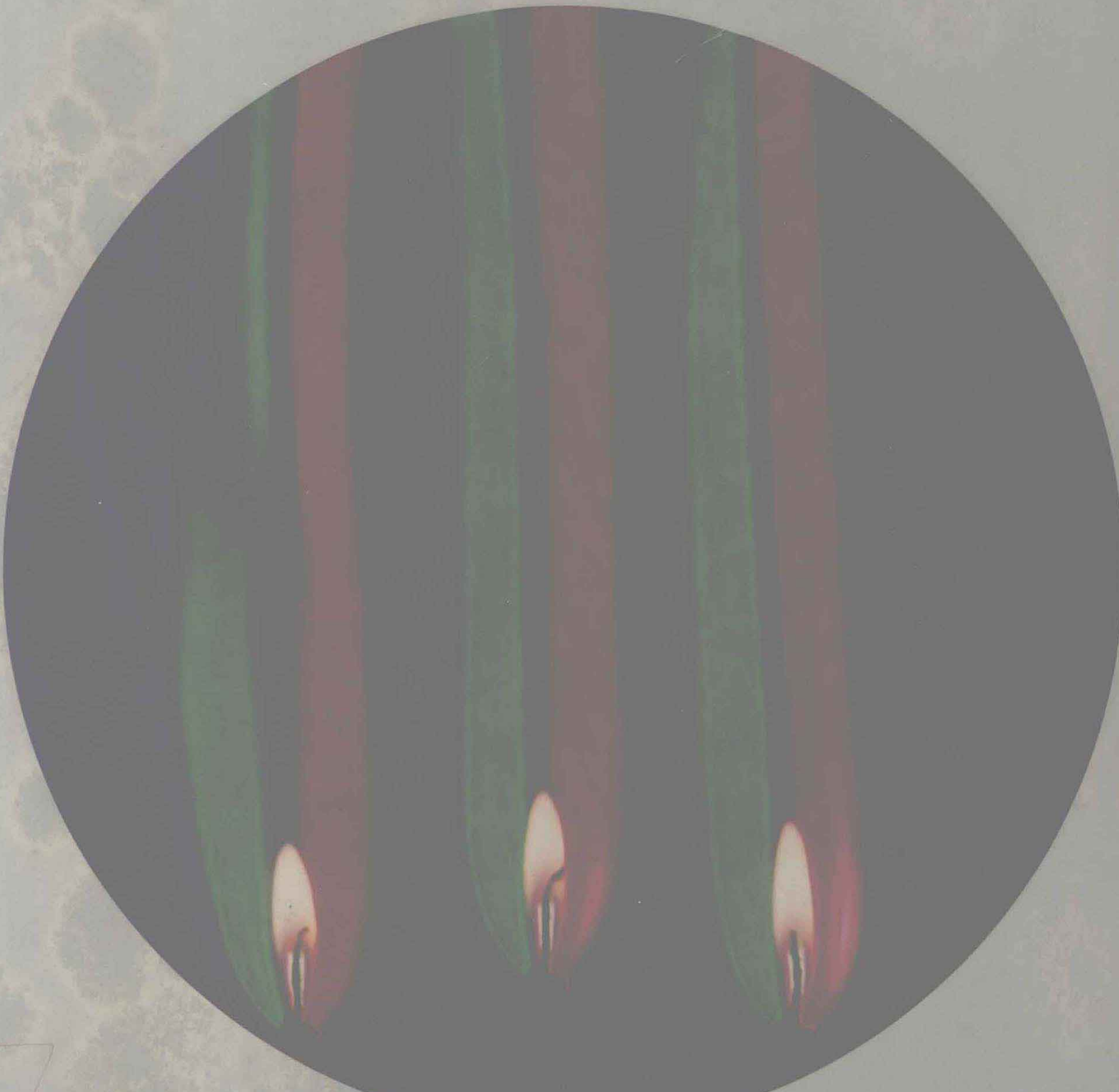
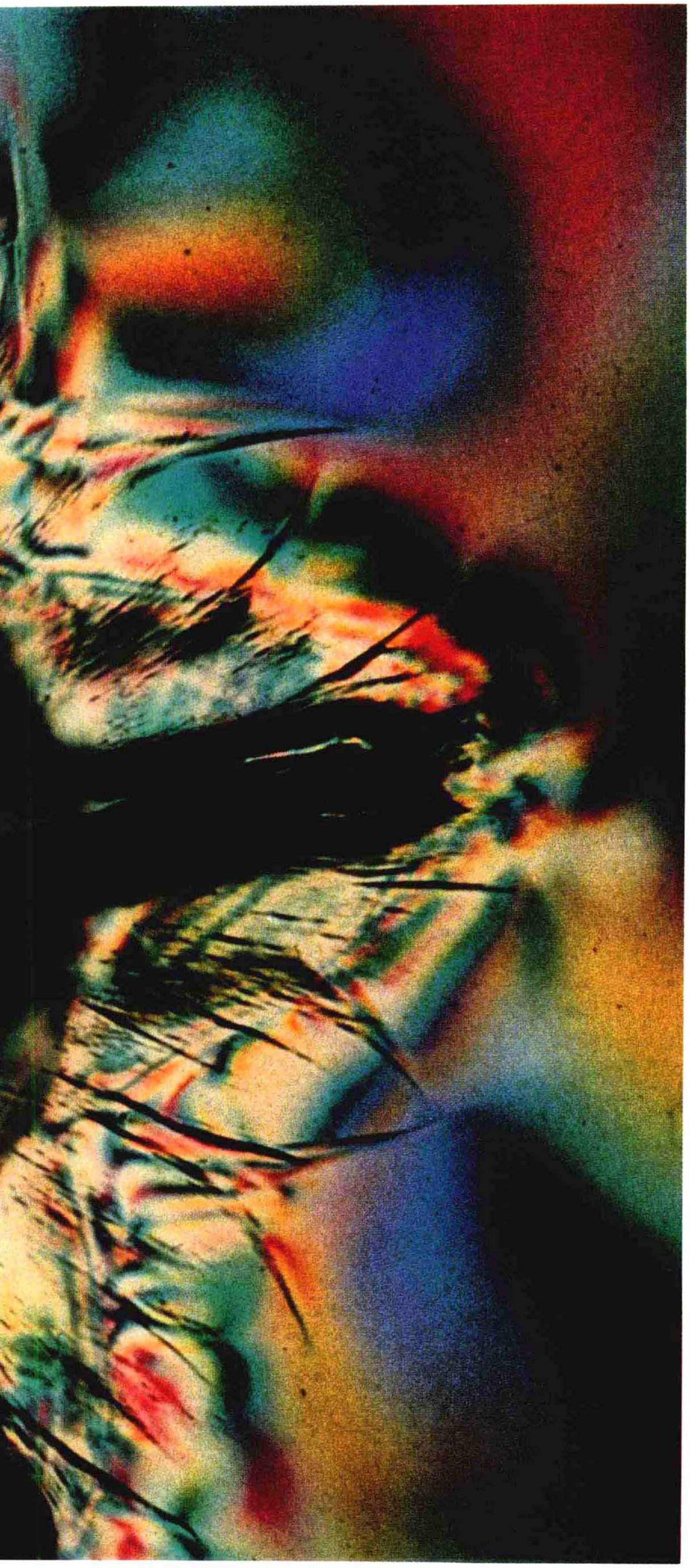
CHEMISTRY
for Engineers and Scientists



FINE and BEALL



Chemistry for Engineers and Scientists

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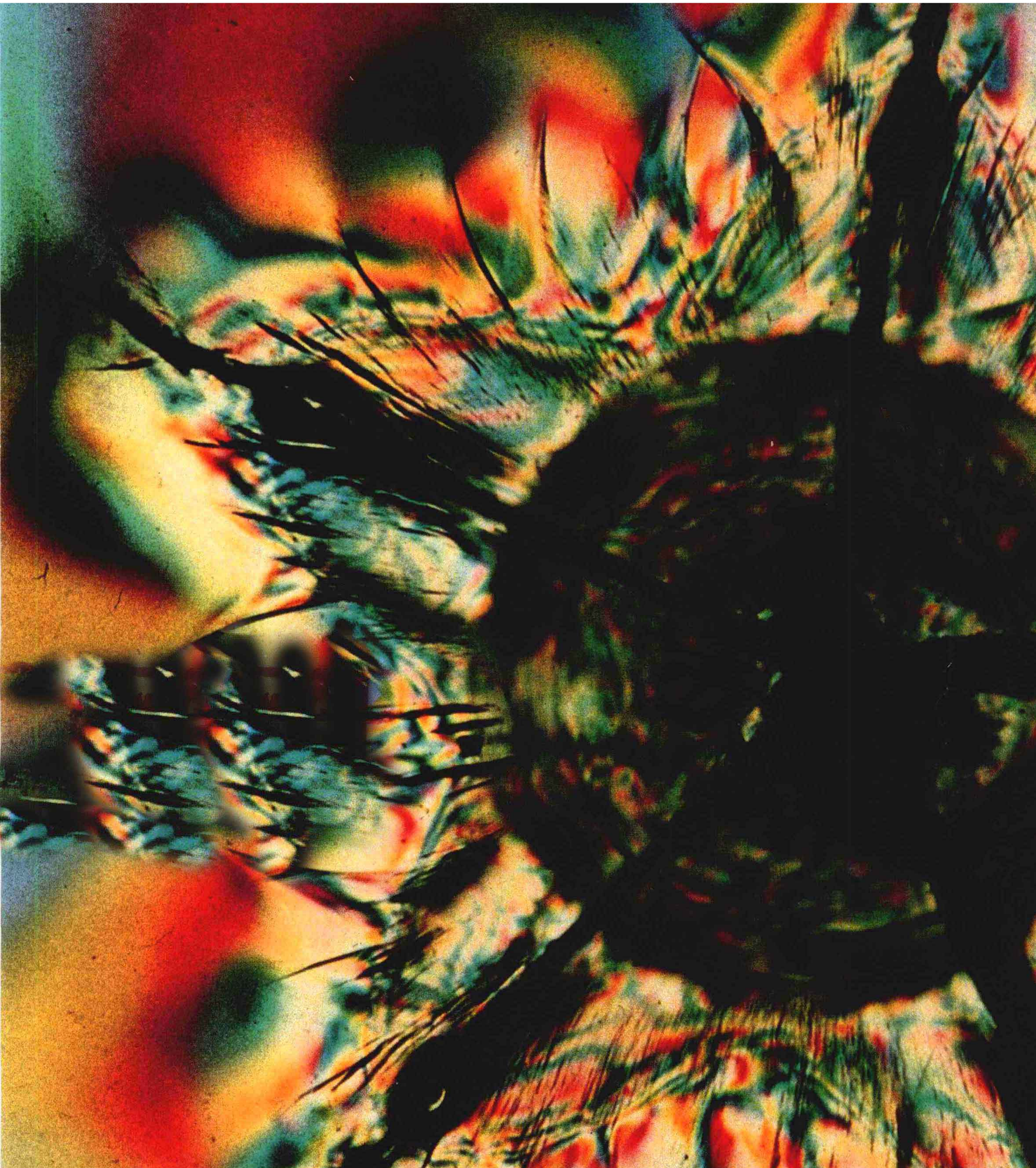
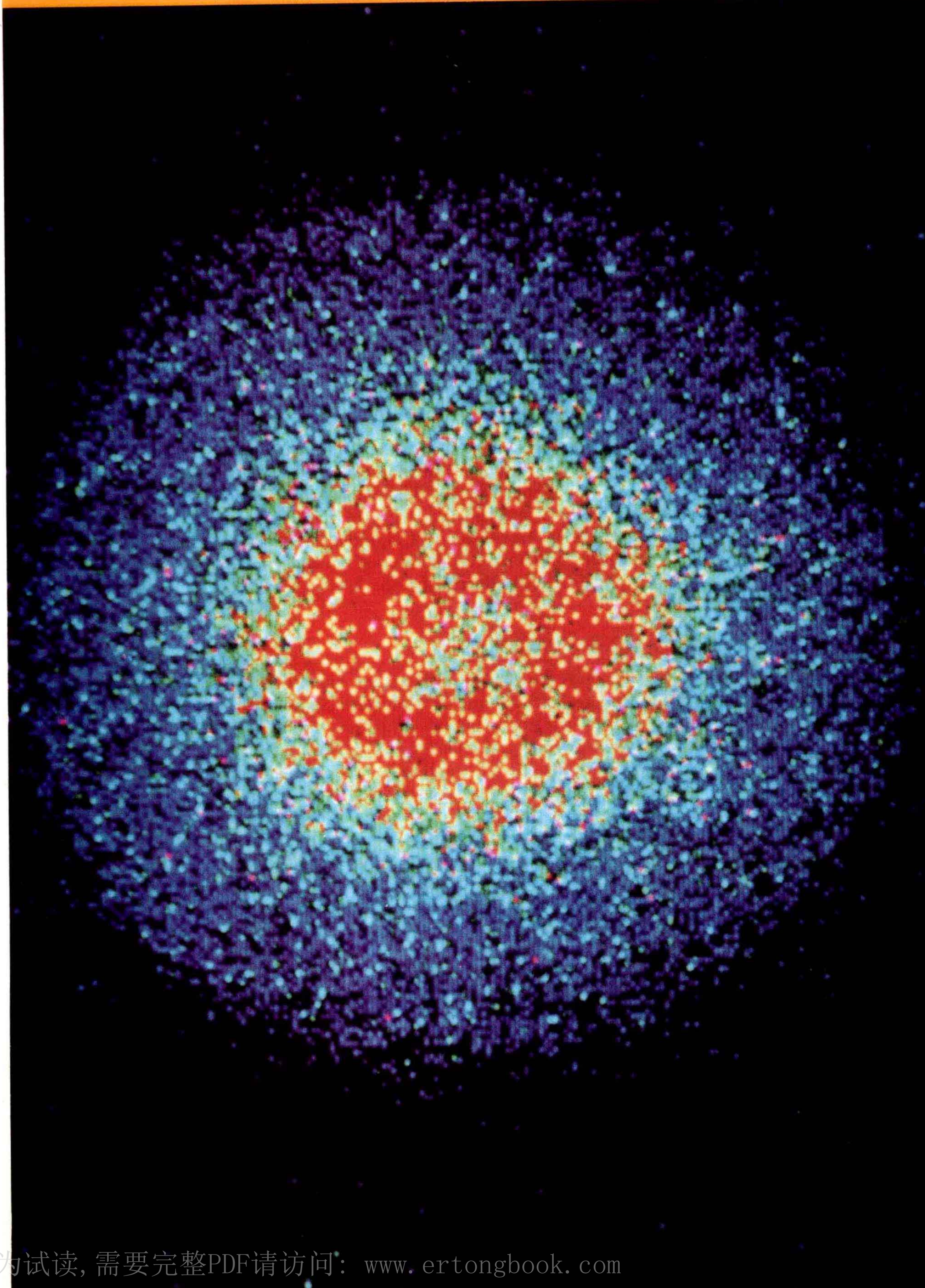
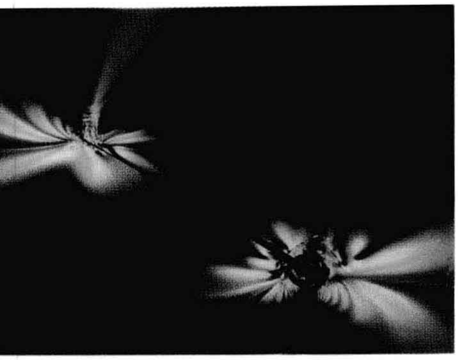


Preface





INTRODUCTION

Our textbook of general chemistry has been written for students studying engineering and science. It represents an introduction to the fundamentals of chemistry and applies those principles to relevant technological examples. We have been guided by the principle that all science students in this day and age will benefit from an exposure to engineering practices, such as chemical engineering, biomedical engineering and materials science; and unquestionably, the more science the practicing engineer learns, the better.

Toward this end, we have included cutting-edge developments in science and technology as recurring themes and have featured product and process chemistry throughout. Historical biographies of famous scientists are sprinkled throughout the book to give the text a human perspective. Nobel prizes in chemistry, in physics and in medicine and physiology have been used as benchmarks, where they are appropriate to the matter under discussion.

Our treatment of the subject is suitable for the first course in chemistry. A working knowledge of algebra is assumed, but calculus is not. Tables and graphs are used extensively. Line drawings have traditionally played an important role in illustrating how and why things work in science and technology, and we have tried to improve on what has been done before. The emphasis throughout is on simplicity and clarity. Photographs have been thoughtfully and purposefully selected to clarify or enhance ideas.

The manuscript for this textbook has been tested by more than 3000 students over three years and in five different situations at Worcester Polytechnic Institute and Columbia University. We believe that this final product will prove both interesting and challenging to the student and rewarding and effective for the teacher.

ORGANIZATION

The book is divided into two parts: **States of Matter, Energy, and Chemical Change**; and **Atomic & Molecular Structure, and Chemical Reactivity**. In the first part, you will find basic definitions, stoichiometry and calculations; descriptive chemistry of the atomic nucleus; a working knowledge of inorganic structure and reactions; gases, liquids, and solutions; equilibria and equilibrium thermodynamics. The second part includes principles of atomic structure; chemical bonding and periodic properties; applications of bonding principles to coordination chemistry, organic chemistry and biochemistry; solid state and materials science; electrochemistry and reaction kinetics. In the first half of the book we concentrate on phenomena that can be directly observed, and then we progress to the somewhat more conceptually difficult topics of atomic and molecular structure in the second half. Structure and reactivity are recurring themes throughout the text, and wherever possible, principles are reduced to practice—as early as Chapter 1, for example, you will find such topics as superconductivity introduced and discussed. On a chapter-by-chapter basis, our textbook is organized as follows:

Chapters 1 and **2** offer a classical introduction to atomic theory and the molecular hypothesis, the chemical formula and the chemical equation, and stoichiometric relationships.

Chapter 3 provides an early introduction of the properties of the nucleus, nuclear chemistry and radioactivity, but discussion of decay processes and "dating" have been deferred. We have chosen to place this chapter early in the text. It is a subject which our students normally find very interesting, and we believe it is especially important to all engineering and science students.

Chapters 4 and **6** present descriptive material on the earth and the atmospheric environment, and afford an opportunity to introduce several important substances ($NaOH$ and H_2SO_4), classes of compounds (acids, bases, salts, oxides, metals and nonmetals), essential themes (the periodic table and Lewis structures), and industrial processes (the contact process and synthesis gas). These chapters are highly suggestive of the way we have chosen to integrate theory and practice throughout the textbook.

Chapters 5, **8**, **9**, and **19** comprise the states of matter: gases are introduced first in Chapter 5. Liquids and solutions are discussed in Chapters 8 and 9. Liquids is a more provocative topic than might be expected because students *think* the liquid state is well understood. Colligative properties make for the central theme of the chapter on solutions; a brief discussion of the colloidal state is included. Solid state (in Chapter 19) is increasingly important in this day and age, and we have treated the subject accordingly. It has been placed in the second half of the book, in conjunction with an extensive treatment of materials in Chapter 20.

The arrangement of thermodynamics and equilibrium is intended to emphasize the interdependence of these topics. **Chapter 7** introduces the concepts of energy, enthalpy, and thermochemistry necessary for the next two chapters on liquids and solutions. In these chapters the concept of phase equilibrium prepares the student for chemical equilibrium and the equilibrium constant in **Chapter 10**. Then, entropy and free energy are introduced in **Chapter 11** and the relationship between the equilibrium constant and free energy can be shown. Finally, in **Chapters 12** and **13**, thermodynamic concepts are utilized for further discussion of equilibria in water solution.

Part Two begins with **Chapters 14** and **15**, which deal with the electronic structure of the atom and modern atomic theory. Properties of electromagnetic radiation, the photoelectric effect and the quantum hypothesis, and the Bohr atom model (in Chapter 14) set the stage for the quantum mechanical atom (in Chapter 15). Important experiments are stressed. There is a philosophical undercurrent, tempered by state-of-the-art applications such as observation of quantum "jumps" and laser light.

Chapters 16 and **18** explore the nature of the chemical bond. **Chapter 17** is an introduction to the descriptive chemistry surrounding the periodic table and periodic law. Bonding theories are stressed, along with the relationships between electronic structure and observed properties. **Chapter 22** extends the discussions of bonding to coordination chemistry—a colorful chapter.

The two chapters on solid state (**Chapter 19**) and materials science (**Chapter 20**) relate structure to properties, and, we believe, constitute a unique treatment of the subjects for any introduction to college chemistry. The chapter on materials science includes metals, ceramics, and plastics in theory and practice, and includes an introduction to physical measurement. Engineering students should welcome both chapters, and science students should also be pleased as they recognize so much of what they see in the world around them, explained as part of this chemistry chapter.

Chapter 21 blends theory and practice in presenting electrochemical principles. Electron transfer at interfaces, batteries, and corrosion follow nicely on the heels of solid state and materials science in preceding chapters. Thermodynamic arguments are used to develop the main themes.

In **Chapters 23** and **24** on chemical kinetics, we have separated the discussions of mechanisms and theories (Chapter 24) from experimental rate laws, rate constants and reaction order (Chapter 23). With this two-chapter format, professors have the option of presenting a brief overview of kinetics or a more in-depth treatment of the topic. In Chapter 23, we conclude our discussions of radioactivity from Chapter 3, with a presentation of first order kinetics, decay processes and "dating."

Chapters 25 and **26** are a broad survey of topics in organic and biochemistry, concluding with an introduction to the important topic of recombinant DNA technology.

FEATURES

- Opening each of the 26 chapters is a **two-page photographic spread** designed to highlight an important contemporary theme and an element of historical perspective in keeping with the contents of the chapter. The Nobel prize is used throughout the text to further validate the importance of applications and the perspective of history by noting the work of laureates in chemistry, physics, and medicine and physiology that have proved to be especially important to the work being described in the chapter.
- As each chapter begins, there are a **few paragraphs of introduction**. This serves to put the chapter into perspective regarding its importance in chemistry and its relationship to previous chapters.
- **Technological applications** of chemistry of special interest to scientists and engineers are included in the text in appropriate places. These are not "boxed" or otherwise separated; they are integral parts of the presentation. A partial sampling of the applied topics that are covered include:

  Superconductors and superconductivity (Chapter 1)

  Nuclear reactors and nuclear medicine (Chapter 3)

  Radiocarbon dating and radiation chemistry (Chapters 3, 5, and 23)

  Chemistry of the high atmosphere, the greenhouse effect, and the chemistry leading to deterioration of the ozone layer (Chapter 6)

  Coal, oil, and energy resources (Chapter 7)

  Case study of an aluminothermic reduction (Chapter 7)

  Fractional distillation (Chapter 8)

  Colloid science (Chapter 9)

  Excited states, laser chemistry, and molecular beams (Chapter 15)

  Modern instrumental methods and diagnostic techniques, including infrared spectroscopy, magnetic resonance imaging and NMR, ESCA and Auger, mass spectrometry (Chapter 15 and several others)

  Liquid crystals, semiconductors, and solid state devices (Chapter 19)

  Industrial diamonds and synthetic gemstones (Chapter 19)

  Nylon and polycarbonate polymers—engineering plastics (Chapters 20 and 25)

  Corrosion, electrochemical manufacturing, and fuel cells (Chapter 22)

  Homogeneous and heterogeneous catalysis (Chapter 24)

  Cyclodextrins as enzyme models (Chapter 26)

  PCBs and recombinant DNA technology (Chapter 26)

- **Industrial processes** are "boxed" in order to set them apart from the body of the text. We have tried to improve upon the traditional engineering drawing with simplified process and product descriptions. Here is a sampling:

  contact process, for sulfuric acid (Chapter 4)

  synthesis gas preparation of methanol, a commodity chemical (Chapter 6)

  fertilizer ammonia—Haber process (Chapter 10)

  nitric acid—Ostwald process (Chapter 13)

  electrolytic aluminum—Hall-Heroult Process (Chapter 21)

  chloralkali—Hooker process (Chapter 22)

  paper chemistry—Kraft process (Chapter 25)

- **Examples and exercises** are vital to the flow of the text and are generally presented in pairs. First, an example is worked out in detail and then an exercise is presented to the student to affirm his or her understanding, accompanied by a validating answer.

- Since we cannot take you all on field trips to literally "see" chemistry firsthand, the next best thing is photography. To that end, **500 color photographs**, in many cases obtained from primary sources—from the people who reported the research and did the work being illustrated—have been carefully placed throughout. Historical photographs have been selected from archival materials to help portray something of the human dimension—especially scientists as young men and women, at about the age of those most likely to be reading this text.

- At the end of each chapter, there are generally 15 to 30 **QUESTIONS**, designed to help students review the material and keep them thinking about what it means.

- Following the questions are four categories of **PROBLEMS**, ranging from easy through medium difficulty to some which are quite challenging. Answers to the odd-numbered problems appear in Appendix A:

  Paired problems—one answered, followed by another that is similar, but not identical—are divided according to the main topics of the chapter.

  Additional problems are a random selection covering all the topics of the chapter.

- **Multiple Principles** problems require the student to recognize more than one essential concept to solve the problem. The principles involved often come from previous chapters.

- **Applied Principles** problems are centered around an economic or industrial element or theme—a reduction of principles to practices.

An intensive and extensive reviewing process was carried out to ensure that the information in this book is as **error-free** as possible. In addition to the many reviewers who read early drafts of this manuscript, the galleys and page proofs were read and checked by the authors and two external reviewers, John Stuehr (Case Western Reserve University) and Dorothy Swain (Oxford College).

ALTERNATE CHAPTER PRESENTATIONS

One of the important aspects of the ordering of topics in this text is the early placement of **nuclear chemistry**. Another is the concentration of observable phenomena (**macroscopic properties**) in the first half of the text and the concentration of theoretical concepts derived from observations (**microscopic properties**) in the second half. This is an order of presentation which we believe is attractive to students of engineering and science and which worked quite successfully at WPI and Columbia. However, since we realize that other valid points of view exist, this textbook has been written (and tested) in a flexible manner so that considerable rearrangement of topics is possible, if desired.

Alternate orders of topics which gave early treatment to the microscopic properties, atomic structure and bonding, were tested in full-year courses over the three years of preliminary versions of this book. The order of topics which was found to be successful for the first semester was:

Chap. 1 The Science of Chemistry
Chap. 2 The Atomic Theory and Chemical Stoichiometry
Chap. 4 Elements, Compounds, and the Earth
Chap. 5 Gases and the Pressure of the Atmosphere
Chap. 6 Chemistry in the Atmospheric Environment
Chap. 8 Liquids and Changes of State
Chap. 9 Properties of Solutions and the Colloidal State
Chap. 3 The Atomic Nucleus
Chap. 14 Atomic Structure I: Theories of the Atom
Chap. 15 Atomic Structure II: Atomic Structure and Quantum Theory
Chap. 16 Bonding I: The Properties of Bonds
Chap. 17 Main Group Elements; Periodic Properties
Chap. 18 Bonding II: Molecular Structure

For the second semester of these trial presentations, three different modifications were tested and proved to be equally satisfactory. Each emphasized different topics and used a different order of chapters. These sequences were:

Emphasis on the solid state and materials:
Chapters 7, 10, 11, 12, 13, 19, 20, 21, 22, 23, 24, 25, 26

Emphasis on organic chemistry and biochemistry:
Chapters 21, 25, 26, 7, 10, 11, 12, 13, 22, 23, 24, 19, 20

Emphasis on materials and organic chemistry:
Chapters 21, 25, 26, 7, 10, 11, 12, 13, 19, 20, 22, 23, 24

Another order of topics, which was tested, clearly separated macroscopic and microscopic properties. In this case the order of chapters was:

Macroscopic properties:
Chapters 1, 2, 4, 5, 6, 8, 9, 10, 12, 13, 7, 11
Microscopic properties:
Chapters 22, 23, 24, 3, 14, 15, 16, 17, 18, 19, 21, 20, 25, 26

If you teach a strict **one-semester course** to engineering majors, the first thirteen chapters of the textbook can be taught directly, with selected sections taken from Chapter 21 (Electrochemistry), Chapter 19 (The Solid State), Chapter 20 (Materials Science), and Chapter 23 (Kinetics I).

ACKNOWLEDGMENTS

The materials you see presented have been extensively reviewed by sympathetic but critical colleagues at colleges and universities, and by over 3000 students at WPI and Columbia during the last three years. As a result of their analyses, we have made many improvements to each draft. We thank these reviewers for their useful comments, which have been used to polish this book into its final form:

REVIEWERS

Jon Bellama, University of Maryland
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Lawrence Conroy, University of Minnesota
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Finally, we would like to acknowledge the patience and support of our wives, Diane and Barbara, to whom this book is dedicated.

Len Fine
Norwalk, Conn.

Herb Beall
Worcester, Mass.

Support Package

Instructor's Manual by Leonard W. Fine, Herbert Beall and Dorothy Swain. Contains chapter summaries, lecture outlines, lists of chemical demonstrations, and solutions to the even-numbered questions and problems in the text.

Student Solutions Manual by Dorothy Swain, Oxford College. Contains the complete solutions to the odd-numbered questions and problems in the text.

Student Study Guide by Robert Bryan, University of Virginia and Ken Robertson, University of Missouri, Rolla. Includes study goals, additional examples and self tests, keyed to the chapters of the text.

The Use of Estimates in Solving Chemistry Problems by Michael Green and Denise Garland. Teaches students how to solve problems in general chemistry, first intuitively and then mathematically. It contains summaries of key topics and many problems solved first by estimating the answer and then by working out the problem in detail.

Laboratory Experiments for General Chemistry by Harold Hunt and Toby Block, Georgia Institute of Technology. Provides laboratory coordinators with 42 experiments, designed to emphasize safety in the lab; includes an instructor's manual for preparing the laboratory.

Computerized Test Bank by Michael Hampton, University of Central Florida and Engineering Software Associates. Consists of more than 1000 multiple-choice questions developed around the learning objectives for each chapter. Available for IBM PC and Macintosh computers. A printed version of the test bank is also available.

Overhead Transparencies. Visual supplements, which include 125 full-color pieces of line art and photographs from the textbook.

Qualitative Analysis and the Properties of Ions in Aqueous Solution by Emil Slowinski, Macalester College and William Masterton, University of Connecticut. A qualitative analysis supplement, which encourages students to develop their own schemes of analysis.

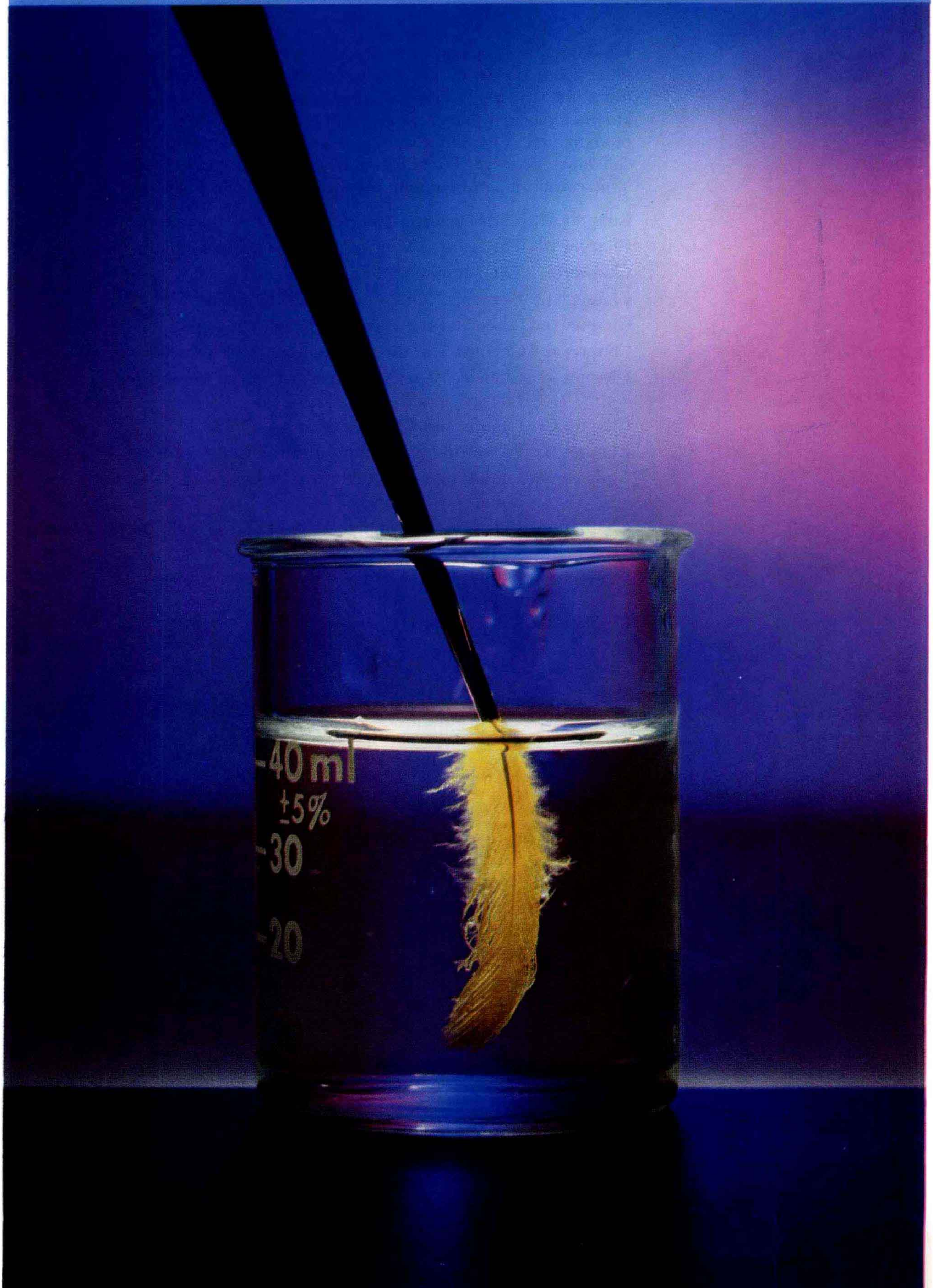
Audio Tape Lessons and Workbook by B. Shakhashiri, R. Schreiner and P. Meyer, University of Wisconsin, Madison. Tapes to help students learn general chemistry at their own pace; students listen to the instructions on the tape and follow the illustrations and examples in the workbook.

Journal of Chemical Education: Software, Periodic Table Videodisc. A visual database of information about applications, properties, and chemical reactivity of the elements.

Tutorial Software by Charles Wilkie, Marquette University. It covers 18 major topic areas in general chemistry; available for IBM PC and Apple II computers.

Chemical Demonstration Videotapes by University of Illinois, Champaign. Schools adopting *Chemistry for Engineers and Scientists* are eligible to choose from a list of 35 available lecture/demonstration videotapes.

Contents Overview



Contents

Nobel Citations

The Nobel Foundation was created under the terms of the will of Alfred Nobel (Swedish, 1833–1896), the inventor of dynamite. Each October, six Nobel Prizes may be announced, one each in chemistry, physics, medicine and physiology, economics (since 1969), literature, and peace. Part of the attraction of these Nobel Prizes lies not only in their substance and the ritual of their presentation, but also in their origin. Here was the chemist who had perfected what others turned into the embodiment of war, the explosive known as dynamite, wishing to turn men's minds toward researches for the good of all, and for world peace. The Nobel Prize in Chemistry was first awarded in 1901, and since that time, more than 100 other chemists have been so honored[†]. In each instance, the award has been for research of high principle and purpose. At the beginning of each chapter, an award citation that seems particularly appropriate, whether in chemistry, physics, or medicine and physiology, is displayed. We begin with one of the 1987 Nobel Prizes, recognizing the discovery of the first high temperature superconducting materials, the response to which has been an unprecedented advance in scientific research and development, perhaps only comparable to the discovery of X-rays, which was recognized in one of the Nobel Prize citations the first year.

[†]The Nobel Peace Prize for 1962 was awarded to Linus Pauling, the 1954 chemistry laureate.