

# Chemistry, High School

## Learning Standards for a Full First-Year Course

### I. CONTENT STANDARDS

#### 1. Properties of Matter

*Central Concept:* Physical and chemical properties reflect the nature of the interactions between molecules or atoms, and can be used to classify and describe matter.

- 1.1 Identify and explain physical properties (e.g., density, melting point, boiling point, conductivity, malleability) and chemical properties (e.g., the ability to form new substances). Distinguish between chemical and physical changes.
- 1.2 Explain the difference between pure substances (elements and compounds) and mixtures. Differentiate between heterogeneous and homogeneous mixtures.
- 1.3 Describe the three normal states of matter (solid, liquid, gas) in terms of energy, particle motion, and phase transitions.

#### 2. Atomic Structure and Nuclear Chemistry

*Central Concepts:* Atomic models are used to explain atoms and help us understand the interaction of elements and compounds observed on a macroscopic scale. Nuclear chemistry deals with radioactivity, nuclear processes, and nuclear properties. Nuclear reactions produce tremendous amounts of energy and lead to the formation of elements.

- 2.1 Recognize discoveries from Dalton (atomic theory), Thomson (the electron), Rutherford (the nucleus), and Bohr (planetary model of atom), and understand how each discovery leads to modern theory.
- 2.2 Describe Rutherford's "gold foil" experiment that led to the discovery of the nuclear atom. Identify the major components (protons, neutrons, and electrons) of the nuclear atom and explain how they interact.
- 2.3 Interpret and apply the laws of conservation of mass, constant composition (definite proportions), and multiple proportions.
- 2.4 Write the electron configurations for the first twenty elements of the periodic table.
- 2.5 Identify the three main types of radioactive decay (alpha, beta, and gamma) and compare their properties (composition, mass, charge, and penetrating power).
- 2.6 Describe the process of radioactive decay by using nuclear equations, and explain the concept of half-life for an isotope (for example, C-14 is a powerful tool in determining the age of objects).
- 2.7 Compare and contrast nuclear fission and nuclear fusion.

#### 3. Periodicity

*Central Concepts:* Repeating (periodic) patterns of physical and chemical properties occur among elements that define families with similar properties. The periodic table displays the repeating patterns, which are related to the atoms' outermost electrons.

- 3.1 Explain the relationship of an element's position on the periodic table to its atomic number. Identify families (groups) and periods on the periodic table.
- 3.2 Use the periodic table to identify the three classes of elements: metals, nonmetals, and metalloids.
- 3.3 Relate the position of an element on the periodic table to its electron configuration and compare its reactivity to the reactivity of other elements in the table.
- 3.4 Identify trends on the periodic table (ionization energy, electronegativity, and relative sizes of atoms and ions).

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# Chemistry, High School

## Learning Standards for a Full First-Year Course

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### 4. Chemical Bonding

*Central Concept:* Atoms bond with each other by transferring or sharing valence electrons to form compounds.

- 4.1 Explain how atoms combine to form compounds through both ionic and covalent bonding. Predict chemical formulas based on the number of valence electrons.
- 4.2 Draw Lewis dot structures for simple molecules and ionic compounds.
- 4.3 Use electronegativity to explain the difference between polar and nonpolar covalent bonds.
- 4.4 Use valence-shell electron-pair repulsion theory (VSEPR) to predict the molecular geometry (linear, trigonal planar, and tetrahedral) of simple molecules.
- 4.5 Identify how hydrogen bonding in water affects a variety of physical, chemical, and biological phenomena (e.g., surface tension, capillary action, density, boiling point).
- 4.6 Name and write the chemical formulas for simple ionic and molecular compounds, including those that contain the polyatomic ions: ammonium, carbonate, hydroxide, nitrate, phosphate, and sulfate.

### 5. Chemical Reactions and Stoichiometry

*Central Concepts:* In a chemical reaction, one or more reactants are transformed into one or more new products. Chemical equations represent the reaction and must be balanced. The conservation of atoms in a chemical reaction leads to the ability to calculate the amount of products formed and reactants used (stoichiometry).

- 5.1 Balance chemical equations by applying the laws of conservation of mass and constant composition (definite proportions).
- 5.2 Classify chemical reactions as synthesis (combination), decomposition, single displacement (replacement), double displacement, and combustion.
- 5.3 Use the mole concept to determine number of particles and molar mass for elements and compounds.
- 5.4 Determine percent compositions, empirical formulas, and molecular formulas.
- 5.5 Calculate the mass-to-mass stoichiometry for a chemical reaction.
- 5.6 Calculate percent yield in a chemical reaction.

### 6. States of Matter, Kinetic Molecular Theory, and Thermochemistry

*Central Concepts:* Gas particles move independently of each other and are far apart. The behavior of gas particles can be modeled by the kinetic molecular theory. In liquids and solids, unlike gases, particles are close to each other. The driving forces of chemical reactions are energy and entropy. The reorganization of atoms in chemical reactions results in the release or absorption of heat energy.

- 6.1 Using the kinetic molecular theory, explain the behavior of gases and the relationship between pressure and volume (Boyle's law), volume and temperature (Charles's law), pressure and temperature (Gay-Lussac's law), and the number of particles in a gas sample (Avogadro's hypothesis). Use the combined gas law to determine changes in pressure, volume, and temperature.
- 6.2 Perform calculations using the ideal gas law. Understand the molar volume at 273 K and 1 atmosphere (STP).

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# Chemistry, High School

## Learning Standards for a Full First-Year Course

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### 6. States of Matter, Kinetic Molecular Theory, and Thermochemistry (cont.)

- 6.3 Using the kinetic molecular theory, describe and contrast the properties of gases, liquids, and solids. Explain, at the molecular level, the behavior of matter as it undergoes phase transitions.
- 6.4 Describe the law of conservation of energy. Explain the difference between an endothermic process and an exothermic process.
- 6.5 Recognize that there is a natural tendency for systems to move in a direction of disorder or randomness (entropy).

### 7. Solutions, Rates of Reaction, and Equilibrium

*Central Concepts:* Solids, liquids, and gases dissolve to form solutions. Rates of reaction and chemical equilibrium are dynamic processes that are significant in many systems (e.g., biological, ecological, geological).

- 7.1 Describe the process by which solutes dissolve in solvents.
- 7.2 Calculate concentration in terms of molarity. Use molarity to perform solution dilution and solution stoichiometry.
- 7.3 Identify and explain the factors that affect the rate of dissolving (e.g., temperature, concentration, surface area, pressure, mixing).
- 7.4 Compare and contrast qualitatively the properties of solutions and pure solvents (colligative properties such as boiling point and freezing point).
- 7.5 Identify the factors that affect the rate of a chemical reaction (temperature, mixing, concentration, particle size, surface area, catalyst).
- 7.6 Predict the shift in equilibrium when a system is subjected to a stress (LeChatelier's principle) and identify the factors that can cause a shift in equilibrium (concentration, pressure, volume, temperature).

### 8. Acids and Bases and Oxidation-Reduction Reactions

*Central Concepts:* Acids and bases are important in numerous chemical processes that occur around us, from industrial procedures to biological ones, from the laboratory to the environment. Oxidation-reduction reactions occur when one substance transfers electrons to another substance, and constitute a major class of chemical reactions.

- 8.1 Define the Arrhenius theory of acids and bases in terms of the presence of hydronium and hydroxide ions in water and the Bronsted-Lowry theory of acids and bases in terms of proton donors and acceptors.
- 8.2 Relate hydrogen ion concentrations to the pH scale and to acidic, basic, and neutral solutions. Compare and contrast the strengths of various common acids and bases (e.g., vinegar, baking soda, soap, citrus juice).
- 8.3 Explain how a buffer works.
- 8.4 Describe oxidation and reduction reactions and give some everyday examples, such as fuel burning and corrosion. Assign oxidation numbers in a reaction.

# Chemistry, High School

## Learning Standards for a Full First-Year Course

### II. SCIENTIFIC INQUIRY SKILLS STANDARDS

Scientific literacy can be achieved as students inquire about chemical phenomena. The curriculum should include substantial hands-on laboratory and field experiences, as appropriate, for students to develop and use scientific skills in chemistry, along with the inquiry skills listed below.

#### **SIS1. Make observations, raise questions, and formulate hypotheses.**

- Observe the world from a scientific perspective.
- Pose questions and form hypotheses based on personal observations, scientific articles, experiments, and knowledge.
- Read, interpret, and examine the credibility and validity of scientific claims in different sources of information, such as scientific articles, advertisements, or media stories.

#### **SIS2. Design and conduct scientific investigations.**

- Articulate and explain the major concepts being investigated and the purpose of an investigation.
- Select required materials, equipment, and conditions for conducting an experiment.
- Identify independent and dependent variables.
- Write procedures that are clear and replicable.
- Employ appropriate methods for accurately and consistently
  - making observations
  - making and recording measurements at appropriate levels of precision
  - collecting data or evidence in an organized way
- Properly use instruments, equipment, and materials (e.g., scales, probeware, meter sticks, microscopes, computers) including set-up, calibration (if required), technique, maintenance, and storage.
- Follow safety guidelines.

#### **SIS3. Analyze and interpret results of scientific investigations.**

- Present relationships between and among variables in appropriate forms.
  - Represent data and relationships between and among variables in charts and graphs.
  - Use appropriate technology (e.g., graphing software) and other tools.
- Use mathematical operations to analyze and interpret data results.
- Assess the reliability of data and identify reasons for inconsistent results, such as sources of error or uncontrolled conditions.
- Use results of an experiment to develop a conclusion to an investigation that addresses the initial questions and supports or refutes the stated hypothesis.
- State questions raised by an experiment that may require further investigation.

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# Chemistry, High School

## Learning Standards for a Full First-Year Course

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### **SIS4. Communicate and apply the results of scientific investigations.**

- Develop descriptions of and explanations for scientific concepts that were a focus of one or more investigations.
- Review information, explain statistical analysis, and summarize data collected and analyzed as the result of an investigation.
- Explain diagrams and charts that represent relationships of variables.
- Construct a reasoned argument and respond appropriately to critical comments and questions.
- Use language and vocabulary appropriately, speak clearly and logically, and use appropriate technology (e.g., presentation software) and other tools to present findings.
- Use and refine scientific models that simulate physical processes or phenomena.

### **III. MATHEMATICAL SKILLS**

Students are expected to know the content of the *Massachusetts Mathematics Curriculum Framework*, through grade 8. Below are some specific skills from the *Mathematics Framework* that students in this course should have the opportunity to apply:

- ✓ Construct and use tables and graphs to interpret data sets.
- ✓ Solve simple algebraic expressions.
- ✓ Perform basic statistical procedures to analyze the center and spread of data.
- ✓ Measure with accuracy and precision (e.g., length, volume, mass, temperature, time)
- ✓ Convert within a unit (e.g., centimeters to meters).
- ✓ Use common prefixes such as *milli-*, *centi-*, and *kilo-*.
- ✓ Use scientific notation, where appropriate.
- ✓ Use ratio and proportion to solve problems.

The following skills are not detailed in the *Mathematics Framework*, but are necessary for a solid understanding in this course:

- ✓ Determine the correct number of significant figures.
- ✓ Determine percent error from experimental and accepted values.
- ✓ Use appropriate metric/standard international (SI) units of measurement for mass (g); length (cm); and time (s).
- ✓ Use the Celsius and Kelvin scales.