Prior Knowledge or Pre- AP Chemistry

Big Idea 1: Prior Knowledge

1A: **All matter is made of atoms. There are a limited number of types of atoms; these are the elements.**

Prior Knowledge

- Atomic theories have developed over time according to the available experimental evidence and the interpretation of this evidence. Theories of atomic structure have evolved from ideas of atoms as small, indestructible spheres to the current model, which indicates that an atom has a very small nucleus composed of protons and neutrons. The nucleus is surrounded by electrons that take up most of the space in an atom.

Historical experiments are limited to models developed by Dalton, Thompson, Rutherford, Bohr, and Schrödinger. Students should not be expected to memorize the names and the experiments. Students should focus on how experimental evidence has led to changes in the atomic model.

- Because the mass of an atom is very small, the mole is used to translate the mass of an atom to the macroscopic level. The mass of a mole of any substance is equal to its formula mass in grams.

- A mole is used as a counting unit, like a dozen.

Students are not expected to memorize Avogadro's number or use it explicitly in calculations (e.g., calculate the number of oxygen atoms in 10 grams of carbon dioxide).

- The reference for atomic masses is carbon-12. One atomic mass unit (amu) equals 1/12 of the mass of a carbon-12 atom.

- The standard unit of concentration is molarity (mol/L), which is a measure of the amount of a substance in solution.

1B: **The atoms of each element have unique structures arising from interactions between electrons and nuclei.**

Prior Knowledge

- Protons are positively charged particles that define the chemical identity of an element. Neutrons have no charge and have approximately the same mass as a proton.

- The nucleus is surrounded by negatively charged electrons that have a relatively small mass compared to that of protons and neutrons. Electrons occupy most of the volume of an atom.

- The protons and electrons in an atom are equal in number.

- An ion is a **species** in which the number of electrons is not equal to the number of protons.

- It is difficult to predict exactly where electrons are located. Nevertheless, the exact energies of electrons can be measured, and regions where electrons are most likely located can be defined.

1C: **Elements display periodicity in their properties when the elements are organized according to increasing atomic number. This periodicity can be explained by the regular variations that occur in the electronic structures of atoms. Periodicity is a useful principle for understanding and predicting trends in atomic properties, in the composition of materials, and generating ideas for designing new materials.**

Prior Knowledge

- The modern version of the periodic table is organized in order of increasing atomic number (number of protons).
- Elements were originally placed in the periodic table based on their repeating properties, which are a result of the number and type of valence electrons.
- Properties of an element can be predicted based on its placement in the periodic table. Groups of elements exhibit similar properties with predictable variations; rows of elements have predictable trends.
- Elements are often classified as metals, nonmetals or metalloids.
- There are a number of elements— such as nitrogen, oxygen, phosphorus, sulfur, hydrogen and carbon — that are important for living systems. Carbon, the most important of these elements, is central to the chemistry of biological systems because of its unique bonding characteristics. Carbon compounds are usually classified as organic compounds.

Organic nomenclature is beyond the scope of these standards.

- Another way to use the periodic table is to consider the elements as arranged in "blocks" based on the elements' outermost electrons. The elements in these blocks (s-block, transition metals, p-block, lanthanides and actinides) in the modern periodic table also have similar properties of predictable variability.

Only the s-block and the p-block should be discussed in detail.

- Based on the current atomic model, electrons can be considered as clouds of electron density, rather than as particles orbiting the nucleus.
- The position of electrons is best described as orbitals that represent the probability of finding an electron in a region of space.

Electrons exhibit characteristics of both particles and waves. This is a property of particles at the atomic-molecular level. This is beyond the scope of these standards.

- Electrons usually occupy the lowest available energy orbitals (ground state).
- Each orbital can describe the probability for a maximum of two electrons. Different types of orbitals are represented by lowercase letters (e.g., *s*, *p*, *d*, and *f*). Each type of orbital has a different shape (e.g., *s* has a spherical shape and *p* has a dumbbell shape).

Instruction should only focus on s and p orbitals.

1. D. Atoms are so small that they are difficult to study directly; atomic models are constructed to explain experimental data on collections of atoms.

Prior Knowledge

- Symbolic representations allow for the visualization of atoms and molecules that are too small to see with conventional microscopes and for the prediction of the properties of these atoms and molecules.
- Electrons have been observed to have definite energy levels, with no values in between. When an electron moves from one energy level to another, it emits or absorbs a photon that has energy equal to the energy difference between the levels. Consequently, each element has a unique emission or absorption spectrum.
- Both the emission and absorption spectra can be used to identify elements wherever they are located.

1. E. Atoms are conserved in physical and chemical processes, but not in nuclear processes.

Prior Knowledge

- Atoms are central to the principle of the conservation of matter.
- When a change occurs, the total number of atoms within a closed system remains the same; therefore, the total mass of the system remains the same.
- Different kinds of models or representations give different information about materials. For example, ball-and-stick models provide information about shape and bond angles; space-filling models give information about surface features.
- All of the elements, except hydrogen and helium, originated from the nuclear fusion reactions of stars. This production of heavier elements from lighter elements by stellar fusion has never ceased and continues today.
- Chemical reactions involve electrons; nuclear reactions involve only changes in the nucleus. Neutrons have little effect on how an atom interacts with other atoms, yet the number of neutrons does affect the mass and stability of the nucleus. Atoms with the same number of protons and a different number of neutrons are called isotopes.
- When an atom has an unstable nucleus, the unstable nucleus emits radiation (e.g. alpha, beta, gamma and positron). This process, called radioactive decay, increases the stability of the nucleus. Atoms with an unstable nucleus are often called radioisotopes.
- Half-life is a measure of the rate of radioactive decay, or the amount of time it takes for half of a radioactive sample to decay to its products. For any radioisotope, the half-life is constant and unique and can be used to determine the age of the material.
- Radioisotopes have several medical applications. The radiation emitted as a result of the unstable nucleus has high energy and can be detected. These characteristics allow radioisotopes to be used as tracers of biological processes and to kill biological materials (e.g., cancer cells).
- Fission, the splitting of a nucleus into small fragments, and fusion, the combining of two nuclei, are types of nuclear reactions.

- When a nuclear reaction occurs, the mass–energy inter-conversion is significant. Nuclear reactions, such as fission and fusion, are accompanied by large energy changes that are much greater than those that accompany chemical reactions.
- Nuclear reactions can be used as a controlled source of energy (e.g., a nuclear power plant).

Big Idea 2: Prior Knowledge

2. A. Matter can be described by its physical properties. The physical properties of a substance generally depend on the spacing between the particles (atoms, molecules, ions) that make up the substance and the forces of attraction among them.

Prior Knowledge

- The physical properties of materials are determined by the strength of the attractions (bonds or intermolecular forces) between particles.
- Matter can be represented at three different levels: macroscopic, atomic–molecular and symbolic. The macroscopic level is observable in the real-world setting. The atomic-molecular level is often represented by visual representations, including animations. The symbolic level includes elemental symbols, chemical formulas and equations, and Lewis diagrams.
- The atomic–molecular level structure of matter determines both the macroscopic structure and the properties of the material.
- There are four states of matter: solid, liquid, gas and plasma.
- The existence and behavior of matter in the solid, liquid, gas or plasma state can be explained by the atomic–molecular theory (the idea that matter is composed of small particles).
- In a gas, the particles have enough kinetic energy to overcome any attractions. Generally, the separation between gas particles is such that their interactions are minimal.
- For a given substance, the temperature (and, therefore, the average kinetic energy) needed for a change of state to take place depends on the attractions between the particles in that substance. In other words, the temperature at which a change of state takes place depends on the amount of energy that is required to overcome the attractions between the particles.
- Vapor pressure occurs when the particles of solids and liquids have enough kinetic energy to enter the vapor (gas) state. Vapor pressure increases with temperature. Liquids boil when their vapor pressure reaches atmospheric pressure.
- The behavior of a given quantity of gas can be described in terms of its pressure, volume and temperature.
- Each state of matter has a predictable behavior that depends on the chemical composition of the substance and the attractions between particles of that substance.
- When a substance changes state, the relative arrangement of the particles changes, as well as the distance between these particles. The atoms that make up the particles of the substance are not rearranged to form a new substance.
- When thermal energy is added to a solid, liquid or gas, most substances increase in volume because the particles have increased kinetic energy, causing a greater distance between the particles.
- For most substances, the distance between particles increases as they change from solid to liquid to gas, meaning that the density of a solid is usually greater than the density of a liquid. The density of a

liquid is always greater than the density of a gas.

- Because solid water has an extensive network of hydrogen bonds that gives it an open structure, the density of solid water is less than that of liquid water. When water freezes, its volume expands.
- The kinetic–molecular theory (KMT) is an explanation of the macroscopic properties (e.g., pressure, temperature, and volume) of gases, using the idea of particle interactions and motions.
- In a solid, the kinetic energy of the particles making up the substance is not great enough to overcome the attractions holding them together. Although the particles vibrate in place, the distance between them does not increase.
- In a liquid, the kinetic energy of the particles making up the substance is sufficient to overcome the attractions, thereby allowing the particles to move relative to each other. Most of the particles, however, do not have enough kinetic energy to completely overcome the attractions and enter the gas state.

2. B. Forces of attraction between particles (including the noble gases and also different parts of some large molecules) are important in determining many macroscopic properties of a substance, including how the observable physical state changes with temperature.

Prior Knowledge

- Intermolecular forces (IMFs) can be predicted based on the shape of the molecule and the polarities of the bonds.
- The shape and polarity of the molecules of a substance determine the relative strength of its intermolecular forces (IMFs).
- There are several types of IMFs, including the following: London dispersion forces (present in all molecules), dipole–dipole (present in polar molecules) and hydrogen bonding (a special case of dipole–dipole).
- Molecular compounds generally have melting and boiling points that are dependent on their molar mass and IMFs.
- A solute will usually be most soluble in a solvent that has similar IMFs.
- Many substances dissolve in water (a polar solvent). Consequently, water is a very useful and familiar solvent.
- Many ionic compounds dissolve in water. In order for this to occur, the forces of attraction between the ions in the solid must be overcome by the ion–dipole interactions with the water.

2. C. The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.

Prior Knowledge

- The forces of attraction between the particles in molecules, ionic lattices, network covalent structures or materials with metallic properties are called chemical bonds.
- Atoms can bond to form molecules, ionic lattices, network covalent structures or materials with metallic properties. Each of these types of structures has different, yet predictable, properties that depend on the identity of the elements and the types of bonds formed.
- When elements bond they form compounds that are named in systematic ways.
- The bonds in most compounds fall on a continuum between the two extreme models of bonding: ionic and covalent.
- An ionic bond involves the attraction between two oppositely charged ions, typically a positively charged metal ion and a negatively charged nonmetal ion. An ion attracts oppositely charged ions from every direction, resulting in the formation of three-dimensional lattices.
- Covalent bonds typically involve at least two electrons shared between the bonding atoms. Nonmetal atoms usually combine by forming one or more covalent bonds between atoms. Covalent bonding can result in the formation of structures ranging from small molecules to large molar mass biopolymers and three-dimensional lattices (e.g., a diamond).
- Only electrons in the highest energy state (valence electrons) are involved in bonding.
- A polar covalent bond forms between two atoms with different electronegativities; the magnitude of the polarity of the bond depends on the electronegativity difference and the distance between the atoms (bond length).
- The atomic–molecular level structure of simple molecules can be represented symbolically in two or three dimensions as molecular formulas, structural formulas (Lewis diagrams), ball-and-stick models or space-filling models. Each of these symbolic representations can provide some unique information about the structure of the substance, as well as some information that is common to all the models.
- Two-dimensional representations (Lewis diagrams) can be drawn by using a set of simple rules.
- Lewis diagrams provide a foundation for predicting three-dimensional electron pair geometries and three-dimensional shapes of simple molecules.
- The atoms of many elements are more stable when they are bonded with other atoms.
- When two isolated atoms bond in the gas phase, energy is released to the surroundings, resulting in a lower energy system.

2. D. The type of bonding in the solid state can be deduced from the properties of the solid state.

Prior Knowledge

- Different kinds of models are more appropriate for representing different chemical substances (e.g., ionic and covalent network species are best represented by models that incorporate elements of the lattice structure).
- Compounds that have three-dimensional lattice networks of bonds, either ionic or covalent, have very high melting and boiling points because bonds must be broken in order to change state from solid to liquid to gas.

Big Idea 3: Prior Knowledge

3.A. Chemical changes are represented by a balanced chemical equation that identifies the ratios with which reactants react and products form.

Prior Knowledge

- When a chemical change occurs, the numeric relationship between the reactants and products is determined at the atomic–molecular level. In order to translate this relationship from the atomic–molecular level to the macroscopic level, the mole and the formula mass in grams are used as a measure of the amount of substance.
- A balanced chemical reaction represents the conservation of matter at both the atomic–molecular level and the macroscopic level by showing the relationship between the reactants and products.
- A stoichiometric calculation is a conversion from one amount (mass, mole, volume of gases, volume of solutions) of substance in any chemical change to another amount and can be made as long as the relationships among all of the reactants and all of the products at the molecular level are known.
- In very large molecules, a specific region may have predictable polarities and reactivities based on the structural features of that region.

3.B. Chemical reactions can be classified by considering what the reactants are, what the products are, or how they change from one into the other. Classes of chemical reactions include synthesis, decomposition, acid-base and oxidation-reduction reactions.

Prior Knowledge

- Many acids and bases contain covalent bonds but may undergo reactions (e.g., reactions with water) that result in the production of an ionic species.
- The formation of a precipitate or a molecular compound, in a chemical reaction between ionic compounds in aqueous solution, often occurs because the new ionic or covalent bonds are stronger than the original ion–dipole interactions of the ions in solution.
- There are structural features of molecules that can give rise to specific kinds of reactivity (e.g., acidity often results when hydrogen is covalently bonded to an electronegative element).
- The acidity of an aqueous solution is often expressed as pH, where pH is related to the concentration of the hydronium ion.
- A common class of reactions (oxidation reactions) often involves the reaction of oxygen with carbon compounds.

The common reaction classifications that are often used in high school chemistry courses often lead to misconceptions because they are not based on the actual chemistry, but on surface features that may be similar from one system to another (such as "exchanging partners"), even though the underlying chemistry is not the same. Therefore, these types of reaction classifications (e.g., single replacement, double replacement) are not addressed here.

3.C Chemical and physical transformations may be observed in several ways and typically involve a change in energy.

Prior Knowledge

- When a substance dissolves in water, it is sometimes difficult to determine whether the process is a physical or chemical change.

Students are not required to determine whether dissolution is a physical or chemical process. They can participate in an investigation of a solution of a salt in order to understand that a clear distinction may not always be determined for certain processes.

- The process of dissolving a solute in a solvent may be considered a reaction, and the process is affected by many of the same factors (temperature, intermolecular forces and surface area) that affect reaction rates.
- A chemical reaction can be considered a system. The reaction is a result of breaking bonds and/or overcoming IMFs in reactants, and of forming new bonds and/or IMFs in products.
- In general, energy is transferred out of a system (exothermic) when the products have stronger bonds than those in the reactants. Energy is transferred into the system (endothermic) when the products have weaker bonds than those in the reactants.

Big Idea 4: Prior Knowledge

4.A. Reaction rates which depend on temperature and other environmental factors, are determined by measuring changes in concentrations of reactants or products over time.

Prior Knowledge

- The rate of reaction can be defined as the change in the amount of products or reactants per unit of time.
- The rates at which reactions occur are affected by factors such as concentration, pressure, temperature and the addition of a catalyst.

4.B. Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.

Prior Knowledge

- All stable species require the input of energy to initiate a reaction. The amount of energy required is called the activation energy barrier.
- When the concentrations/pressures of the reactants are increased, the probability of a molecular collision increases. Because a molecular collision may lead to a reaction, the rate of reaction increases as the probability of a molecular collision increases.
- When the kinetic energy of the reactants increases, indicated by a rise in temperature, the probability of a molecular collision increases. When molecules/atoms collide with increased energy, they are more likely to react.
- In order for reactions to occur, the reacting particles must collide in the appropriate orientation and with enough energy. Not all collisions are effective.
- Most reactions occur in solution or in the gas state because the reacting particles are free to move and can collide and interact with each other. Reactions among solids are not as prevalent because a reaction can only occur at the surface of a solid.

4.D. Reaction rates may be increased by the presence of a catalyst.

Catalysts, such as enzymes in biological systems and the surfaces in an automobile's catalytic converter, increase the rate of a chemical reaction. Catalysts may function by lowering the activation energy of an elementary step in a reaction, thereby increasing the rate of that elementary step but leaving the mechanism of the reaction otherwise unchanged. Other catalysts participate in the formation of a new reaction intermediate, thereby providing a new reaction mechanism that provides a faster pathway between reactants and products.

Prior Knowledge

- The addition of a catalyst provides an alternate pathway for reactions to occur, usually with a lower activation energy barrier. More molecules therefore have enough energy to overcome the activation energy barrier, leading to an increased rate of reaction.
- One of the functions of an enzyme is to hold molecules in an orientation that can lead to a reaction.

Big Idea 5: Prior Knowledge

5.A. Two systems with different temperatures that are in thermal contact will exchange energy. The quantity of thermal energy transferred from one system to another is called heat.

Prior Knowledge

- Temperature is a measure of the average kinetic energy of all particles in a substance. Temperature is independent of the amount of matter present, while thermal energy is dependent on the amount of matter present.
- Thermal energy transfer (heat) occurs from a warm object to a cooler object.
- The part of the universe that is being studied is called a system. A real or imaginary boundary separates the system from the rest of the universe, or the surroundings. By defining a system, any change the system undergoes can be tracked.
- A closed system does not interact with its surroundings — matter and energy cannot get into or out of the system. Most systems of interest in our everyday lives are open systems — matter and energy can be transferred into or out of the system.
- If energy moves from a system to its surroundings, the temperature of the surroundings will increase. This is often described as an exothermic process. If energy moves from the surroundings to a system, then the temperature of the surroundings will decrease. This is often described as an endothermic reaction. Temperature changes in large surroundings may not be detectable.
- Thermal energy is the energy associated with the movement (translational, rotational and vibrational) of all particles in a system. Although thermal energy cannot be directly measured, the effects of changes in the thermal energy of the system can be observed and calculated.

In the "real world," thermal energy and heat are often used synonymously; however, in the physical sciences the term "heat" is reserved for the transfer of thermal energy (e.g., from a hot object to a cold object). For the purposes of this standards document, and in order to avoid misunderstandings, the terms "thermal energy" and "thermal energy transfer" are used.

- At the atomic–molecular scale, thermal energy is associated with the kinetic energy of molecules. As the thermal energy increases, the molecules move (translate, rotate and vibrate) faster.
- The thermal energy of an object depends on its mass, temperature and chemical composition.
- When energy is transferred (e.g., from the exothermic reaction system to the surroundings), some of the energy (in the form of thermal energy) always becomes less available to bring about change. Consequently, the amount of useful energy decreases over time, even though the total energy is constant.

5.B. Energy is neither created nor destroyed but only transformed from one form to another.

Prior Knowledge

- Mass–energy is always conserved for all defined systems, for all types of interactions, and at all scales.
- In chemical systems, the interconversion of mass and energy is negligible. Therefore, in chemical systems only energy changes need to be considered; mass–energy conversions need not be considered.
- The total energy of a chemical system is impossible to measure. When a chemical system reacts, its energy change can be measured by observing the effect of that change on a property of a substance within the system (e.g., the temperature of water is easily measured and can be related to changes in energy).
- At the atomic–molecular scale, electromagnetic radiation (photons) is absorbed by molecules. Some of this radiation can be transformed into kinetic energy (molecules vibrate and move faster) that appears as thermal energy and causes a rise in temperature.

5.E. Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.

Prior Knowledge

- Entropy is a measure of the number of possible arrangements of atoms, molecules or energy in a system — the more possible arrangements, the more entropy the system has. Any thermodynamically favored process is accompanied by an increase in the total entropy (i.e., the entropy of the universe) and in the dispersion of energy.

While entropy is commonly discussed in terms of randomness or disorder, this can lead to significant misconceptions — including the idea that systems cannot spontaneously become more organized. On the contrary, increases in entropy often drive the organization of systems (e.g., protein folding and micelle formation).

Big Idea 6: Prior Knowledge

6.A. Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.

Prior Knowledge

- All reactions are reversible, and many reactions do not proceed completely toward products. This does not mean that the reaction has stopped, but rather that the rate of the reverse reaction is equal to the rate of the forward reaction.
- Although some reactions appear to proceed only in one direction, the reverse reaction can occur; however, the occurrence of the reverse reaction is highly unlikely (e.g., combustion reactions).

6.B. Systems at equilibrium are responsive to external perturbations, with the response leading to a change in the composition of the system.

Prior Knowledge

- According to Le Chatelier's principle, if a chemical system at equilibrium is disturbed by a change in the conditions (e.g., temperature, pressure on gaseous equilibrium systems, concentration) of the system, then the equilibrium system will respond by moving to a new equilibrium state, reducing the effect of the change.

6. D. The equilibrium constant is related to temperature and the difference in Gibbs free energy between reactants and products.

Prior Knowledge

- Reactions that appear to proceed only in one direction usually release a large amount of energy. An input of energy is required to make such a reaction go backwards.
- An unfavorable reaction can be made to occur by removing products as they are formed. The removal of products forces the system to shift its equilibrium position.