

GLOBAL
EDITION



General, Organic, and Biological Chemistry

Structures of Life

SIXTH EDITION

Timberlake



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STRUCTURES OF LIFE

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General, Organic, and Biological Chemistry

STRUCTURES OF LIFE

Sixth Edition
Global Edition

Karen Timberlake

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About the Author



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Professor Timberlake has been writing chemistry textbooks for 40 years. During that time, her name has become associated with the strategic use of pedagogical tools that promote student success in chemistry and the application of chemistry to real-life situations. More than one million students have learned chemistry using texts, laboratory manuals, and study guides written by Karen Timberlake. In addition to *General, Organic and Biological Chemistry*, sixth edition, she is also the author of *An Introduction to General, Organic, and Biological Chemistry*, thirteenth edition, with the accompanying *Laboratory Manual, Essential Laboratory Manual for General, Organic, and Biological Chemistry*, and *Basic Chemistry*, fifth edition.

Professor Timberlake belongs to numerous scientific and educational organizations including the American Chemical Society (ACS) and the National Science Teachers Association (NSTA). She has been the Western Regional Winner of the Excellence in College Chemistry Teaching Award given by the Chemical Manufacturers Association. She received the

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When Professor Timberlake is not writing textbooks, she and her husband relax by playing tennis, ballroom dancing, traveling, trying new restaurants, and cooking.

DEDICATION

I dedicate this book to

- My husband, Bill, for his patience, loving support, and preparation of late meals
- My son, John, daughter-in-law, Cindy, grandson, Daniel, and granddaughter, Emily, for the precious things in life
- The wonderful students over many years whose hard work and commitment always motivated me and put purpose in my writing

FAVORITE QUOTES

The whole art of teaching is only the art of awakening the natural curiosity of young minds.

—Anatole France

One must learn by doing the thing; though you think you know it, you have no certainty until you try.

—Sophocles

Discovery consists of seeing what everybody has seen and thinking what nobody has thought.

—Albert Szent-Györgyi

I never teach my pupils; I only attempt to provide the conditions in which they can learn.

—Albert Einstein

Preface

Welcome to the sixth edition of *General, Organic, and Biological Chemistry, Structures of Life*. This chemistry text was written and designed to help you prepare for a career in a health-related profession, such as nursing, dietetics, respiratory therapy, and environmental and agricultural science. This text assumes no prior knowledge of chemistry. My main objective in writing this text is to make the study of chemistry an engaging and positive experience for you by relating the structure and behavior of matter to its role in health and the environment. This new edition introduces more problem-solving strategies, more problem-solving guides, new Analyze the Problem with Connect features, new Try It First and Engage features, conceptual and challenge problems, and new sets of combined problems.

It is my goal to help you become a critical thinker by understanding scientific concepts that will form a basis for making important decisions about issues concerning health and the environment. Thus, I have utilized materials that

- help you to learn and enjoy chemistry
- relate chemistry to careers that may interest you
- develop problem-solving skills that lead to your success in chemistry
- promote learning and success in chemistry

New for the Sixth Edition

New and updated features have been added throughout this sixth edition, including the following:

- **NEW AND UPDATED! Chapter Openers** provide engaging clinical stories in the health profession and introduce the chemical concepts in each chapter.
- **NEW! Clinical Updates** added at the end of each chapter continue the story of the Chapter Opener and describe the follow-up treatment.
- **NEW! Engage** feature in the margin asks students to think about the paragraph they are reading and to test their understanding by answering the Engage question.
- **NEW! Try It First** precedes the Solution section of each Sample Problem to encourage the student to work on the problem before reading the given Solution.
- **NEW! Connect** feature added to **Analyze the Problem** boxes indicates the relationships between *Given* and *Need*.
- **NEW! Clinical Applications** added to Practice Problems show the relevance between the chemistry content and medicine and health.
- **NEW! Strategies for Learning Chemistry** are added that describe successful ways to study and learn chemistry.

- **NEW! Expanded Study Checks in Sample Problems** now contain multiple questions to give students additional self-testing practice.
- **NEW!** The names and symbols for the newest elements 113, Nihonium, Nh, 115, Moscovium, Mc, 117, Tennessine, Ts, and 118, Oganesson, Og.
- **NEW!** The **Steps in the Sample Problems** include a worked-out Solution plan for solving the problem.
- **NEW! Table Design** now has cells that highlight and organize related data.
- **NEW! Test** feature added in the margin encourages students to solve related Practice Problems to practice retrieval of content for exams.
- **NEW! Interactive Videos** give students the experience of step-by-step problem solving for problems from the text.
- **NEW! Review** topics are now placed in the margin at the beginning of a Section, listing the Key Math Skills and Core Chemistry Skills from the previous chapters, which provide the foundation for learning new chemistry principles in the current chapter.
- **UPDATED! Key Math Skills** review basic math relevant to the chemistry the students are learning throughout the text. A **Key Math Skill Review** at the end of each chapter summarizes and gives additional examples.
- **UPDATED! Core Chemistry Skills** identify the key chemical principles in each chapter that are required for successfully learning chemistry. A **Core Chemistry Skill Review** at the end of each chapter helps reinforce the material and gives additional examples.
- **UPDATED! Analyze the Problem** features included in the Solutions of the Sample Problems strengthen critical-thinking skills and illustrate the breakdown of a word problem into the components required to solve it.
- **UPDATED! Practice Problems, Sample Problems, and Art** demonstrate the connection between the chemistry being discussed and how these skills will be needed in professional experience.
- **UPDATED! Combining Ideas** features offer sets of integrated problems that test students' understanding and develop critical thinking by integrating topics from two or more previous chapters.
- **UPDATED!** New zoom design highlights macro-to-micro art and captions are now on a gray screen to emphasize the art and text content.
- **UPDATED! Concept Maps** are updated with new design that shows a clearer path linking concept to concept.
- **UPDATED!** Biochemistry chapters 15, 17, and 19 to 24 have been rewritten to strengthen connections between sections, and include new Study Checks and new Chemistry Links to Health.

Chapter Organization of the Sixth Edition

In each textbook I write, I consider it essential to relate every chemical concept to real-life issues. Because a chemistry course may be taught in different time frames, it may be difficult to cover all the chapters in this text. However, each chapter is a complete package, which allows some chapters to be skipped or the order of presentation to be changed.

Chapter 1, Chemistry in Our Lives, discusses the Scientific Method in everyday terms, guides students in developing a study plan for learning chemistry, with a section of Key Math Skills that reviews the basic math, including scientific notation, needed in chemistry calculations.

- The Chapter Opener tells the story of two murders and features the work and career of forensic scientists.
- A new Clinical Update feature describes the forensic evidence that helps to solve the murders and includes Clinical Applications.
- Scientific Method: Thinking Like a Scientist is expanded to include *law* and *theory*.
- An updated Section 1.3 Studying and Learning Chemistry expands the discussion of strategies that improve learning and understanding of content.
- New Section 1.5 Writing Numbers in Scientific Notation is added.
- Key Math Skills are: Identifying Place Values, Using Positive and Negative Numbers in Calculations, Calculating Percentages, Solving Equations, Interpreting Graphs, and Writing Numbers in Scientific Notation.

Chapter 2, Chemistry and Measurements, looks at measurement and emphasizes the need to understand numerical relationships of the metric system. Significant figures are discussed in the determination of final answers. Prefixes from the metric system are used to write equalities and conversion factors for problem-solving strategies. Density is discussed and used as a conversion factor.

- The Chapter Opener tells the story of a patient with high blood pressure and features the work and career of a registered nurse.
- The Clinical Update describes the patient's status and follow-up visit with his doctor.
- Sample Problems relate problem solving to health-related topics such as the measurements of blood volume, omega-3 fatty acids, radiological imaging, body fat, cholesterol, and medication orders.
- Clinical Applications feature questions about measurements, daily values for minerals and vitamins, and equalities and conversion factors for medications.
- The Key Math Skill is: Rounding Off.
- Core Chemistry Skills are: Counting Significant Figures, Using Significant Figures in Calculations, Using Prefixes, Writing Conversion Factors from Equalities, Using Conversion Factors, and Using Density as a Conversion Factor.

Chapter 3, Matter and Energy, classifies matter and states of matter, describes temperature measurement, and discusses energy, specific heat, energy in nutrition, and changes of state. Physical and chemical properties and physical and chemical changes are discussed.

- The Chapter Opener describes diet and exercise for an overweight adolescent at risk for type 2 diabetes and features the work and career of a dietitian.
- The Clinical Update describes the diet prepared with a dietitian for weight loss.
- Practice Problems and Sample Problems include high temperatures used in cancer treatment, the energy produced by a high-energy shock output of a defibrillator, body temperature lowering using a cooling cap, ice bag therapy for muscle injury, dental implants, and energy values for food.
- Core Chemistry Skills are: Identifying Physical and Chemical Changes, Converting Between Temperature Scales, Using Energy Units, Using the Heat Equation, and Calculating Heat for Change of State.
- The interchapter problem set, Combining Ideas from Chapters 1 to 3, completes the chapter.

Chapter 4, Atoms and Elements, introduces elements and atoms and the periodic table. The names and symbols for the newest elements 113, Nihonium, Nh, 115, Moscovium, Mc, 117, Tennessine, Ts, and 118, Oganesson, Og, are added to the periodic table. Electron configurations are written for atoms and the trends in periodic properties are described. Atomic numbers and mass numbers are determined for isotopes. The most abundant isotope of an element is determined by its atomic mass. Atomic mass is calculated using the masses of the naturally occurring isotopes and their abundances. Electron arrangements are written using orbital diagrams, electron configurations, and abbreviated electron configurations.

- The Chapter Opener and Clinical Update feature the improvement in crop production by a farmer.
- Atomic number and mass number are used to calculate the number of protons and neutrons in an atom.
- The number of protons and neutrons are used to calculate the mass number and to write the atomic symbol for an isotope.
- The trends in periodic properties are described for valence electrons, atomic size, ionization energy, and metallic character.
- Core Chemistry Skills are: Counting Protons and Neutrons, Writing Atomic Symbols for Isotopes, Writing Electron Configurations, Using the Periodic Table to Write Electron Configurations, Identifying Trends in Periodic Properties, and Drawing Lewis Symbols.

Chapter 5, Nuclear Chemistry, looks at the types of radiation emitted from the nuclei of radioactive atoms. Nuclear equations are written and balanced for both naturally occurring radioactivity and artificially produced radioactivity. The half-lives of radioisotopes are discussed, and the amount of time for a sample to decay is calculated. Radioisotopes important in the

field of nuclear medicine are described. Fission and fusion and their role in energy production are discussed.

- The Chapter Opener describes a patient with possible coronary heart disease who undergoes a nuclear stress test and features the work and career of a radiation technologist.
- The Clinical Update discusses the results of cardiac imaging using the radioisotope Tl-201.
- Sample Problems and Practice Problems use nursing and medical examples, including phosphorus-32 for the treatment of leukemia, titanium seeds containing a radioactive isotope implanted in the body to treat cancer, yttrium-90 injections for arthritis pain, and millicuries in a dose of phosphorus-32.
- New art includes the illustration of the organs of the body where medical radioisotopes are used for diagnosis and treatment.
- Core Chemistry Skills are: Writing Nuclear Equations and Using Half-Lives.

Chapter 6, Ionic and Molecular Compounds, describes the formation of ionic and covalent bonds. Chemical formulas are written, and ionic compounds—including those with polyatomic ions—and molecular compounds are named.

- The Chapter Opener describes the chemistry of aspirin and features the work and career of a pharmacy technician.
- The Clinical Update describes several types of compounds at a pharmacy and includes Clinical Applications.
- Section 6.6 is now titled Lewis Structures for Molecules and Polyatomic Ions, and 6.9 is now titled Intermolecular Forces in Compounds.
- New material on polyatomic ions compares the names of *ate* ions and *ite* ions, the charge of sulfate and sulfite, phosphate and phosphite, carbonate and hydrogen carbonate, and the formulas and charges of halogen polyatomic ions with oxygen.
- Core Chemistry Skills are: Writing Positive and Negative Ions, Writing Ionic Formulas, Naming Ionic Compounds, Writing the Names and Formulas for Molecular Compounds, Drawing Lewis Structures, Using Electronegativity, Predicting Shape, Identifying Polarity of Molecules, and Identifying Intermolecular Forces.
- The interchapter problem set, Combining Ideas from Chapters 4 to 6, completes the chapter.

Chapter 7, Chemical Reactions and Quantities, shows students how to balance chemical equations and to recognize the types of chemical reactions: combination, decomposition, single replacement, double replacement, and combustion. Students are introduced to moles and molar masses of compounds, which are used in calculations to determine the mass or number of particles in a given quantity as well as limiting reactants and percent yield. The chapter concludes with a discussion of energy in reactions.

- The Chapter Opener describes the symptoms of heart and pulmonary disease and discusses the career of an exercise physiologist.

- A new Clinical Update, Improving Natalie's Overall Fitness, discusses her test results and suggests exercise to improve oxygen intake.
- A new order of topics begins with Section 7.5 Molar Mass, 7.6 Calculations Using Molar Mass, 7.7 Mole Relationships in Chemical Equations, and 7.8 Mass Calculations for Chemical Reactions, Section 7.9 Limiting Reactants and Percent Yield, and 7.10 Energy in Chemical Reactions.
- New Sample Problems are: Oxidation and Reduction, and Exothermic and Endothermic Reactions.
- New expanded art shows visible evidence of several types of chemical reactions.
- Core Chemistry Skills are: Balancing a Chemical Equation, Classifying Types of Chemical Reactions, Identifying Oxidized and Reduced Substances, Converting Particles to Moles, Calculating Molar Mass, Using Molar Mass as a Conversion Factor, Using Mole–Mole Factors, Converting Grams to Grams, Calculating Quantity of Product from a Limiting Reactant, Calculating Percent Yield, and Using the Heat of Reaction.

Chapter 8, Gases, discusses the properties of gases and calculates changes in gases using the gas laws: Boyle's, Charles's, Gay-Lussac's, Avogadro's, Dalton's, and the Ideal Gas Law. Problem-solving strategies enhance the discussion and calculations with the ideal gas laws.

- The Chapter Opener features the work and career of a respiratory therapist who uses oxygen to treat a child with asthma.
- The Clinical Update describes exercise to manage exercise-induced asthma. Clinical Applications are related to lung volume and gas laws.
- Sample Problems and Challenge Problems use nursing and medical examples, including, calculating the volume of oxygen gas delivered through a face mask during oxygen therapy, preparing a heliox breathing mixture for a scuba diver, and home oxygen tanks.
- Core Chemistry Skills are: Using the Gas Laws, Using the Ideal Gas Law, Calculating Mass or Volume of a Gas in a Chemical Reaction, and Calculating Partial Pressure.
- The interchapter problem set, Combining Ideas from Chapters 7 and 8, completes the chapter.

Chapter 9, Solutions, describes solutions, electrolytes, saturation and solubility, insoluble salts, concentrations, and osmosis. The concentrations of solutions are used to determine volume or mass of solute. The volumes and molarities of solutions are used in calculations of dilutions and titrations. Properties of solutions, freezing and boiling points, osmosis in the body, and dialysis are discussed.

- The Chapter Opener describes a patient with kidney failure and dialysis treatment and features the work and career of a dialysis nurse.
- The Clinical Update explains dialysis treatment and electrolyte levels in dialysate fluid.

- A new example of suspensions used to purify water in treatment plants is added.
- New art illustrates the freezing point decrease and boiling point increase for aqueous solutions with increasing number of moles of solute in one kilogram of water.
- Core Chemistry Skills are: Using Solubility Rules, Calculating Concentration, Using Concentration as a Conversion Factor, Calculating the Quantity of a Reactant or Product for a Chemical Reaction in Solution, and Calculating the Boiling Point/Freezing Point of a Solution.

Chapter 10, Reaction Rates and Chemical Equilibrium, looks at the rates of reactions and the equilibrium condition when forward and reverse rates for a reaction become equal. Equilibrium expressions for reactions are written and equilibrium constants are calculated. Le Châtelier's principle is used to evaluate the impact on concentrations when stress is placed on the system.

- The Chapter Opener describes the symptoms of infant respiratory distress syndrome (IRDS) and discusses the career of a neonatal nurse.
- The Clinical Update describes a child with anemia, hemoglobin–oxygen equilibrium, and a diet that is high in iron-containing foods.
- Core Chemistry Skills are: Writing the Equilibrium Expression, Calculating an Equilibrium Constant, Calculating Equilibrium Concentrations, and Using Le Châtelier's Principle.

Chapter 11, Acids and Bases, discusses acids and bases and their strengths, and conjugate acid–base pairs. The dissociation of strong and weak acids and bases is related to their strengths as acids or bases. The dissociation of water leads to the water dissociation expression, K_w , the pH scale, and the calculation of pH. Chemical equations for acids in reactions are balanced and titration of an acid is illustrated. Buffers are discussed along with their role in the blood. The pH of a buffer is calculated.

- The Chapter Opener describes a blood sample for an emergency room patient sent to the clinical laboratory for analysis of blood pH and CO_2 gas and features the work and career of a clinical laboratory technician.
- The Clinical Update describes the symptoms and treatment for acid reflux disease (GERD).
- Key Math Skills are: Calculating pH from $[\text{H}_3\text{O}^+]$ and Calculating $[\text{H}_3\text{O}^+]$ from pH.
- Core Chemistry Skills are: Identifying Conjugate Acid–Base Pairs, Calculating $[\text{H}_3\text{O}^+]$ and $[\text{OH}^-]$ in Solutions, Writing Equations for Reactions of Acids and Bases, Calculating Molarity or Volume of an Acid or Base in a Titration, and Calculating the pH of a Buffer.
- The interchapter problem set, Combining Ideas from Chapters 9 to 11, completes the chapter.

Chapter 12, Introduction to Organic Chemistry: Hydrocarbons, compares inorganic and organic compounds, and describes the structures and naming of alkanes, alkenes including cis–trans isomers, alkynes, and aromatic compounds.

- The Chapter Opener describes a fire victim and the search for traces of accelerants and fuel at the arson scene and features the work and career of a firefighter/emergency medical technician.
- The Clinical Update describes the treatment of burns in the hospital and the types of fuels identified in the fire.
- Subsections in 12.4 Solubility and Density and 12.5 Identifying Alkenes and Alkynes are revised for clarity.
- More line-angle formulas for organic structures in Practice Problems have been added.
- Core Chemistry Skills are: Naming and Drawing Alkanes and Writing Equations for Hydrogenation, Hydration, and Polymerization.

Chapter 13, Alcohols, Phenols, Thiols, and Ethers, describes the functional groups and names of alcohols, phenols, thiols, and ethers.

- The new Chapter Opener describes local anesthetics for surgery to repair a torn anterior cruciate ligament (ACL) and features the work and career of a nurse anesthetist.
- The Clinical Update describes some foods added to a diet plan including a comparison of their functional groups.
- New art includes new career photo of a nurse anesthetist, ball-and-stick models added to primary, secondary, and tertiary alcohol structures in Section 13.3 to visualize the classification of alcohols, anesthesia apparatus for delivery of isoflurane, exhausted athlete, and perming hair.
- Chemistry Link to Health “Hand Sanitizers” is revised and “Methanol Poisoning” is moved into “Oxidation of Alcohol in the Body” at the end of Section 13.4.
- Core Chemistry Skills are: Identifying Alcohols, Phenols, and Thiols, Naming Alcohols and Phenols, Writing Equations for the Dehydration of Alcohols, and Writing Equations for the Oxidation of Alcohols.

Chapter 14, Aldehydes and Ketones, discusses the nomenclature, structures, and oxidation and reduction of aldehydes and ketones. The chapter discusses the formation of hemiacetals and acetals.

- The Chapter Opener describes the risk factors for melanoma and discusses the career of a dermatology nurse.
- The Clinical Update discusses melanoma, skin protection, and functional groups of sunscreens.
- New art using line-angle formulas is drawn for separate equations of hemiacetal and acetal formation.
- Sections 14.3 Oxidation and Reduction of Aldehydes and Ketones and 14.4 Addition of Alcohols: Hemiacetals and Acetals are revised for clarity.
- A summary of the Tollens' and Benedict's tests is added to section 14.3.
- Core Chemistry Skills are: Naming Aldehydes and Ketones, and Forming Hemiacetals and Acetals.
- New structures of pamplemousse acetal in grapefruit and rose acetal in perfume are added.
- The interchapter problem set, Combining Ideas from Chapters 12 to 14, completes the chapter.

Chapter 15, Carbohydrates, describes the carbohydrate molecules monosaccharides, disaccharides, and polysaccharides and their formation by photosynthesis. Monosaccharides are classified as aldo or keto pentoses or hexoses. Chiral molecules are discussed along with Fischer projections and D and L notations. The formation of glycosidic bonds in disaccharides and polysaccharides is described.

- The Chapter Opener describes a diabetes patient and her diet and features the work and career of a diabetes nurse.
- The Clinical Update describes a diet and exercise program to lower blood glucose.
- New art accompanies content on tooth decay and use of xylitol, the structures of amino sugars and uronic acids, and hyaluronic acid used as facial fillers.
- New Chemistry Links to Health are: Dental Cavities and Xylitol Gum, and Varied Biological Roles of Carbohydrate Polymers: The Case of Glycosaminoglycans.
- New Study Checks include penicillamine to treat rheumatoid arthritis, and ethambutol to treat tuberculosis.
- Section on Chirality is moved to Chapter 15.
- Core Chemistry Skills are: Identifying Chiral Molecules, Identifying D and L Fischer Projections for Carbohydrates, and Drawing Haworth Structures.

Chapter 16, Carboxylic Acids and Esters, discusses the functional groups and naming of carboxylic acids and esters. Chemical reactions include esterification and acid and base hydrolysis of esters.

- The Chapter Opener describes heart surgery and discusses the work and career of a surgical technician.
- The Clinical Update describes the chemistry and use of liquid bandages.
- More line-angle structures for carboxylic acids and esters have been added.
- New art of ester-containing fruit has been added.
- Core Chemistry Skills are: Naming Carboxylic Acids and Hydrolyzing Esters.

Chapter 17, Lipids, discusses fatty acids and the formation of ester bonds in triacylglycerols and glycerophospholipids. Chemical properties of fatty acids and their melting points along with the hydrogenation of unsaturated triacylglycerols are discussed. Steroids, such as cholesterol and bile salts, are described. The role of phospholipids in the lipid bilayer of cell membranes is discussed as well as the lipids that function as steroid hormones.

- The updated Chapter Opener describes a patient with symptoms of familial hypercholesterolemia and features the work and career of a clinical lipid specialist.
- The Clinical Update describes medications a program to and a diet to lower cholesterol.
- New art diagrams include glaucoma and its treatment with a prostaglandin, healthy and nonhealthy livers, and the steroid structure of spironolactone.
- Chemistry Links to Health are: Omega-3 Fatty Acids in Fish Oils and Infant Respiratory Distress Syndrome (IRDS).

- New Chemistry Links to Health are: A Prostaglandin-like Medication for Glaucoma That Also Thickens Eyelashes, and A Steroid Receptor Antagonist That Prevents the Development of Male Sexual Characteristics.
- Core Chemistry Skills are: Identifying Fatty Acids, Drawing Structures for Triacylglycerols, Drawing the Products for the Hydrogenation, Hydrolysis, and Saponification of a Triacylglycerol, and Identifying the Steroid Nucleus.

Chapter 18, Amines and Amides, emphasizes the nitrogen atom in their functional groups and their names. Properties of amines including classification, boiling point, solubility in water, and use as neurotransmitters are included. Alkaloids are discussed as the naturally occurring amines in plants. Chemical reactions include dissociation and neutralization of amines, amidation, and acid and base hydrolysis of amides.

- The Chapter Opener describes pesticides and pharmaceuticals used on a ranch and discusses the career of an environmental health practitioner.
- The Clinical Update describes the collection of soil and water samples for testing of insecticides and antibiotics.
- New line-angle formulas are drawn for amines, alkaloids, heterocyclic amines, and neurotransmitters.
- Introduction to Section 18.5, Amides is revised.
- Chemistry Link to Health Synthesizing Drugs and Opioids is revised.
- Clinical Applications include novocaine, lidocaine, ritalin, niacin, serotonin, histamine, acetylcholine, dose calculations of pesticides and antibiotics, enrofloxacin, and voltaren.
- Core Chemistry Skills are: Forming Amides and Hydrolyzing Amides.
- The interchapter problem set, Combining Ideas from Chapters 15 to 18, completes the chapter.

Chapter 19, Amino Acids and Proteins, discusses amino acids, formation of peptide bonds and the primary, secondary, tertiary, and quaternary structural levels of proteins. The ionized structures of amino acids are drawn at physiological pH.

- A new Chapter Opener discusses the symptoms of sickle-cell anemia in a child, the mutation in amino acids that causes the crescent shape of abnormal red blood cells, and the career of a hematology nurse.
- A new Clinical Update discusses the diagnosis of sickle-cell anemia using electrophoresis and its treatment.
- The protein structure sections are reorganized as: 19.2 Proteins: Primary Structure; 19.3 Proteins: Secondary Structure; and 19.4 Proteins: Tertiary and Quaternary Structures.
- Chemistry Links to Health are: Essential Amino Acids and Complete Proteins, Protein Secondary Structures and Alzheimer's Disease, and Sickle-Cell Anemia.
- New Chemistry Links to Health are: Cystinuria, and Keratoconus.
- New art includes normal cornea, cornea with keratoconus, collagen fibers in keratoconus, and insoluble fiber formation in sickle-cell anemia.

- New Sample Problems are: 19.3 Identifying a Tripeptide and 19.4 Drawing a Peptide.
- Core Chemistry Skills are: Drawing the Structure for an Amino Acid at Physiological pH and Identifying the Primary, Secondary, Tertiary, and Quaternary Structures of Proteins.

Chapter 20, Enzymes and Vitamins, relates the importance of the three-dimensional shape of proteins to their function as enzymes. The shape of an enzyme and its substrate are factors in enzyme regulation. End products of an enzyme-catalyzed sequence can increase or decrease the rate of an enzyme-catalyzed reaction. Other regulatory processes include allosteric enzymes, covalent modification and phosphorylation, and zymogens. Proteins change shape and lose function when subjected to pH changes and high temperatures. The important role of water-soluble vitamins as coenzymes is related to enzyme function.

- The Chapter Opener discusses the symptoms of lactose intolerance and describes the career of a physician assistant.
- The Clinical Update describes the hydrogen breath test to confirm lactose intolerance and a diet that is free of lactose and use of Lactaid.
- Chemistry Link to Health is: Isoenzymes as Diagnostic Tools.
- New Chemistry Links to Health are: Fabry Disease and Taking Advantage of Enzyme Inhibition to Treat Cancer: Imatinib.
- New art includes the structure of galactosidase A and enzyme inhibition of imatinib used to treat myeloid leukemia.
- Core Chemistry Skills are: Describing Enzyme Action, Classifying Enzymes, Identifying Factors Affecting Enzyme Activity, and Describing the Role of Cofactors.

Chapter 21, Nucleic Acids and Protein Synthesis, describes the nucleic acids and their importance as biomolecules that store and direct information for the synthesis of cellular components. The role of complementary base pairing is discussed in both DNA replication and the formation of mRNA during protein synthesis. The role of RNA is discussed in the relationship of the genetic code to the sequence of amino acids in a protein. Mutations describe ways in which the nucleotide sequences are altered in genetic diseases.

- The Chapter Opener describes a patient's diagnosis and treatment of breast cancer and discusses the work and career of a histology technician.
- A Clinical Update describes estrogen-positive tumors, the impact of the altered genes BRCA1 and BRCA2 on the estrogen receptor, and medications to suppress tumor growth.
- A new Section discusses recombinant DNA, polymerase chain reaction, and DNA fingerprinting.
- The Chemistry Link to Health Protein Sequencing was moved from Chapter 19 to Chapter 21.
- New Chemistry Links to Health are: Cataracts and Ehlers–Danlos Syndrome.

- Core Chemical Skills are: Writing the Complementary DNA Strand, Writing the mRNA Segment for a DNA Template, and Writing the Amino Acid for an mRNA Codon.
- The interchapter problem set, Combining Ideas from Chapters 19 to 21, completes the chapter.

Chapter 22, Metabolic Pathways for Carbohydrates, describes the stages of metabolism and the digestion of carbohydrates, our most important fuel. The breakdown of glucose to pyruvate is described using glycolysis, which is followed under aerobic conditions by the decarboxylation of pyruvate to acetyl CoA. The synthesis of glycogen and the synthesis of glucose from noncarbohydrate sources are discussed.

- The Chapter Opener describes the symptoms of a glycogen storage disease and discusses the career of a hepatology nurse.
- The Clinical Update describes medical treatment of frequent feedings of glucose for von Gierke's disease, in which a child has a defective glucose-6-phosphatase and cannot break down glucose-6-phosphate to glucose.
- Chemistry Link to Health is: Glycogen Storage Diseases (GSDs).
- New Chemistry Links to Health are: Galactosemia and Glucocorticoids, and Steroid-Induced Diabetes.
- Sections 22.4 "Glycolysis: Oxidation of Glucose", 22.6 "Glycogen Synthesis and Degradation", and 22.7 "Gluconeogenesis: Glucose Synthesis" are revised for clarity.
- New art includes diagrams of normal lactose oxidation compared to galactosemia, and the impact of glucocorticoids on glucose metabolism.
- Core Chemistry Skills are: Identifying Important Coenzymes in Metabolism, Identifying the Compounds in Glycolysis, and Identifying the Compounds and Enzymes in Glycogenesis and Glycogenolysis.

Chapter 23, Metabolism and Energy Production, looks at the entry of acetyl CoA into the citric acid cycle and the production of reduced coenzymes for electron transport, oxidative phosphorylation, and the synthesis of ATP. The malate–aspartate shuttle describes the transport of NADH from the cytosol into the mitochondrial matrix.

- The new Chapter Opener discusses a child with mitochondrial myopathy and discusses the work and career of a physical therapist.
- A new Clinical Update discusses treatment that helps increase a child's functional capacity.
- New Clinical Applications include problems about diseases associated with enzyme deficiencies.
- New material discusses diseases of enzymes in the citric acid cycle such as fumarase deficiency that causes neurological impairment, developmental delay, and seizures.
- Feedback Control, Covalent Modification, and Enzyme Inhibition subsections are expanded to enhance student understanding.

- A new subsection Diseases of the Citric Acid Cycle is added to Section 23.1.
- Section 23.2 Electron Transport and ATP is revised for clarity.
- Chemistry Links to Health are: Toxins: Inhibitors of Electron Transport, Uncouplers of ATP Synthase, and Efficiency of ATP Production.
- Core Chemistry Skills are: Describing the Reactions in the Citric Acid Cycle and Calculating the ATP Produced from Glucose.

Chapter 24, Metabolic Pathways for Lipids and Amino Acids, discusses the digestion of lipids and proteins and the metabolic pathways that convert fatty acids and amino acids into energy. Discussions include the conversion of excess carbohydrates to triacylglycerols in adipose tissue and how the intermediates of the citric acid cycle are converted to nonessential amino acids.

- The Chapter Opener describes a liver profile with elevated levels of liver enzymes for a patient with chronic hepatitis C infection and discusses the career of a public health nurse.
- The Clinical Update describes interferon and ribavirin therapy for hepatitis C.

Acknowledgments

The preparation of a new text is a continuous effort of many people. I am thankful for the support, encouragement, and dedication of many people who put in hours of tireless effort to produce a high-quality book that provides an outstanding learning package. I am thankful for the outstanding contributions of Professor MaryKay Orgill whose updates and clarifications enhanced the content of the biochemistry chapters 15, 17, and 19 to 24. The editorial team at Pearson has done an exceptional job. I want to thank Jeanne Zalesky, Director, Courseware Portfolio Management, and Scott Dustan, Courseware Portfolio Manager, who supported our vision of this sixth edition.

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Thanks to Kristen Flathman, Managing Producer, Coleen Morrison, Courseware Analyst, and Jennifer Hart, Courseware Director for their excellent review of pages and helpful suggestions.

I am especially proud of the art program in this text, which lends beauty and understanding to chemistry. I would like to

- New material discusses the digestion of triacylglycerols and dietary fats, lipase deficiency, eruptive xanthomas, calculating ATP from beta oxidation of an unsaturated fatty acid, and ketoacidosis.
- Sections 24.1 Digestion of Triacylglycerols, 24.2 Oxidation of Fatty Acids, and 24.3 ATP and Fatty Acid Oxidation are revised for clarity.
- New art includes xanthomas, ackee fruit, and injection of interferon.
- Chemistry Links to Health are: Diabetes and Ketone Bodies and Phenylketonuria (PKU).
- A new Chemistry Link to Health discusses Jamaican vomiting sickness.
- Clinical Applications include new problems about Jamaican vomiting sickness caused by an inhibitor of acyl CoA dehydrogenase, and inhibitors of beta oxidation.
- Core Chemistry Skills are: Calculating the ATP from Fatty Acid Oxidation (β Oxidation), Describing How Ketone Bodies are Formed, and Distinguishing Anabolic and Catabolic Pathways.
- The interchapter problem set, Combining Ideas from Chapters 22 to 24, completes the chapter.

thank Jay McElroy, Art Courseware Analyst and Stephanie Marquez, Photo and Illustration Project Manager; Maria Guglielmo Walsh, Design Manager, and Tamara Newnam, Cover and Interior Designer, whose creative ideas provided the outstanding design for the cover and pages of the book. I appreciate the tireless efforts of Clare Maxwell, Photo Researcher, and Matt Perry, Rights and Permissions Project Manager in researching and selecting vivid photos for the text so that students can see the beauty of chemistry. Thanks also to *Bio-Rad Laboratories* for their courtesy and use of *KnowItAll ChemWindows*, drawing software that helped us produce chemical structures for the manuscript. The macro-to-micro illustrations designed by Jay McElroy and Imagineering Art give students visual impressions of the atomic and molecular organization of everyday things and are a fantastic learning tool. I also appreciate all the hard work in the field put in by the marketing team and Elizabeth Ellsworth Bell, Marketing Manager.

I am extremely grateful to an incredible group of peers for their careful assessment of all the new ideas for the text; for their suggested additions, corrections, changes, and deletions; and for providing an incredible amount of feedback about improvements for the book. I admire and appreciate every one of you.

If you would like to share your experience with chemistry, or have questions and comments about this text, I would appreciate hearing from you.

Karen Timberlake
Email: khemist@aol.com

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Career Focus Engages Students

Best-selling author Karen Timberlake, joined by new contributing author MaryKay Orgill, connects chemistry to real-world and career applications like no one else. The sixth edition of *General, Organic, and Biological Chemistry: Structures of Life* engages students by helping them see the connections between chemistry, the world around them, and future careers.

Acids and Bases

11

Larry, a 30-year-old man, is brought to the emergency room after an automobile accident where he is unresponsive. One of the emergency room nurses takes a blood sample, which is then sent to Brianna, a clinical laboratory technician, who begins the process of analyzing the pH, the partial pressures of O₂ and CO₂, and the concentrations of glucose and electrolytes.

Brianna determines that Larry's blood pH is 7.30 and the partial pressure of CO₂ gas is above the desired level. Blood pH is typically in the range of 7.35 to 7.45, and a value less than 7.35 indicates a state of acidosis. Respiratory acidosis occurs because an increase in the partial pressure of CO₂ gas in the bloodstream prevents the biochemical buffers in blood from making a change in the pH.

Brianna recognizes these signs and immediately contacts the emergency room to inform them that Larry's airway may be blocked. In the emergency room, they provide Larry with an IV containing bicarbonate to increase the blood pH and begin the process of unblocking his airway. Shortly afterward, Larry's airway is cleared, and his blood pH and partial pressure of CO₂ gas return to normal.

CAREER

Clinical Laboratory Technician

Clinical laboratory technicians, also known as medical laboratory technicians, perform a wide variety of tests on body fluids and cells that help in the diagnosis and treatment of patients. These tests range from determining blood concentrations of glucose and cholesterol to determining drug levels in the blood for transplant patients or a patient undergoing treatment. Clinical laboratory technicians also prepare specimens in the detection of cancerous tumors and type blood samples for transfusions. Clinical laboratory technicians must also interpret and analyze the test results, which are then passed on to the physician.



CLINICAL UPDATE

Acid Reflux Disease

After Larry was discharged from the hospital, he complained of a sore throat and dry cough, which his doctor diagnosed as acid reflux. You can view the symptoms of acid reflux disease (GERD) in the **CLINICAL UPDATE Acid Reflux Disease**, pages 448–449, and learn about the pH changes in the stomach and how the condition is treated.

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Chapter Openers emphasize clinical connections by showing students relevant, engaging, and topical examples of how health professionals use chemistry everyday in their careers.

Clinical Updates added at the end of each chapter continue the story of the chapter opener and describe the follow-up treatment, helping students see the connections to the chemistry learned in the chapter.

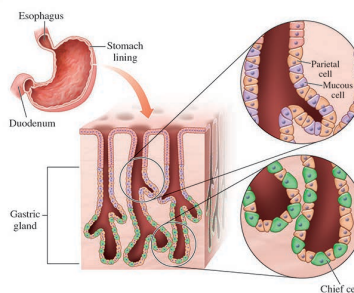
Chemistry Links to Health and **Chemistry Links to the Environment** apply chemical concepts to health and medical topics as well as topics in the environment, such as bone density, weight loss and weight gain, alcohol abuse, kidney dialysis, dental cavities and xylitol gum, hyperglycemia and hypoglycemia, Alzheimer's disease, sickle-cell anemia, cancer, cataracts, galactosemia, and steroid-induced diabetes, illustrating the importance of understanding chemistry in real-life situations.

Chemistry Link to Health

Stomach Acid, HCl

Gastric acid, which contains HCl, is produced by parietal cells that line the stomach. When the stomach expands with the intake of food, the gastric glands begin to secrete a strongly acidic solution of HCl. In a single day, a person may secrete 2000 mL of gastric juice, which contains hydrochloric acid, mucins, and the enzymes pepsin and lipase.

The HCl in the gastric juice activates a digestive enzyme from the chief cells called *pepsinogen* to form *pepsin*, which breaks down proteins in food entering the stomach. The secretion of HCl continues until the stomach has a pH of about 2, which is the optimum for activating the digestive enzymes without ulcerating the stomach lining. In addition, the low pH destroys bacteria that reach the stomach. Normally, large quantities of viscous mucus are secreted within the stomach to protect its lining from acid and enzyme damage. Gastric acid may also form under conditions of stress when the nervous system activates the production of HCl. As the contents of the stomach move into the small intestine, cells produce bicarbonate that neutralizes the gastric acid until the pH is about 5.



Parietal cells in the lining of the stomach secrete gastric acid HCl.

Builds Students' Critical Thinking

One of Karen Timberlake's goals is to help students become critical thinkers. Color-coded tips found throughout each chapter are designed to provide guidance and encourage students to really think about what they are reading and help develop important critical-thinking skills.

in $[\text{H}_3\text{O}^+]$ and a decrease in $[\text{OH}^-]$, which makes an acidic solution. If base is added, $[\text{OH}^-]$ increases and $[\text{H}_3\text{O}^+]$ decreases, which gives a basic solution. However, for any aqueous solution, whether it is neutral, acidic, or basic, the product $[\text{H}_3\text{O}^+][\text{OH}^-]$ is equal to K_w (1.0×10^{-14} at 25 °C) (see TABLE 11.6).

TABLE 11.6 Examples of $[\text{H}_3\text{O}^+]$ and $[\text{OH}^-]$ in Neutral, Acidic, and Basic Solutions

| Type of Solution | $[\text{H}_3\text{O}^+]$ | $[\text{OH}^-]$ | K_w (25 °C) |
|------------------|---------------------------------|---------------------------------|-----------------------|
| Neutral | $1.0 \times 10^{-7} \text{ M}$ | $1.0 \times 10^{-7} \text{ M}$ | 1.0×10^{-14} |
| Acidic | $1.0 \times 10^{-2} \text{ M}$ | $1.0 \times 10^{-12} \text{ M}$ | 1.0×10^{-14} |
| Acidic | $2.5 \times 10^{-5} \text{ M}$ | $4.0 \times 10^{-10} \text{ M}$ | 1.0×10^{-14} |
| Basic | $1.0 \times 10^{-9} \text{ M}$ | $1.0 \times 10^{-5} \text{ M}$ | 1.0×10^{-14} |
| Basic | $5.0 \times 10^{-11} \text{ M}$ | $2.0 \times 10^{-4} \text{ M}$ | 1.0×10^{-14} |

Using the K_w to Calculate $[\text{H}_3\text{O}^+]$ and $[\text{OH}^-]$ in a Solution

If we know the $[\text{H}_3\text{O}^+]$ of a solution, we can use the K_w to calculate $[\text{OH}^-]$. If we know the $[\text{OH}^-]$ of a solution, we can calculate $[\text{H}_3\text{O}^+]$ from their relationship in the K_w , as shown in Sample Problem 11.6.

$$K_w = [\text{H}_3\text{O}^+][\text{OH}^-]$$
$$[\text{OH}^-] = \frac{K_w}{[\text{H}_3\text{O}^+]} \quad [\text{H}_3\text{O}^+] = \frac{K_w}{[\text{OH}^-]}$$

▶ SAMPLE PROBLEM 11.6 Calculating the $[\text{H}_3\text{O}^+]$ of a Solution

TRY IT FIRST

A vinegar solution has a $[\text{OH}^-] = 5.0 \times 10^{-12} \text{ M}$ at 25 °C. What is the $[\text{H}_3\text{O}^+]$ of the vinegar solution? Is the solution acidic, basic, or neutral?

SOLUTION

STEP 1 State the given and needed quantities.

| ANALYZE THE PROBLEM | Given | Need | Connect |
|---------------------|---|--------------------------|---|
| | $[\text{OH}^-] = 5.0 \times 10^{-12} \text{ M}$ | $[\text{H}_3\text{O}^+]$ | $K_w = [\text{H}_3\text{O}^+][\text{OH}^-]$ |

STEP 2 Write the K_w for water and solve for the unknown $[\text{H}_3\text{O}^+]$.

$$K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14}$$

Solve for $[\text{H}_3\text{O}^+]$ by dividing both sides by $[\text{OH}^-]$.

$$\frac{K_w}{[\text{OH}^-]} = \frac{[\text{H}_3\text{O}^+][\text{OH}^-]}{[\text{OH}^-]}$$
$$[\text{H}_3\text{O}^+] = \frac{1.0 \times 10^{-14}}{[\text{OH}^-]}$$

STEP 3 Substitute the known $[\text{OH}^-]$ into the equation and calculate.

$$[\text{H}_3\text{O}^+] = \frac{1.0 \times 10^{-14}}{5.0 \times 10^{-12}} = 2.0 \times 10^{-3} \text{ M}$$

Because the $[\text{H}_3\text{O}^+]$ of $2.0 \times 10^{-3} \text{ M}$ is larger than the $[\text{OH}^-]$ of $5.0 \times 10^{-12} \text{ M}$, the solution is acidic.

TEST

Try Practice Problems 11.35 and 11.36

ENGAGE

If you know the $[\text{H}_3\text{O}^+]$ of a solution, how do you use the K_w to calculate the $[\text{OH}^-]$?

CORE CHEMISTRY SKILL

Calculating $[\text{H}_3\text{O}^+]$ and $[\text{OH}^-]$ in Solutions

ENGAGE

Why does the $[\text{H}_3\text{O}^+]$ of an aqueous solution increase if the $[\text{OH}^-]$ decreases?

NEW! Test feature found in the margin throughout each chapter encourages students to solve related Practice Problems to practice retrieval of content for exams.

UPDATED! Core Chemistry Skills found throughout each chapter identify the fundamental chemistry concepts that students need to understand in the current chapter.

NEW! Engage feature asks students to think about what they are reading and immediately assess their understanding by answering the Engage question, which is related to the topic. With regular self-assessment, students connect new concepts to prior knowledge to help them retrieve that content during exams.

and Problem-Solving Skills

New problem-solving features enhance Karen Timberlake's unmatched problem-solving strategies and help students deepen their understanding of content while improving their problem-solving skills.

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CORE CHEMISTRY SKILL

Calculating Molarity or Volume of an Acid or Base in a Titration

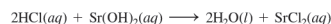
ENGAGE

Why do you need to use a balanced equation for a neutralization problem?

SAMPLE PROBLEM 11.12 Titration of an Acid

TRY IT FIRST

If 16.3 mL of a 0.185 M Sr(OH)₂ solution is used to titrate the HCl in a 25.0-mL (0.0250 L) sample of gastric juice, what is the molarity of the HCl solution?



SOLUTION

STEP 1 State the given and needed quantities and concentrations.

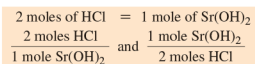
| | Given | Need | Connect |
|---------------------|--|------------------------------|----------------------------|
| ANALYZE THE PROBLEM | 25.0 mL (0.0250 L) of HCl solution, 16.3 mL of 0.185 M Sr(OH) ₂ solution | molarity of the HCl solution | molarity, mole–mole factor |
| | Neutralization Equation 2HCl(aq) + Sr(OH) ₂ (aq) → 2H ₂ O(l) + SrCl ₂ (aq) | | |

STEP 2 Write a plan to calculate the molarity.

mL of Sr(OH)₂ solution $\xrightarrow{\text{Metric factor}}$ L of Sr(OH)₂ solution $\xrightarrow{\text{Molarity}}$ moles of Sr(OH)₂ $\xrightarrow{\text{Mole–mole factor}}$ moles of HCl $\xrightarrow{\text{Divide by liters}}$ molarity of HCl solution

STEP 3 State equalities and conversion factors, including concentrations.

$$\frac{1000 \text{ mL of Sr}(\text{OH})_2 \text{ solution}}{1000 \text{ mL Sr}(\text{OH})_2 \text{ solution}} = \frac{1 \text{ L of Sr}(\text{OH})_2 \text{ solution}}{1 \text{ L Sr}(\text{OH})_2 \text{ solution}} \quad \text{and} \quad \frac{0.185 \text{ mole of Sr}(\text{OH})_2}{1 \text{ L Sr}(\text{OH})_2 \text{ solution}} = \frac{1 \text{ L of Sr}(\text{OH})_2 \text{ solution}}{0.185 \text{ mole Sr}(\text{OH})_2}$$



STEP 4 Set up the problem to calculate the needed quantity.

$$16.3 \text{ mL Sr}(\text{OH})_2 \text{ solution} \times \frac{1 \text{ L Sr}(\text{OH})_2 \text{ solution}}{1000 \text{ mL Sr}(\text{OH})_2 \text{ solution}} \times \frac{0.185 \text{ mole Sr}(\text{OH})_2}{1 \text{ L Sr}(\text{OH})_2 \text{ solution}} \times \frac{2 \text{ moles HCl}}{1 \text{ mole Sr}(\text{OH})_2} = 0.00603 \text{ mole of HCl}$$

$$\text{molarity of HCl solution} = \frac{0.00603 \text{ mole HCl}}{0.0250 \text{ L HCl solution}} = 0.241 \text{ M HCl solution}$$

INTERACTIVE VIDEO

Acid–Base Titration

TEST

Try Practice Problems 11.61 to 11.66

STUDY CHECK 11.12

What is the molarity of an HCl solution if 28.6 mL of a 0.175 M NaOH solution is needed to titrate a 25.0-mL sample of the HCl solution?

ANSWER

0.200 M HCl solution

NEW! Try It First precedes the Solution section of each Sample Problem to encourage the student to work on the problem before reading the given Solution.

NEW! Connect feature added to Analyze the Problem boxes indicates the relationships between Given and Need.

NEW! Solution provides steps for successful problem solving within the Sample Problem.

Continuous Learning Before, During, and After Class

BEFORE CLASS

NEW! Mastering Chemistry Primer tutorials are focused on remediating students taking their first college chemistry course.

Topics include math in the context of chemistry, chemical skills and literacy, as well as some basics of balancing chemical equations, mole–mole factors, and mass–mass calculations—all of which were chosen based on extensive surveys of chemistry professors across the country.

The primer is offered as a prebuilt assignment that is automatically generated with all chemistry courses.

