
Raytheon		F_2 prep.; uses of halogens: photography, teflon		20 (100% from Freeman)
Houghton Mifflin	e^- config. effects; dissoc. constants		Bohr models; iodimetry; disproportionation	13 (54% from Freeman)
Prentice-Hall			ion + atom sizes; omits pos. oxid. states of halogens; omits F_2 properties	20 (80% from Freeman)

Table 35. Comparison of Experiments in the Four Versions, Relevant to Chapter 19 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Electrolysis of $KI_{(aq)}$	30	41	21	28
Chemistry of iodine	31	42	22	34

Third Row of the Periodic Table

Changes in kind of properties are evident as one considers the elements across a row of the periodic table. Physical properties of the third-row elements range from those typical of metals to those typical of non-metals. The variations are related to the kind of bond that is characteristic of each element. Gradual decrease in ability of an element to act as a reducing agent and gradual change from basic hydroxide through amphoteric hydroxide to acidic hydroxide are interpreted. Descriptive information about the occurrence and preparation of third-row elements is provided as well, in Chapter 20 of the Freeman version.

Raytheon's detailed treatment of third-row elements is limited to investigation of their acidic and basic properties (Raytheon, pp. 272-274). Except for some added photographs, the Houghton Mifflin presentation is almost identical to Freeman. In Prentice-Hall, material is carefully integrated and clarified so that it departs farthest from the "encyclopedic recitation of facts" that Freeman aimed to avoid (Freeman, Teachers Guide, p. 659).

Trends among second-row elements are described briefly in Prentice-Hall, and elements of the third row are compared with them. Sodium is compared with lithium in electron configuration, ionization energy, and metallic character. It is observed that for the first three elements of each row, metallic character decreases from the element at the top of the column to the elements farther down in the column.

Electronic structure of silicon after electron promotion is shown in Prentice-Hall. It is suggested that the very small electrical conductivity of silicon may result from a few valence electrons acquiring enough energy to be non-localized, perhaps into 3d orbitals. The slight conductance makes this element useful in transistors. In describing the structure of silicon, Freeman merely states that the presence of a few non-localized electrons accounts for the slight conductivity of silicon and that most of the electrons are localized in covalent bonds.

Prentice-Hall (p. 501) provides a table of the first four ionization energies of the first four elements in rows two and three of the periodic table. A detailed table of physical properties of elements of row three is provided which includes appearance, hardness, melting point, boiling point, electrical conductance, ductility, malleability, lustre, density at 25°C, and other properties. There are separate sets of properties for red phosphorus and white phosphorus. Red phosphorus is not described in the other three versions of the course.

Although silicon is in the same family as carbon, no form of silicon having the planar structure of graphite has been found. None of the third-row elements participates in multiple bonds like carbon and nitrogen do (Prentice-Hall, p. 502).

Chemistry of phosphorus is described more fully in Prentice-Hall than in other versions. It is stated that in yellow phosphorus, the component P_4 molecules are held together by van der Waals forces only. Therefore, white phosphorus has a lower melting point and lower boiling point than red phosphorus, which is a network solid. Black phosphorus is much like the red allotrope, with a structure resembling double corrugated sheets (Prentice-Hall, p. 503). It is flaky and crystalline, somewhat like graphite.

Structural models of P_4O_6 and P_4O_{10} are provided in Prentice-Hall (p. 508). When phosphorus reacts, electrons must be released (or shared) from atoms in the phosphorus molecule, not from single atoms in the gaseous state. White phosphorus is the most reactive form, tending to insert an oxygen atom between each pair of phosphorus atoms on the edge of the tetrahedron to form P_4O_6. Oxidation of P_4O_6 adds an oxygen atom to each of the free electron pairs on each phosphorus atom, to form P_4O_{10}.

Sulfur forms a diatomic molecule, S_2, at very high temperatures, although third-row elements do not tend to form conventional multiple bonds with each other. Solid sulfur consists of cyclic S_8 molecules with strong van der Waals forces and has a melting point of approximately 100°C. At higher temperatures, one of the bonds in the ring can break open to form chains that intertwine and grow, as a viscous, almost rubbery liquid is produced (Prentice-Hall, p. 504).

Trends in the second and third rows are compared. In the third row, the tendency to form metals extends farther to the right because ionization energies remain lower. The tendency to form network solids extends farther to the right in the third row since there is no tendency to form multiple bonds.

Definitions of oxidation and reduction are clearly reviewed in basic terms (Prentice-Hall, p. 505) before the oxidizing and reducing capacities of elements of the third row are investigated. The presentation in Freeman (p. 367) does not deliberately integrate the old material with the new and thus it does not facilitate the learning process. In Prentice-Hall, the mechanism for oxidation of solid sodium to sodium ions in aqueous solution is not developed, but is left for more advanced courses.

Magnesium hydroxide is described as a weaker base than sodium hydroxide. Magnesium ion, Mg^{2+}, has a greater oxidation number and smaller size than Na^{+} ion, and thus has a stronger attraction for electrons. By the same line of reasoning, one can explain why aluminum hydroxide is weaker than magnesium hydroxide (Prentice-Hall, p. 511).

A clear description of possible bond breakages in MOH (where M represents an element from the third row plus unspecified oxygen and OH groups) is provided by Raytheon (p. 272). If the element has a low ionization energy, electrons are released to oxygen. Therefore, sodium hydroxide and magnesium hydroxide are strong bases. If the element has a high ionization energy, it has a strong tendency to attract electrons from the oxygen atom. Therefore, the oxygen atom is less able to bind the proton. This behaviour is represented by the strong acids, H_2SO_4 and $HClO_4$, which readily liberate protons.

A rule of thumb is provided in Prentice-Hall (p. 513) for estimating the approximate ionization constant of an acid from the number of oxygen atoms attached to the central atom of the acid. There is a regular decrease in strength of the hydrogen-oxygen bond as we proceed from hypochlorous to perchloric acid.

The methods of preparation and occurrence in nature of third-row elements are not described in Prentice-Hall. Photographs of Great Salt Lake flats, flooded for extraction of sodium chloride, and of molten sulfur pouring from the discharge pipe of a sulfur well are provided by Houghton Mifflin.

Freeman supplies 17 questions to examine the student's knowledge of third-row elements. In Houghton Mifflin and Prentice-Hall, respectively, 22 out of 26 and 17 out of 20 questions are taken from Freeman.

Laboratory work in Freeman and Houghton Mifflin is a comparison of relative acid-base strength of the hydroxides of row three of the periodic table. The same investigation is designed as a demonstration in Prentice-Hall.

Summary

Table 36. Comparison of Chapter 20 of Freeman Textbook with Corresponding Material in the Three Revisions

	Topics treated		
Version	Phys. properties	Chem. properties	Chapter-end exercises
Freeman	omits red P		17
Raytheon		(acidic + basic properties only)	
Houghton Mifflin	photographs: salt mine, salt flats, molten S		26 (85% from Freeman)
Prentice-Hall	comp. with row 2; 3d electrons of Si; detailed table, row 3; no multiple bonds, row 3; phosphorus networks; molten S structure	P_4O_6, P_4O_{10} struct. models + formation; strengths of acids + bases; omits prep. and source of elements	20 (85% from Freeman)

Table 37. Comparison of Experiments in the Four Versions, Relevant to Chapter 20 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Third-row elements	32		24	Dem. 22

Second Column of the Periodic Table

Application of principles in the study of alkaline earth elements is the intent of Chapter 21 of the Freeman version. Trends shown in the structure of the atoms and in ionization energy are investigated. Attention is given to basic properties of the oxides and solubility of the salts. Commercial sources of second-column elements and methods for their extraction are described.

Raytheon does not deal with the chemistry of alkaline earth elements. The Prentice-Hall presentation is limited to ionization energy and structure of the atoms. Table 21-11 from Freeman (p. 379) consisting of data on interatomic distances, has been organized more clearly in Prentice-Hall (pp. 523,524). Two tables have been formed - one providing metallic radii derived from distance between atoms in metal, and the other providing ionic radii based on internuclear distance in the solid oxide (assuming that the O^{2-} radius is 1.32 Å). The double bond radius is omitted.

Houghton Mifflin's treatment of alkaline earth elements is almost identical to Freeman. Unfortunately, the colour photograph of four flame tests that is provided in Houghton Mifflin is very misleading. All of the flames look orange, whereas the barium flame should be pale green and the magnesium flame should be white. In Freeman (p. 382), BeO^{2-} was incorrectly indicated as a product in equation (6). Houghton Mifflin (p. 464) corrects it to read BeO_2^{2-}.

No questions are supplied by Freeman at the end of Chapter 21 but there are some exercises within the body of the Chapter, to examine the student's knowledge of column two elements. Prentice-Hall provides three questions, and Houghton Mifflin gives 23 of which 9 are taken from Freeman's exercises.

Laboratory work includes development of a scheme of qualitative analysis, qualitative analysis for second-column cations, and analysis for Ag^+, Hg_2^{2+}, and Pb^{2+} ions. Prentice-Hall omits flame tests in the second-column analysis. All versions except Houghton Mifflin contain a qualitative analysis for anions.

Summary

Table 38. Comparison of Chapter 21 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated	Chapter-end exercises
Freeman	error in formula	nil
Houghton Mifflin	poor photograph of flame tests	23 (39% from Freeman)
Prentice-Hall	(ioniz. energy + at. structure only); clear tables	3

Table 39. Comparison of Experiments in the Four Versions, Relevant to Chapter 21 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Qual. analysis scheme	33	19 (for R.Ch.7)	S-7	S-6
Qual. anal., column 2	34	20 (for R.Ch.7)	23	20
Qual. anal., Ag^{+}, Hg_2^{2+}, Pb^{2+}	35	22 (for R.Ch.8)	17	S-7
Anion analysis	36	23 (for R.Ch.9)		S-8

Fourth-Row Transition Elements

Regularities shown by fourth-row elements with d-orbital valence electrons are investigated in Chapter 22 of Freeman. The geometry, bonding, and reactions of complex ions and complex compounds formed by transition elements are examined. Specific properties of the elements are described and are linked to chemical theories where possible.

The quantity of purely descriptive detail about transition elements is reduced in the Raytheon and Prentice-Hall versions as compared with Freeman. For example, detailed description is limited to one or two transition elements rather than including all ten elements. A few interesting photographs and diagrams of chemical processes have been introduced in the revisions, as well as some additional relevant facts.

Description of chromium compounds and complexes, including variation of colour with oxidation number, is briefer and clearer in Raytheon (pp. 400-402) than in the other versions. Attention is restricted to fewer compounds.

Colours that are characteristic of many compounds of transition elements are due to absorption of light in the visible part of the spectrum. Energy levels, mainly d-orbitals, account for the absorption. Zinc as Zn^{2+}, in which all d-orbitals are filled, is colourless in all its compounds (Houghton Mifflin, p. 510). A change in environment may cause a change in energy-level spacing, and change in colour. For example, when ammonia is added, $Cu^{2+}(aq)$ ion changes from light blue to deep blue (Freeman, p. 400), and $Ni^{2+}(aq)$ ion changes from green to blue (Raytheon, p. 399).

Models for cobalt complexes - $(CoCl_4)^{2-}$, which colours its solutions blue, and $[Co(H_2O)_6]^{2+}$, which colours its solutions red - are provided by Prentice-Hall (p. 536). An equation is supplied to account for the colour change from blue to pink that occurs when cobalt (II) chloride paper is used as a moisture-sensitive unit.

All versions except Raytheon describe alums and the amphoteric nature of complexes. Bonding patterns that correspond with specific geometric arrangement of complex ions (for example, dsp^2 bonding with square planar geometry) are not identified in Raytheon. The use of methylene blue for treatment of carbon monoxide poisoning is not mentioned. Prentice-Hall is the only version that describes cobalamin, the coenzyme of vitamin B_{12}. Complexes of cobalt and other metals are believed to be used by bacteria in the root of the clover plant to convert nitrogen of the air to protein. Synthesis of the same protein from nitrogen in the laboratory requires a temperature of $450^\circ C$ to $500^\circ C$ and pressures of hundreds of atmospheres (Prentice-Hall, p. 542).

The formation of the earth is described in Raytheon. The earth's centre is believed to be mainly nickel and iron. It is speculated that molten iron at a temperature of several thousand degrees moved toward the centre and silicates, which are less dense and make up the outer layers of the earth's crust, floated on top of the liquid metals.

Properties of each fourth-row transition element are described in detail in Freeman and Houghton Mifflin. Houghton Mifflin provides a photograph of cage-zone refining of titanium. Melted titanium is trapped inside a bar of the solid metal, in a bell jar containing argon or neon.

Raytheon gives detailed description of the most commonly used transition element only - the element iron. Both iron and chromium are described in Prentice-Hall.

Operations involved in the use of a blast furnace, from loading of ore to removal of iron and slag, are listed in Raytheon, along with the temperature and chemical equation for each chemical change that occurs. These facts are placed in appropriate positions beside a cross-sectional diagram of an operating blast furnace. A similar diagram is provided in Houghton Mifflin. However, temperatures are not given and relevant equations are scattered through the text. The same version contains a photograph of a man "tapping" the blast furnace (removing molten iron). Three methods of converting cast iron into steel are explained in Freeman and Houghton Mifflin. A method for quantitative determination of iron is suggested in Prentice-Hall, involving titration of Fe^{2+} with the oxidizing agent, potassium dichromate.

The Goldschmidt process for producing pure chromium is described in Houghton Mifflin and Freeman. A photograph of the pure copper cathodes in an electrolytic refinery is given in the former textbook.

Twenty questions are provided in Freeman which will test the student's knowledge of fourth-row transition elements. The corresponding questions in Raytheon and Prentice-Hall are all taken from Freeman, as well as 18 of the 20 questions in Houghton Mifflin.

Laboratory work includes the separation of iron, cobalt, and nickel ions with an anion exchange resin, and investigation into the corrosion of iron. Procedures are given for the preparation of three compounds -

a complex salt, potassium dichromate, and chrome alum. All versions except Raytheon contain the method for preparing a double salt.

Summary

Table 40. Comparison of Chapter 22 of Freeman Textbook with Corresponding Material in the Three Revisions

	Topics treated		
Version	Industrial	Additional	Chapter-end exercises
Freeman	Fe to steel, 3 ways; detail, 10 elements	Cu^{2+} colour	20
Raytheon	omits alums and methylene blue; detail on iron and blast furnace	formation of earth; briefest re Cr cpds; Ni^{2+} colour; omits amphoteric complexes, bonding patterns	17 (100% from Freeman)
Houghton Mifflin	Ti refining; blast furnace for Fe, diagram + photog; Fe to steel, 3 ways; detail, 10 elements	colourless Zn^{2+}	20 (90% from Freeman)
Prentice-Hall	detail on iron and chromium	cobalt complexes, detail; cobalamin; quant. anal. for Fe	18 (100% from Freeman

Table 41. Comparison of Experiments in the Four Versions, Relevant to Chapter 22 of Freeman Textbook

Subject of experiment	Experiment Number			
	Freeman	Raytheon	H.M.	P-H.
Sep. of transition metal ions	37	43	26	35
Corrosion of iron	38	35	S-8	29
Prep. complex salt and double salt	39		25	37
Prep. $K_2Cr_2O_7$	40	45	S-9	38
Prep. chrome alum	41	46	S-10	39

Some Sixth- and Seventh-Row Elements

Lanthanides and actinides are elements in which the 4f and 5f orbitals respectively are filling up. These thirty elements are described in the Freeman and Houghton Mifflin versions only. Electron configuration, oxidation states, and occurrence are investigated. Types of radioactive behaviour and sources of nuclear energy are considered.

Houghton Mifflin provides a little more information than Freeman. For example, the electronics industry is identified as one market for rare earth elements. Europium oxide is used in colour-television picture tubes.

In comparing lanthanides and actinides, the Houghton Mifflin version notes that uranium, an actinide, is best known as the uranyl ion, UO_2^{2+}, in which uranium has oxidation number 6, whereas neodymium, its mate in the lanthanides, has no important complexes except those of Nd(III) and there are no Nd(VI) complexes at all. The lanthanides appear to have a simpler chemistry than the actinides, which have a multiplicity of oxidation states.

Photographs of the top of a nuclear breeder reactor and of a human operator using mechanical hands to move radioactive material are shown in Houghton Mifflin (p. 534). There are also diagrams representing radioactive decay of uranium-238, nuclear fission of uranium-235 and nuclear fusion of hydrogen isotopes.

There are exercises within the chapter instead of questions at the end of Chapter 23 of Freeman. Houghton Mifflin provides 18 questions of which 5 are taken from Freeman's exercises, to examine the student's knowledge of lanthanides and actinides.

Relevant laboratory work is found in the Prentice-Hall version and includes a determination of half-lives of metastable indium-113 and barium-137, and determination of the shielding thickness of lead.

Summary

Table 42. Comparison of Chapter 23 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated	Chapter-end exercises
Freeman	no photographs; sl. less info. than in H.M.	nil
Houghton Mifflin	europium oxide, use; U vs. Nd; photog;nuclear reactor; diagrams for nuclear reactions	18 (28% from Freeman)
Prentice-Hall	expts:half-life determinations (#S-11), shielding thickness of Pb (#S-12), relevant to Ch. 7 of P-H.	

Some Aspects of Biochemistry

The application of chemical principles in biochemistry is shown in Chapter 24 of the Freeman version. Properties of sugars, cellulose, starch, and fats are described. Metabolism of glucose is investigated and enzymes are examined briefly. The study of ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) has been omitted from the Freeman version, as those topics were considered more suitable for advanced courses in chemistry (Freeman Teachers Guide, p. 745).

Houghton Mifflin supplies a treatment of biochemistry that is almost identical to Freeman except for the inclusion of several photographs, some of which are of questionable value. Prentice-Hall gives the least traditional account. Reactions for the metabolism of glucose and the acetic acid cycle are omitted and DNA and RNA are dealt with in Prentice-Hall.

The reduction of glucose to sorbitol followed by reaction of sorbitol with acids to form esters is not described in Raytheon and Houghton Mifflin. The oxidation of an aldose to carboxylic acid by cupric ion, to produce the red solid cuprous oxide, is also omitted. All versions except Prentice-Hall provide equations for the energy-yielding reactions of glucose, pyruvic acid, and acetic acid.

Photographs of sugar-cane harvesting, rice harvesting, and honeybees on a honeycomb are provided in Houghton Mifflin (p. 584). These photographs are of questionable value except perhaps for culturally disadvantaged children or for elementary-school picture collections. Still more critical comments are applicable to the photographs of a basket of eggs, pieces of raw meat, and a glass of milk which take up seven-eighths of a page. These objects are too universally familiar to merit space in a high school chemistry textbook (Houghton Mifflin, p. 586). They would be excellent for teaching vocabulary to immigrants from foreign countries.

The detailed structure of the enzyme, lysozyme was determined in 1966. This enzyme increases the rate at which polysaccharides in bacterial walls are broken into smaller units (Raytheon, p. 376). Ribonuclease, which helps to break down ribonucleic acid, was the first enzyme to be synthesized. The synthesis was reported by American scientists in 1969 (Prentice-Hall, p. 559). Photographs of crystals of catalase and urease are provided in Houghton Mifflin. Since these enzyme crystals are microscopic in size, the photographs show them highly magnified. The pictures are valuable in that they give the student a concept of properties of pure substances that he is not likely to observe firsthand.

Pictures of magnified yeast cells and muscle cells which convert glucose to simpler substances for the release of energy, are provided as well.

Description of "false substrates" which slow down or stop reactions by inhibiting enzymic catalysis is included in all versions except Raytheon. Explanation of enzyme specificity is not provided either.

Prentice-Hall is the only version that deals with nucleic acids. Deoxyribonucleic acid was first isolated as gelatinous material in 1869. It was suggested in 1884 as the carrier of genetic information. In 1953, the now-accepted structure of DNA was established by Watson, Wilkins, and Crick. Two very long, thin, polymeric chains of nucleotides are twisted about each other in a double helix. Each nucleotide consists of a deoxyribose sugar molecule linked to a phosphoric acid molecule and a nitrogen-containing base attached to the sugar molecule. Hereditary information is transmitted by the order in which nitrogen bases are attached to the deoxyribose-phosphate backbone of the DNA chain.

The template action by which each DNA helix can duplicate itself is described. Using natural DNA as their template in contact with DNA polymerase and a mixture of the four nucleotides that constitute DNA, Kornberg and Goulian synthesized an active virus. The synthetic virus, first produced in 1967, could attack and kill bacteria as effectively as natural DNA.

The role of RNA in biology is still not well understood. It contains ribose sugar in the chain instead of deoxyribose and has the nitrogen base, uracil substituted for thymine. Generally, RNA forms single strands. The use of RNA for cancer treatment is described in Prentice-Hall.

Twelve questions requiring the pupil to have knowledge of biochemistry are provided by Houghton Mifflin, of which 5 are taken from Freeman's exercises.

No laboratory experiments are provided that are relevant to Freeman, Chapter 24.

Summary

Table 43. Comparison of Chapter 24 of Freeman Textbook with Corresponding Material in the Three Revisions

Version	Topics treated	Chapter-end exercises
Freeman	omits nucleic acids	nil
Raytheon	omits sorbital esters and aldose oxidn.; lysozyme structure; omits enzyme specificity	nil
Houghton Mifflin	omits sorbital esters and aldose oxidn.; appropriate photographs? catalase, urease, yeast, muscle photog.	12 (42% from Freeman)
Prentice-Hall	omits glucose metabolism and acetic acid cycle; ribonuclease synthesis; DNA history, properties; virus synthesis; RNA, structure and use	nil

Chemistry of Earth, the Planets, and the Stars

Chemical principles that apply to samples in test tubes apply to the entire universe. However, planetary chemistry and geochemistry involve the study of some very slow processes that occur over millions of years. Structure of the earth and ways of determining the age of the earth are described in Chapter 25 of Freeman, in addition to the chemistry of planets, meteorites, and stars.

Lunar exploration is given detailed treatment only in Prentice-Hall. Raytheon provides interesting information about nuclear reactions but omits the chemistry of planets and stars.

A table of data for radioactive rays is supplied by Raytheon. For alpha, beta, and gamma rays, the speed after emission, composition, and penetrating power are indicated. Detailed interpretation of nuclear equations is also given. The emission of a beta particle occurs when a neutron disintegrates, producing three particles - a proton, an electron, and a neutrino. Stages in radioactive decay of uranium-238 to lead-206 are shown in graphical form. The concept of half-life of radioactive species is explained clearly. Prentice-Hall is the only version which does not supply a detailed description of the spontaneous nuclear reactions from which the age of the earth has been estimated.

Graphs represent the repulsion that exists between an alpha particle and the nucleus of an atom, and the absence of repulsion between the neutron and nucleus of an atom. This difference accounts for the greater probability of nuclear reaction with a neutron than with an alpha particle. A proton can be accelerated to allow it to react with the lithium nucleus, producing two helium atoms. Similarly, beryllium compounds have been penetrated by alpha particles.

The positron or positive electron was discovered by Anderson in his study of cosmic rays (Raytheon, p. 419). Positrons are emitted in the spontaneous decay of nitrogen-13. Each positron tends to react with a negative electron to produce gamma radiation.

To promote nuclear fusion, by overcoming the repulsive force of two hydrogen nuclei, the temperature must be about 2×10^8 ^oK, according to Raytheon, such that the gases are converted to plasma. The fusion of four protons to form one helium nucleus is responsible for the energy production during the longest period of existence of a star, such as the sun. The amount of radiant energy emitted by a star is proportional to the mass of the star (Houghton Mifflin, p. 616).

A table of approximate distances of six celestial bodies from earth, and a diagram of nine known planets revolving about the sun, are included in the Houghton Mifflin version. The atmospheres of nine planets are described in tabular form in Prentice-Hall.

Interesting information about Mars is provided in Prentice-Hall and Houghton Mifflin. The atmosphere is believed to have high concentrations of carbon dioxide and atomic oxygen. The surface is covered with craters similar to those on the moon but there has been no erosion by water which suggests that there has been no life on Mars for a few hundred million years. Mars has no magnetic field; therefore, the core is not hot and molten. There is no volcanic or radioactive energy in the lithosphere of Mars.

The isotopes of carbon are described in a table in Raytheon, including the type of decay and half-life characteristic of each isotope. Radiocarbon dating and isotopic tagging are described as applications for the radioactive isotopes.

Meteors are described in the greatest detail in Houghton Mifflin. They range from microscopic size to perhaps several miles in diameter. Those that strike the earth's surface are called meteorites. An estimated two million tons of micrometeorites per year fall to earth.

Information gained from space flights before anyone had landed on the moon is contained in Prentice-Hall. A device designed by Dr. Turkevich was used to estimate the composition of the moon's surface layer. The scattering of alpha particles directed at the surface of the moon indicated the atomic mass of atoms that were struck. A table is provided in Prentice-Hall indicating the composition of the lunar surface as measured by the alpha-particle scattering device. Other interesting lunar data are supplied by the textbook.

Raytheon provides 11 questions to examine the student's knowledge of radioactivity and nuclear changes, and Houghton Mifflin has 25 questions about earth and space.

Summary

Table 44. Comparison of Chapter 25 of Freeman Textbook with Corresponding Material in the Three Revisions

	Topics treated		
Version	Nuclear reactions	Earth, planets, stars	Chapter-end exercises
Freeman			nil
Raytheon	radioactive rays; neutrino + beta particle; U-238 decay graph; ½-life; positron; fusion; carbon isotopes, uses	omits planets, stars	11 (45% from Freeman)
Houghton Mifflin		solar system diag; detail, Mars; meteors	25 (none from Freeman)
Prentice-Hall	omits U-238 decay detail	Turkevich device; lunar exploration detail; Mars detail	nil

CHAPTER VI

COMPARISON OF TEACHERS' GUIDES AND PROGRESS TESTS FOR THE FOUR VERSIONS

Teachers' Guides

The teachers' guides are designed for the teacher who is isolated from other chemistry teachers, with less than ideal training, teaching in a poorly equipped school.

For each chapter of the textbook, Freeman and Houghton Mifflin include a separate section in their teachers' guides, describing the philosophy and new concepts. The content of the chapter is interpreted and pedagogical methods for presentation of theory and experiments are suggested. The recommended time schedule coordinates readings, problems, films, and experiments. "Background Discussion" consists of advanced concepts in philosophy and theory of chemistry, some of which the teacher may incorporate into class lessons. Specific films, books, and other supplementary materials are listed. Answers are given for textbook exercises and problems, and more questions suitable for quizzes are provided in the Guide for Chapters 1 to 17 (Freeman, Teachers Guide, p. 3).

Organization of the Houghton Mifflin Teacher's Guide differs slightly from Freeman by insertion of the time schedule and related materials for the entire 25 chapters in one block in Appendix I. Raytheon is the only version having the teacher's guide in two volumes. There is a Teacher's Laboratory Guide and a Teacher's Guide. The total content of the Raytheon Guides is much like Freeman.

Prentice-Hall's teacher's guide is in one volume and contains two sections for easy reference - a guide to the student text in Part One and a guide to student laboratory manual in Part Two. Part One includes for each chapter, background discussion supplying pertinent information to the teacher, a development section describing rationale of the chapter and methods of teaching it, and worked-out answers to in-context exercises and end-of-chapter questions and problems.

The guides contain a list of film sources and a list of chemicals and equipment needed for a class of 30 students with each student working alone except in a few specified experiments. Raytheon's supply list, which indicates quantities for 30 students working in pairs or groups, is at the back of the Teacher's Laboratory Guide. The 1969 Catalog of Macalaster Scientific Company, a Division of Raytheon Education Company (pp. 51-53), lists a special student-team assortment of glassware, hardware, and chemicals, to be used with the Raytheon revision of the CHEM Study textbook.

Demonstration experiments have been designed to function as visual substitutes for actual laboratory work. They are described in detail in the teachers' guides and the textbook assumes that they are done when indicated in the schedule. The numbers of demonstrations are as follows: 5 in Freeman, 4 in Houghton Mifflin, 33 in Raytheon, and 23 in Prentice-Hall.

Two manuals for semimicro experiments have been published by Raytheon for the CHEM Study Programme. One of them is designed to challenge the superior student to think for himself and the other one emphasizes individual progress and development of the student's ability to organize data and make generalizations. There is a separate teacher's guide for each of these publications.[1]

Supplementary materials published by Prentice-Hall may serve as a guide to both students and teachers. The Foundations of Modern Chemistry Series, edited by Dr. Robert W. Parry, deals with six topics relevant to the Prentice-Hall revision of CHEM Study. Five pamphlets of programmed instruction are also available, for the topics of chemical symbols, chemical formulas and names, molecular weight calculations, weight and volume relationships, and balancing chemical equations.

Progress Tests

All versions except Prentice-Hall have now published multiple-choice achievement tests. They are designed to measure whether the student is mastering the course content and can apply the major principles to new or parallel situations (Freeman, Teacher's Guide, p. 2).

Two alternate series have been published and classroom-tested by Freeman. Each set consists of five tests covering three or four chapters each, a semester final, and a year final. Chapters 19 to 25 of the textbook have not been included in the content of the tests, as it was expected that teachers would take a variety of approaches to the descriptive chemistry. All Freeman tests are open-book.

One series of tests is available from Raytheon and is reproduced, with permission, from tests prepared for use with the Freeman version.

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[1]D. C. Heath and Company Elementary and Secondary Material Catalog, 1970, p. 34.

There are seven tests covering two or three chapters each, a semester final, and a year final. All are open-book tests.

A booklet of 34 tests is available from Houghton Mifflin. Twenty-five of them are chapter tests designed to measure recognition and recall of facts and concepts discussed within a single chapter. The seven cumulative tests cover two to four chapters each, except for the last test which covers Chapters 18 to 25. There is a mid-year exam based on Chapters 1 to 10 of the textbook, and a final exam. All of these, except the chapter tests, are open-book tests.

A package consisting of five cumulative tests, covering Chapters 1 to 17, a semester exam, and a final exam, will be available from Prentice-Hall in August of 1970.[1] They will be multiple-choice, open-book tests.

[1]Information contained in a letter from the Manager, Educational Book Division, Prentice-Hall of Canada Ltd., Scarborough, Ontario, dated May 22, 1970.

Summary

Table 45. Comparison of Teachers' Guides and Progress Tests in the Four Versions

Factor examined	Freeman	Raytheon	H.M.	P-H.
Teacher's guide	1 vol.	2 vols.	1 vol.	1 vol.
No. of demonstrations	5	33	4	23
No. of expts.	46	46	38	51
No. of expts. not in Freeman version		12	2	5
Progress tests/set	5 cumulative 2 exams (Ch. 1-18)	7 cumul. 2 exams (Ch. 1-18)	25 chapter tests 7 cumul. 2 exams (Ch.1-25)	5 cumul. 2 exams (Ch. 1-17)

CHAPTER VII

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Systematic comparison of CHEM Study and the three revisions reveals important differences in content. Characteristic patterns are evident in format, clarity of models, and facility in selection of a plane of communication that is appropriate for the high school student. Some revisions have been more successful than Freeman in avoiding recitation of facts, particularly in the descriptive chemistry.

Preliminary examination of format reveals that the pages of Prentice-Hall and Raytheon revisions look most inviting since they are not crowded with information. The Raytheon version has a 3¼-inch margin at the outside of the book and a 3/4-inch margin at the inside. The margins in Prentice-Hall are 2½ inches and ½ inch. Both textbooks have one column of print per page. The wide margins are useful for students' notes and explanations. In the Freeman textbook, margins are ½ inch and 1 inch wide, with two columns of print. Houghton Mifflin has two columns of print, with margins of ½ inch and 3/4 inch. Some coloured ink is used for emphasis in Raytheon and Prentice-Hall.

Scientific models are devised in order to explain abstract ideas in terms of what is concrete and universally knowable. To be really strong, the model must involve a situation with which the reader can identify personally or which he can experience firsthand. Thus, as long as people use real fireplaces inside their homes and build campfires outside, Freeman's analogy of the boy lost in the woods, trying to burn gingerale bottles to keep warm will be too naive and weak to be acceptable as an analogy to scientific method. This judgment is supported by the fact that after classroom experience with the Freeman version, the authors of the Houghton Mifflin revision have completely omitted the analogy and Prentice-Hall authors have converted it to an account of the experience of Martin, the Martian.

Prentice-Hall's super-rubber balls seem capable of more closely approximating the elastic collisions of molecules than the billiard balls and ball bearings described in the other versions. The pole-vaulting analogy to activated complex formation in Prentice-Hall, complete with sketches, is more relevant to the youthful reader than alternate analogies to rolling objects over hills. The simplicity and credibility of Raytheon's irregular-staircase model representing the energy levels of a hydrogen atom makes it better than the bookcase and still more superior to the triple-beam-balance model. Additional analogies are provided in Raytheon and Prentice-Hall for which there are no counterparts in the other versions.

The revisions, in some instances, have a higher degree of scientific rigour than the Freeman version. For example, the pressure-volume products for a given gas sample at constant temperature are not identical but are in agreement within limits of acceptable uncertainty in the tables in Houghton Mifflin and Prentice-Hall. Thus, they correspond more realistically with acceptable student-data than the identical numerical values that are shown for the products in Freeman and Raytheon. Rate of reaction is more accurately defined in Raytheon and Prentice-Hall, as concentration-change per unit time instead of quantity-change per unit time. The Freeman version, published in 1963, describes the rare gases as "inert" whereas they are more correctly called "noble" in the revisions. The standard atomic mass unit is exactly defined only in Prentice-Hall as representing one-twelfth of the mass of a carbon-12 atom.

Some principles of psychology of learning seem to have been overlooked in the revisions. Many photographs are contained in the Houghton Mifflin version, although there is evidence to show that diagrams are more effective as a teaching device since they lead the reader to "simplify the learning of a concept by focusing on its major attributes" (De Cecco, p. 412). The photographs of such familiar objects as a glass of milk and a basket of eggs should be omitted entirely. Raytheon, having neglected the concept of steady state, lacks a negative example which would have been valuable to students learning the concept of equilibrium.

Definitions given for molecular weight are contradictory. Depending on which book you are reading, the term may represent the weight of one mole of substance or one molecule of substance. Since there is disagreement, persons using "molecular weight" should be sure to define the term for their own context before using it, until chemists decide on one interpretation.

Raytheon and Prentice-Hall make the most earnest effort to explain chemical phenomena from first principles. Vapour pressure is explained in molecular terms in the latter versions whereas the Freeman presentation is quite authoritarian. Raytheon describes the behaviour of molecules in the processes of condensation, vaporization, and melting. The electron-pair repulsion theory and the concept of hybrid orbitals are presented in Prentice-Hall to explain sizes of bond angles in compounds. Another major contribution is Raytheon's clarification of the relationship between threshold energy and activation energy, achieved by setting the graphs adjacent to each other with the graph of kinetic energies rotated to show that threshold energy equals activation energy for formation of a given complex. There are more examples of clarity in presentation of concepts in Raytheon and Prentice-Hall than in the other versions.

There is very little attention given in any of the four versions to pointing out regular patterns in nomenclature of organic and inorganic compounds. Unless the teacher provides considerable drill in naming compounds and writing formulas, geared to her class, the student will not likely be literate in chemistry. Raytheon and Prentice-Hall give the clearest structure for solving problems related to chemical equations and dissociation constants.

Raytheon and Prentice-Hall have refrained from recitation of facts, particularly in the descriptive chemistry. The latter version does not deal with the preparation and source of elements in the third row of the periodic table and describes in detail only two of the ten fourth-row transition elements. The series of reactions involved in glucose metabolism, the acetic acid cycle, and uranium-238 decay are omitted.

Raytheon deals with only one fourth-row transition element in detail and does not contain chapters on sixth- and seventh-row transition elements or alkaline earth elements. Houghton Mifflin's content is nearly identical to Freeman.

Freeman's textbook has been criticized for its shortage of information about applications of chemistry in industry. Raytheon and Houghton Mifflin revisions have responded by including information about the structure and function of dry cells, lead storage cells, and the blast furnace. Production of black-and-white photographs is explained in detail in Raytheon. However, chemistry courses could be given more vitality by greater exposure of the student to the chemical processes and principles involved in efficient operation of chemical industries.

The Prentice-Hall version, published about two years later than the other revisions, contains more information about recent developments in science. There is a quotation from Bartlett, with coloured pictures from his synthesis of xenon hexafluoroplatinate. The π-orbitals that account for properties of graphite and benzene are described as well as properties and structure of deoxyribonucleic acid.

Natural phenomena involving chemical principles are explained in Prentice-Hall. For example, coral reefs and oyster shells will grow only when the animal makes adjustments so that calcium and carbonate ion concentrations are great enough to allow precipitation. Human life can be maintained when the body fluid has a certain hydrogen-ion concentration. It is believed that cobalt complexes are partly responsible for the ready conversion of nitrogen of the air to protein on the root of a clover plant. Such information makes chemistry more meaningful and relevant.

Laboratory work provides concrete experience that allows the student to discover principles and reinforces learning. The totals of demonstrations and experiments, followed by the number of experiments in parentheses, are: 79(46) in Raytheon, 74(51) in Prentice-Hall, 51(46) in Freeman, and 42(38) in Houghton Mifflin. Twelve of Raytheon's and five of Prentice-Hall's experiments do not appear in Freeman. Houghton Mifflin contains only two experiments that do not appear in Freeman.

As Appendix B and the chapter tables in this thesis show, all three revisions have borrowed very freely from the Freeman chapter-end questions, so that the alternate versions are not good sources of additional questions on most topics. Houghton Mifflin's progress tests have the most extensive coverage of the textbook. The teachers' guides are much alike in content.

Conclusions

The format of the Raytheon and Prentice-Hall versions is well-spaced and coloured ink has been used with discrimination. Models and analogies in these versions have clarity and relevance for the youthful reader.

The three revisions display greater scientific rigour than Freeman. The definition of molecular weight given in Freeman is contradicted in Prentice-Hall. Until chemists agree on a uniform interpretation, persons using the term must be sure to define it for their context. To the unindoctrinated English-speaking person, the term implies that one molecule is involved, so that it seems more logical and more considerate to future students of chemistry to adopt that common-sense interpretation.

New information is most carefully integrated with the student's previously acquired knowledge in Raytheon and Prentice-Hall, with less reliance on intuitive grasp of concepts. Much of the non-integrated factual material that is in Freeman and Houghton Mifflin has been omitted.

To produce students literate in chemistry, more attention must be given to regularities in nomenclature and to practice exercises in naming compounds and writing formulas than seems to be suggested by any of the four versions.

Prentice-Hall, the last revision to be published, included information about modern discoveries in chemistry which had great impact such as the reactivity of xenon and structure and function of DNA.

Concrete experience in experiments and demonstrations is most plentiful from the Raytheon and Prentice-Hall versions, although the limited time available to chemistry classes may make a selection process necessary. The teachers' guides are much alike in content. Houghton Mifflin's testing programme gives the most complete textbook coverage.

The textbook with integrated laboratory experiments, published by Houghton Mifflin, is a reprinting of the Freeman version with minor changes, an outcome which the CHEM Study Steering Committee had resolved to avoid (Merrill and Ridgway, p. 71). However, the Raytheon and Prentice-Hall versions incorporate greater changes, designed to facilitate and enrich the learning process.

Recommendations

Two recommendations of textbooks emerge from this study:

1. Raytheon, because of its elimination of the more difficult and little-used mathematical derivations, its clarity of explanations, and its reduction of non-integrated facts, provides the best course for the terminal student who will not take post-secondary courses in chemistry and for the prospective nurse.

2. Prentice-Hall, which is relevant to the youthful reader, most up-to-date, and has as much depth but more appeal than the Freeman version, will give the most secure understanding to the person who is keenly interested in chemistry and/or who intends to do post-secondary studies in chemistry.

For building and handling curriculum, the following provisions are recommended:

1. Steps should be taken to give students insight into industrial applications of chemical theory. There are at least three means of accomplishing this end. Attractive pamphlets could be prepared and revised when necessary by teams consisting of a technician or technologist employed in the industry and a collaborating chemistry teacher, to ensure that the plane of communication is stimulating but not so advanced as to be discouraging. Ideally, the student should have a tour of some industrial plants conducted by a guide who is aware of the depth of chemical knowledge of the student and is able to augment it. Some schools have made arrangements for particularly keen students to assist research scientists for one week.

2. More programmed instruction should be published and used by students to acquire mastery of concepts and skills. Prentice-Hall's programmed units, including Chemical Formulas and Names and Balancing Chemical Equations[1] should be available to all high school students. Teachers should present the nomenclature of compounds in a systematic way if the student is to master the basic symbolism of chemistry and become literate with reasonable effort.

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[1]From Programmed Units in Chemistry, by Virginia Powell.

BIBLIOGRAPHY

Boon, A. Progress tests, chemistry: an investigative approach. Boston: Houghton Mifflin Company, 1969.

Cotton, F.A., & Lynch, L.D. Chemistry: an investigative approach. Boston: Houghton Mifflin Company, 1968.

Cotton, F.A., & Lynch, L.D. Teacher's guide for chemistry: an investigative approach. Boston: Houghton Mifflin Company, 1968.

Davis, J.E., Jr., MacNab, W.K., Haenisch, E.L., McClellan, A.L., & O'Connor, P.R. Laboratory manual for chemistry: experiments and principles. Boston: Raytheon Education Company, 1968.

De Cecco, J.P. The psychology of learning and instruction: educational psychology. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1968.

Dietz, P.M., Tellefsen, R.L., Parry, R.W., & Steiner, L.E. Preliminary edition, chemistry: experimental foundations, teacher's guide to the laboratory work. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1969.

Macalaster Scientific Company Catalog 1969. Nashua, N.H.: Raytheon Education Company, 1968.

Malm, L.E. (Ed.) Laboratory manual for chemistry - an experimental science. San Francisco: W.H. Freeman and Company, 1963.

McClellan, A.L., MacNab, W.K., Davis, J.E., Jr., Haenisch, E.L., & O'Connor, P.R. Teacher's laboratory guide for chemistry: experiments and principles. Lexington, Mass.: Raytheon Education Company, 1968.

McClellan, A.L., Davis, J.E., Jr., Haenisch, E.L., MacNab, W.K., & O'Connor, P.R. Teacher's guide for chemistry: experiments and principles. Lexington, Mass.: Raytheon Education Company, 1968.

McClellan, A.L. (Ed.) Teachers guide for chemistry - an experimental science. San Francisco: W.H. Freeman and Company, 1963.

Merrill, R.J., & Ridgway, D.W. The CHEM Study story. San Francisco: W.H. Freeman and Company, 1969.

O'Connor, P.R., Davis, J.E., Jr., Haenisch, E.L., MacNab, W.K., & McClellan, A.L. Chemistry: experiments and principles. Boston: Raytheon Education Company, 1968.

Parry, R.W., Dietz, P.M., Tellefsen, R.L., & Steiner, L.E. Teachers guide, chemistry: experimental foundations. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1970.

Parry, R.W., Steiner, L.E., Tellefsen, R.L., & Dietz, P.M. Chemistry: experimental foundations. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1970.

Pimentel, G.C. (Ed.) Chemistry - an experimental science. San Francisco: W.H. Freeman and Company, 1963.

Ridgway, D.W. (Ed.) Chemical Education Material Study Newsletter. Berkeley: University of California, Lawrence Hall of Science, 1969, Vol. 8, No. 1.

Tellefsen, R.L., Dietz, P.M., Parry, R.W., & Steiner, L.E. Laboratory manual, chemistry: experimental foundations. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1970.

Van Cleave, A.B. CHEM Study in Saskatchewan, 1963-1969. Canadian Chemical Education, 1970, Vol. 5, No. 2.

Weast, R.C. (Ed.) Handbook of physics and chemistry, 48th ed. Cleveland: The Chemical Rubber Co., 1967-68, D-86.

APPENDIX A

Table of Contents, Taken from Freeman Version

APPENDIX B

Questions and Problems in Revisions, Taken from Freeman Textbook

Freeman Chapter	Chapter and question numbers		
	Raytheon	Houghton Mifflin	Prentice-Hall
2	Ch.2: 2-15, 18-25, 28-32	Ch.4: Q 20-25, P 1,2,12-17	Ch.2: 3,9,11-26,28
3	Ch.3: 1-11, 20-27, (29-31 from F.Ch.13)	as above	Ch.3: 1-3,7-12, 14-20
4	Ch.4: 1-23 (25-31 from F.Ch.13)	Ch.3: Q 3,5,7,9,11, 13,17,19,21 P 1,3,5,7,11, 13,15,17,19, 21,23	Ch.4: 1-23
5	Ch.5: 11-16,18,19,22,23 Ch.6: 1-3,6-9,13-16, 21-24,29-31	Ch.5: 11	Ch.5: 4-7,9,10,13-21 (11,12 from F.Ch.4)
6	Ch.7: 1-8	Ch.6: 10-14,16-23,26-28	Ch.8: 1-5,8-12,14-20, 27,28
7	Ch.11: 5-8,10-19,27-29, 31,32	Ch.12: Q 1-3,6-8,11-15 P 1-5,7-10	Ch.9: 1-23
8	Ch.12: 1-7,9-11,14,15, 17-21,23,27	Ch.13: 2,3,6,8-10,13, 16-19,21-25	Ch.10: 1-20

In the same row as the number of a given Freeman chapter, are listed the questions copied from Freeman, numbered in the way that they appear in the revisions. For example, at the end of Chapter 4 in Houghton Mifflin, questions 20-25 are taken from Chapter 2 of Freeman.

Freeman Chapter	Chapter and question numbers		
	Raytheon	Houghton Mifflin	Prentice-Hall
9	Ch.13: 3-7,9-23,33,34	Ch.14: 1,5,7-12,14-17,19-30	Ch.11: 1-23, 26-28
10	Ch.6: 25,26,32-28 Ch.13: 24-32,35,36	Ch.15: Q 1,2,11-22 P 1-8,10-13	Ch.12: 1-9,12-15, 18-21,25-29
11	Ch.14: 1-3,6-24,26	Ch.16: Q 4,6,11-13 P 2-6,11-18	Ch.13: 3-12,14-19, 21,22,26-29
12	Ch.15: 1-3,6-9,14-20, 26,27,29,30	Ch.17: Q 3-5,7-10 P 1-18	Ch.14: 2-5,7-15, 17-25
13	Ch.3: 29,30,31 Ch.4: 25-31	Ch.11: Q 8-12 (from F.Ch.3) P 5,9,11-13 (from F.Ch.3) 1,2,8,10,14-20 (F.Ch.13)	
14	Ch.8: 3,4,9,10 (17-20 from F.Ch.6)	Ch.7: Q 6,7-10 P 1-3,5-9	Ch.6: 1-4,16,17 (6-11,13,14,18,19 from F.Ch.5) Ch.7: 4,7,10,17-20,22,23 (3,5,6,11-14,16,21 from F.Ch.6)
15	Ch.9: 1,3,5-10,13,15,16	Ch.8: Q 1,7-9,14-19 (Q 20 from F.Ch.14) P 1-3,6 (P 5 from F.Ch.14)	Ch.15: 2,8,10,12-22 (4-6 from F.Ch.14)
16	Ch.10: 7,9,11-17,19 Ch.17: 3-5,9-11	Ch.9: 2-8,11,12,14-16,19-26	Ch.16: 1-6,11,13-24

APPENDIX B (continued)

Freeman Chapter	Chapter and question numbers		
	Raytheon	Houghton Mifflin	Prentice-Hall
17	Ch.17: 12-23	Ch.10: Q 1-9 P 1-6	Ch.17: 1-10,15-20
18	Ch.18: 1,2,4,6-10,13, 14,16-19	Ch.23: Q 6-9,11,12,14-16, 20-23 P 3-10	Ch.18: 1-8,11-24
19	Ch.19: 1-20	Ch.18: Q 1,2,7,10-13	Ch.20: 1,3-6,9-18,20
20		Ch.20: Q 2-7,11-16 P 1-10	Ch.19: 1-3,5-18
21		Ch.19: Q 4,14-16,19,20 P 1-3	
22	Ch.20: 1-17	Ch.21: Q 1,3-9,11-20	Ch.21: 1-18
23		Ch.22: P 1,3-6	
24		Ch.24: Q 8,9 P 1-3	
25	Ch.21 (1,2 from F.Ch.14) (3,8,10 from F.Ch.7)		