This scope and sequence is ambitious for a general chemistry course. In schools using a biology, chemistry, physics sequence, some teachers choose to omit units 9 and 12. Further reduction of content breadth can be achieved if units 1-3 are addressed in a physical science course. In like manner, schools using a physics, chemistry, biology sequence could address units 1-3 in a freshman physics course and start the chemistry course with a review and move right into unit 4. The concepts in unit 12B set the stage for biology.

### Unit 1: Physical Properties of Matter

**Matter is composed of featureless spheres (BB’s) that have mass and volume. These particles are essentially the “atoms” proposed by Democritus.**

- Mass is a measure of how much stuff an object is made of.
- Matter is conserved because during all kinds of change we are just rearranging the particles.
- Volume is a measure of how much space the object occupies.
  - Mass and volume are properties of an *object*.
- **Density** – how much stuff for each unit volume. This is a property of a *substance*.

### Unit 2: Energy - Particles in Motion

*We examine evidence that our BB’s are in constant, random, thermal motion. Temperature & thermal energy, factors affecting gas pressure, KMT.*

- The motion of our spheres depends on the temperature. The spheres interact with one another by collisions.
- Matter can exist in three phases, which are characterized by the arrangement of particles. This arrangement affects the density and compressibility of each phase. Particles of matter are in constant motion. Thermal energy ($E_{th}$) is related to the motion of the particles and is measured by temperature. Energy is transferred from particle to particle via collisions.
- Gas pressure is explained in terms of the collisions of the particles with the sides of the container. There are functional relationships between the pressure of a gas and the volume, temperature and the number of gas particles in a container.

### Unit 3: Energy and States of Matter

*Our BB’s exert attractions on one another. Energy is a conserved substance-like quantity that is stored in various accounts and transferred in various ways.*

- Matter can exist in three phases - these are characterized by the arrangement of the particles and the attractive forces that bind them. We call these particles molecules from the Latin (little lumps of stuff).
- Energy is involved whenever the state (phase, temperature, etc.) of the system changes. Attractions between particles lower the energy of the system; the more tightly bound the particles, the lower the energy due to interactions - we call this account: phase energy. During phase changes, changes in phase energy ($E_{ph}$) result in a new arrangement or orientation of the particles. Energy can be transferred between the system and surroundings via heating (collisions of countless microscopic particles), working (due to forces between macroscopic bodies or due to the expansion or contraction of gases) and radiating (due to the emission or absorption of photons).

### Unit 4: Describing Substances

*The particles that make up substances can be compounded from smaller particles. The fact that compounds have definite composition leads us to Dalton’s model of the atom.*

- Matter is composed or pure substances or mixtures of these pure substances. The molecules of pure substances have definite composition and properties whereas the composition and properties of mixtures are variable. Molecules of pure substances can be broken down into simpler particles (atoms or molecules).
### Unit 5: Counting Particles Too Small to See

*From Avogadro's Hypothesis we are able to count molecules by weighing macroscopic samples.*

For gases at the same temperature and pressure we can deduce the following:

1. From combining volumes, we can determine the ratio in which molecules react.
2. From masses of these gases we can determine the relative mass of individual molecules.

From these results it is possible to determine the molar masses of the elements; using these masses and formulas of compounds, one can determine molar masses of compounds. These tools allow one to relate how much stuff to how many particles.

### Unit 6: Particles with Internal Structure

*We find that atoms have the property of charge and some internal structure; we use the Thomson model of the atom to account for our observations.*

Two kinds of charge exist in atoms. Charge plays a role in the attractive forces that hold solids and liquids together and binds the atoms in molecules or crystal lattices.

Molecular substances are composed of neutral molecules, whereas ionic substances are lattice-work structures of ions. These two kinds of substance have different structures and physical properties.

### Unit 7: Chemical Reactions: Particles and Energy

*Chemical reactions involve the rearrangement of atoms in molecules to form new molecules. This rearrangement of atoms results in a change in the chemical potential energy (E_{ch}) of the system. This produces changes in thermal energy (E_{th}), resulting in energy transfers between system and surroundings.*

Mass is conserved because the atoms in the products are the same as those found in the reactants. A chemical reaction can be represented symbolically as a balanced equation. Because the grouping of atoms into molecules is changed in a chemical reaction, the total number of molecules (or formula units) in the products need not be the same as that in the reactants.

The energy required to separate atoms in a compound is greater than that during a phase change. Substances store varying amounts of chemical potential energy (E_{ch}) due to the arrangement of atoms. It is not possible to measure this amount of energy directly. However, rearrangement of atoms during a reaction produces changes in E_{th}; the resulting energy transfers (as Q) between system and surroundings can be measured. From these one can deduce differences in the E_{ch} of reactants and products. Energy bar graphs are useful for accounting for energy (stored and transferred) during chemical change.

### Unit 8: Introduction to Stoichiometry

*Equations representing chemical reactions relate numbers of particles (molecules or formula units) to weighable amounts of these particles.*

Stoichiometry should not be reduced to a formulaic approach designed to get the right answer. Proportional relationships exist between the numbers of particles involved in a chemical and allow us to make predictions about how much stuff will be required or produced. The Before-Change-After (BCA) table stresses the proportional relationships between moles of reactants and products. Since we don't have mole-meters, conversions to or from moles are about the convenience of dealing with quantities (such as mass) we can measure. These calculations are secondary to the mole relationships suggested by the balanced chemical equation.

### Unit 9: Further Applications of Stoichiometry

*Equations representing chemical reactions can also relate numbers of particles (molecules or formula units) to volumes of gases, solution volumes, and the change in chemical potential energy.*

Molar volumes of gases and molar concentrations of solutions are analogs to molar mass used in the previous unit. They enable one to relate how much of a measured quantity to how many particles are involved. Chemical potential energy involved in a reaction is proportional to the number of particles. It may be included as a term in the balanced equation for a reaction and treated in the same manner as reactants and products in the BCA table. \( \Delta H \) is used as our best approximation of the change in \( E_{ch} \) or \( E_{ph} \).
Unit 10: Models of the Atom (revisited)

From an examination of the radiation emitted by hot metals and atomic gases we conclude that atoms must have internal structure not explained by Thomson’s model. We use the Rutherford and Bohr models to extend our understanding of the atom.

Students examine the evidence for the Thomson, Rutherford, and Bohr models of the atom to better understand how models change to explain new phenomena.

Unit 11: Bonding and the Periodic Table

We extend the Bohr model to many-electron atoms, using it to provide a structural explanation for the organization of the Periodic Table. The combinations of atoms into compounds through “bonding” can be described using several different models. The Periodic Table can help us make predictions about elements and compounds.

Ionization energy can be used to empirically determine the electronic structure of the atom, which accounts for the specific charges of cations and anions that form ionic compounds. The combining power, or valence, of different elements can be used to explain patterns of sharing electrons that exist in molecular compounds. Students examine strengths and weaknesses of models of covalent bonding as well as the utility of various representations of molecular structure.

Unit 12A: Temperature and Thermal Energy

We know that a system undergoes structural change, its thermal energy also changes, eventually resulting in a transfer of energy between the system and the surroundings. We adopt a “kinetic” view of energy transfer to account for the direction of energy flow between objects with different temperatures.

Students examine the exchange of energy quanta across the boundary between hot and cold objects to help them develop an energy-density view of temperature and a dynamic model of thermal equilibrium.

Unit 12B: Intermolecular Attractions and Biological Macromolecules

We suggest a model to account for attractions between molecules and the effect on physical properties. Then we move to an investigation of organic molecules important to life.

Students know that electrons play a role in chemical bonding; we now show that differences in the way the valence electrons are distributed in molecules account for the different types of attractions between molecules. This also helps to explain the distinction chemists make between attractions and chemical bonds. Students next move on to the concept of families of organic compounds whose behavior is largely governed by functional groups and then to how condensation polymerization results in the formation of molecules (proteins, carbohydrates, phospholipids, nucleic acids) essential to life.

Unit 13: Chemical Equilibrium

We employ a kinetic view of particles moving back and forth across an interface to model a variety of processes (both physical and chemical) as they approach and reach the state of equilibrium.

Students use a particle model to describe the competing processes in liquid-vapor and solid-solute equilibria, then move on to an examination of chemical equilibrium. Next, students examine LeChatelier’s Principle at both macroscopic and particle levels. Finally, they adapt the BCA table approach to determine equilibrium concentrations of reactants and products.

Unit 14: Acids and Bases

We extend what we’ve learned about equilibrium to the Bronsted-Lowry model of acids and bases, characteristics of strong and weak acids and neutralization reactions.

After an introduction to the general properties of acids and bases, students use the Bronsted-Lowry model of the competition for H⁺ ions by different species to account for differences in the relative strengths of acids and bases. From a closer examination of the [H₃O⁺] near the endpoint of a titration, students recognize the equilibrium that exists between H₂O, H₃O⁺ and OH⁻. The pH scale is developed as a means to more readily manage the wide range of [H₃O⁺] in acid-base reactions.