

High School Curriculum Standards: Chemistry

Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Key Idea 3:

Matter is made up of particles whose properties determine the observable characteristics of matter and its reactivity.

Chemistry is the study of matter—its properties and its changes. The idea that matter is made up of particles is over 2000 years old, but the idea of using properties of these particles to explain observable characteristics of matter has more recent origins. In ancient Greece, it was proposed that matter is composed of particles of four elements (earth, air, water, and fire) and that these particles are in continual motion. The idea that particles could explain properties of matter was not used for about 2000 years. In the late 1600s the properties of air were attributed to its particulate nature; however, these particles were not thought to be fundamental. Instead, it was thought that they could change into other particles with different properties.

In the late 1700s solid evidence about the nature of matter, gained through quantitative scientific experiments, accumulated. Such evidence included the finding that during a chemical reaction matter was conserved. In the early 1800s a theory was proposed to explain these experimental facts. In this theory, atoms were hard, indivisible spheres of different sizes and they combined in simple whole-number ratios to form compounds. The further treatment of particles of matter as hard spheres in continual motion resulted in the 1800s in the kinetic molecular theory of matter, which was used to explain the properties of gases.

In the late 1800s evidence was discovered that particles of matter could not be considered hard spheres; instead, particles were found to have an internal structure. The development of cathode ray tubes, and subsequent experiments with them in the 1860s, led to the proposal that small, negatively charged particles—electrons—are part of the internal structure of atoms. In the early 1900s, to explain the results of the "gold foil experiment," a small, dense nucleus was proposed to be at the center of the atom with electrons moving about in the empty space surrounding the nucleus. Around this time, energy was proposed to exist in small, indivisible packets called quanta. This theory was used to develop a model of the atom which had a central nucleus surrounded by shells of electrons. The model was successful in explaining the spectra of the hydrogen atom and was used to explain aspects of chemical bonding. Additional experiments with radioactivity provided evidence that atomic nuclei contained protons and neutrons.

Further investigation into the nature of the electron determined that it has wave-like properties. This feature was incorporated into the wave-mechanical model of the atom, our most sophisticated model, and is necessary to explain the spectra of multi-electron atoms.

Note: The use of e.g. denotes examples which may be used for in-depth study. The terms for example and such as denote material which is testable. Items in parentheses denote further definition of the word(s) preceding the item and are testable.

PERFORMANCE INDICATOR 3.1 Explain the properties of materials in terms of the arrangement and properties of the atoms that compose them.

Major Understandings:

3.1a The modern model of the atom has evolved over a long period of time through the work of many scientists.

3.1b Each atom has a nucleus, with an overall positive charge, surrounded by negatively charged electrons.

3.1c Subatomic particles contained in the nucleus include protons and neutrons.

**PERFORMANCE
INDICATOR 3.1**

continued

3.1d The proton is positively charged, and the neutron has no charge. The electron is negatively charged.

3.1e Protons and electrons have equal but opposite charges. The number of protons equals the number of electrons in an atom.

3.1f The mass of each proton and each neutron is approximately equal to one atomic mass unit. An electron is much less massive than a proton or a neutron.

3.1g The number of protons in an atom (atomic number) identifies the element. The sum of the protons and neutrons in an atom (mass number) identifies an isotope. Common notations that represent isotopes include: ^{14}C , $^{14}_6\text{C}$, carbon-14, C-14.

3.1h In the wave-mechanical model (electron cloud model) the electrons are in orbitals, which are defined as the regions of the most probable electron location (ground state).

3.1i Each electron in an atom has its own distinct amount of energy.

3.1j When an electron in an atom gains a specific amount of energy, the electron is at a higher energy state (excited state).

3.1k When an electron returns from a higher energy state to a lower energy state, a specific amount of energy is emitted. This emitted energy can be used to identify an element.

3.1l The outermost electrons in an atom are called the valence electrons. In general, the number of valence electrons affects the chemical properties of an element.

3.1m Atoms of an element that contain the same number of protons but a different number of neutrons are called isotopes of that element.

3.1n The average atomic mass of an element is the weighted average of the masses of its naturally occurring isotopes.

3.1o Stability of an isotope is based on the ratio of neutrons and protons in its nucleus. Although most nuclei are stable, some are unstable and spontaneously decay, emitting radiation.

3.1p Spontaneous decay can involve the release of alpha particles, beta particles, positrons, and/or gamma radiation from the nucleus of an unstable isotope. These emissions differ in mass, charge, ionizing power, and penetrating power.

3.1q Matter is classified as a pure substance or as a mixture of substances.

3.1r A pure substance (element or compound) has a constant composition and constant properties throughout a given sample, and from sample to sample.

3.1s Mixtures are composed of two or more different substances that can be separated by physical means. When different substances are mixed together, a homogeneous or heterogeneous mixture is formed.

3.1t The proportions of components in a mixture can be varied. Each component in a mixture retains its original properties.

**PERFORMANCE
INDICATOR 3.1**

continued

3.1u Elements are substances that are composed of atoms that have the same atomic number. Elements cannot be broken down by chemical change.

3.1v Elements can be classified by their properties and located on the Periodic Table as metals, nonmetals, metalloids (B, Si, Ge, As, Sb, Te), and noble gases.

3.1w Elements can be differentiated by physical properties. Physical properties of substances, such as density, conductivity, malleability, solubility, and hardness, differ among elements.

3.1x Elements can also be differentiated by chemical properties. Chemical properties describe how an element behaves during a chemical reaction.

3.1y The placement or location of an element on the Periodic Table gives an indication of the physical and chemical properties of that element. The elements on the Periodic Table are arranged in order of increasing atomic number.

3.1z For Groups 1, 2, and 13-18 on the Periodic Table, elements within the same group have the same number of valence electrons (helium is an exception) and therefore similar chemical properties.

3.1aa The succession of elements within the same group demonstrates characteristic trends: differences in atomic radius, ionic radius, electronegativity, first ionization energy, metallic/nonmetallic properties.

3.1bb The succession of elements across the same period demonstrates characteristic trends: differences in atomic radius, ionic radius, electronegativity, first ionization energy, metallic/nonmetallic properties.

3.1cc A compound is a substance composed of two or more different elements that are chemically combined in a fixed proportion. A chemical compound can be broken down by chemical means. A chemical compound can be represented by a specific chemical formula and assigned a name based on the IUPAC system.

3.1dd Compounds can be differentiated by their physical and chemical properties.

3.1ee Types of chemical formulas include empirical, molecular, and structural.

3.1ff Organic compounds contain carbon atoms, which bond to one another in chains, rings, and networks to form a variety of structures. Organic compounds can be named using the IUPAC system.

3.1gg Hydrocarbons are compounds that contain only carbon and hydrogen. Saturated hydrocarbons contain only single carbon-carbon bonds. Unsaturated hydrocarbons contain at least one multiple carbon-carbon bond.

3.1hh Organic acids, alcohols, esters, aldehydes, ketones, ethers, halides, amines, amides, and amino acids are categories of organic compounds that differ in their structures. Functional groups impart distinctive physical and chemical properties to organic compounds.

3.1ii Isomers of organic compounds have the same molecular formula, but different structures and properties.

**PERFORMANCE
INDICATOR 3.1**

continued

3.1jj The structure and arrangement of particles and their interactions determine the physical state of a substance at a given temperature and pressure.

3.1kk The three phases of matter (solids, liquids, and gases) have different properties.

3.1ll Entropy is a measure of the randomness or disorder of a system. A system with greater disorder has greater entropy.

3.1mm Systems in nature tend to undergo changes toward lower energy and higher entropy.

3.1nn Differences in properties such as density, particle size, molecular polarity, boiling and freezing points, and solubility permit physical separation of the components of the mixture.

3.1oo A solution is a homogeneous mixture of a solute dissolved in a solvent. The solubility of a solute in a given amount of solvent is dependent on the temperature, the pressure, and the chemical natures of the solute and solvent.

3.1pp The concentration of a solution may be expressed in molarity (M), percent by volume, percent by mass, or parts per million (ppm).

3.1qq The addition of a nonvolatile solute to a solvent causes the boiling point of the solvent to increase and the freezing point of the solvent to decrease. The greater the concentration of solute particles, the greater the effect.

3.1rr An electrolyte is a substance which, when dissolved in water, forms a solution capable of conducting an electric current. The ability of a solution to conduct an electric current depends on the concentration of ions.

3.1ss The acidity or alkalinity of an aqueous solution can be measured by its pH value. The relative level of acidity or alkalinity of these solutions can be shown by using indicators.

3.1tt On the pH scale, each decrease of one unit of pH represents a tenfold increase in hydronium ion concentration.

3.1uu Behavior of many acids and bases can be explained by the Arrhenius theory. Arrhenius acids and bases are electrolytes.

3.1vv Arrhenius acids yield $\text{H}^+(\text{aq})$, hydrogen ion as the only positive ion in an aqueous solution. The hydrogen ion may also be written as $\text{H}_3\text{O}^+(\text{aq})$, hydronium ion.

3.1ww Arrhenius bases yield $\text{OH}^-(\text{aq})$, hydroxide ion as the only negative ion in an aqueous solution.

3.1xx In the process of neutralization, an Arrhenius acid and an Arrhenius base react to form a salt and water.

3.1yy There are alternate acid-base theories. One theory states that an acid is an H^+ donor and a base is an H^+ acceptor.

3.1zz Titration is a laboratory process in which a volume of a solution of known concentration is used to determine the concentration of another solution.

PERFORMANCE INDICATOR 3.2

Use atomic and molecular models to explain common chemical reactions.

Major Understandings:

- 3.2a A physical change results in the rearrangement of existing particles in a substance. A chemical change results in the formation of different substances with changed properties.
- 3.2b Types of chemical reactions include synthesis, decomposition, single replacement, and double replacement.
- 3.2c Types of organic reactions include addition, substitution, polymerization, esterification, fermentation, saponification, and combustion.
- 3.2d An oxidation-reduction (redox) reaction involves the transfer of electrons (e^-).
- 3.2e Reduction is the gain of electrons.
- 3.2f A half-reaction can be written to represent reduction.
- 3.2g Oxidation is the loss of electrons.
- 3.2h A half-reaction can be written to represent oxidation.
- 3.2i Oxidation numbers (states) can be assigned to atoms and ions. Changes in oxidation numbers indicate that oxidation and reduction have occurred.
- 3.2j An electrochemical cell can be either voltaic or electrolytic. In an electrochemical cell, oxidation occurs at the anode and reduction at the cathode.
- 3.2k A voltaic cell spontaneously converts chemical energy to electrical energy.
- 3.2l An electrolytic cell requires electrical energy to produce a chemical change. This process is known as electrolysis.

PERFORMANCE INDICATOR 3.3

Apply the principle of conservation of mass to chemical reactions.

Major Understandings:

- 3.3a In all chemical reactions there is a conservation of mass, energy, and charge.
- 3.3b In a redox reaction the number of electrons lost is equal to the number of electrons gained.
- 3.3c A balanced chemical equation represents conservation of atoms. The coefficients in a balanced chemical equation can be used to determine mole ratios in the reaction.
- 3.3d The empirical formula of a compound is the simplest whole-number ratio of atoms of the elements in a compound. It may be different from the molecular formula, which is the actual ratio of atoms in a molecule of that compound.
- 3.3e The formula mass of a substance is the sum of the atomic masses of its atoms. The molar mass (gram-formula mass) of a substance equals one mole of that substance.
- 3.3f The percent composition by mass of each element in a compound can be calculated mathematically.

**PERFORMANCE
INDICATOR 3.4**

Use kinetic molecular theory (KMT) to explain rates of reactions and the relationships among temperature, pressure, and volume of a substance.

Major Understandings:

3.4a The concept of an ideal gas is a model to explain the behavior of gases. A real gas is most like an ideal gas when the real gas is at low pressure and high temperature.

3.4b Kinetic molecular theory (KMT) for an ideal gas states that all gas particles:

- are in random, constant, straight-line motion.
- are separated by great distances relative to their size; the volume of the gas particles is considered negligible.
- have no attractive forces between them.
- have collisions that may result in a transfer of energy between gas particles, but the total energy of the system remains constant.

3.4c Kinetic molecular theory describes the relationships of pressure, volume, temperature, velocity, and frequency and force of collisions among gas molecules.

3.4d Collision theory states that a reaction is most likely to occur if reactant particles collide with the proper energy and orientation.

3.4e Equal volumes of gases at the same temperature and pressure contain an equal number of particles.

3.4f The rate of a chemical reaction depends on several factors: temperature, concentration, nature of the reactants, surface area, and the presence of a catalyst.

3.4g A catalyst provides an alternate reaction pathway, which has a lower activation energy than an uncatalyzed reaction.

3.4h Some chemical and physical changes can reach equilibrium.

3.4i At equilibrium the rate of the forward reaction equals the rate of the reverse reaction. The measurable quantities of reactants and products remain constant at equilibrium.

3.4j LeChatelier's principle can be used to predict the effect of stress (change in pressure, volume, concentration, and temperature) on a system at equilibrium.

Key Idea 4:

Energy exists in many forms, and when these forms change energy is conserved.

Throughout history, humankind has tried to effectively use and convert various forms of energy. Energy is used to do work that makes life more productive and enjoyable. The Law of Conservation of Matter and Energy applies to phase changes, chemical changes, and nuclear changes that help run our modern world. With a complete understanding of these processes and their application to the modern world comes a responsibility to take care of waste, limit pollution, and decrease potential risks.

PERFORMANCE

INDICATOR 4.1

Observe and describe transmission of various forms of energy.

Major Understandings:

4.1a Energy can exist in different forms, such as chemical, electrical, electromagnetic, thermal, mechanical, nuclear.

4.1b Chemical and physical changes can be exothermic or endothermic.

4.1c Energy released or absorbed during a chemical reaction can be represented by a potential energy diagram.

4.1d Energy released or absorbed during a chemical reaction (heat of reaction) is equal to the difference between the potential energy of the products and potential energy of the reactants.

PERFORMANCE

INDICATOR 4.2

Explain heat in terms of kinetic molecular theory.

Major Understandings:

4.2a Heat is a transfer of energy (usually thermal energy) from a body of higher temperature to a body of lower temperature. Thermal energy is the energy associated with the random motion of atoms and molecules.

4.2b Temperature is a measurement of the average kinetic energy of the particles in a sample of material. Temperature is not a form of energy.

4.2c The concepts of kinetic and potential energy can be used to explain physical processes that include: fusion (melting), solidification (freezing), vaporization (boiling, evaporation), condensation, sublimation, and deposition.

PERFORMANCE INDICATOR 4.4 Explain the benefits and risks of radioactivity.

Major Understandings:

4.4a Each radioactive isotope has a specific mode and rate of decay (half-life).

4.4b Nuclear reactions include natural and artificial transmutation, fission, and fusion.

4.4c Nuclear reactions can be represented by equations that include symbols which represent atomic nuclei (with mass number and atomic number), subatomic particles (with mass number and charge), and / or emissions such as gamma radiation.

4.4d Radioactive isotopes have many beneficial uses. Radioactive isotopes are used in medicine and industrial chemistry for radioactive dating, tracing chemical and biological processes, industrial measurement, nuclear power, and detection and treatment of diseases.

4.4e There are inherent risks associated with radioactivity and the use of radioactive isotopes. Risks can include biological exposure, long-term storage and disposal, and nuclear accidents.

4.4f There are benefits and risks associated with fission and fusion reactions.

Key Idea 5:

Energy and matter interact through forces that result in changes in motion.

Atoms and molecules are in constant motion. Chemical bonding between atoms involves energy and the interaction of electrons with atomic nuclei. Intermolecular attractions, which may be temporary, occur when there is an asymmetric distribution of charge.

Within all chemical interactions, matter and energy are conserved according to the Law of Conservation of Matter and Energy. During a chemical change energy is absorbed or released as bonds are broken or formed. In maintaining conservation of matter and energy, nuclear changes convert matter into energy. The energy released during a nuclear change is much greater than the energy released during a chemical change.

The discovery of the energy stored in the nucleus of an atom, its uses, and its inherent benefits and risks is a continuing process that began with the serendipitous detection of the first radioactive isotope. Early researchers added to this knowledge and expanded our ability to utilize this newly discovered phenomenon. Using radioactivity, the inner structure of the atom was defined by other researchers. Scientists involved in the development of nuclear fission and the atomic bomb explored both peaceful and destructive uses of nuclear energy. Modern researchers continue to search for ways in which the power of the nucleus can be used for the betterment of the world.

**PERFORMANCE
INDICATOR 5.2**

Explain chemical bonding in terms of the behavior of electrons.

Major Understandings:

5.2a Chemical bonds are formed when valence electrons are:

- transferred from one atom to another (ionic)
- shared between atoms (covalent)
- mobile within a metal (metallic)

5.2b Atoms attain a stable valence electron configuration by bonding with other atoms. Noble gases have stable valence configurations and tend not to bond.

5.2c When an atom gains one or more electrons, it becomes a negative ion and its radius increases. When an atom loses one or more electrons, it becomes a positive ion and its radius decreases.

5.2d Electron-dot diagrams (Lewis structures) can represent the valence electron arrangement in elements, compounds, and ions.

5.2e In a multiple covalent bond, more than one pair of electrons are shared between two atoms. Unsaturated organic compounds contain at least one double or triple bond.

5.2f Some elements exist in two or more forms in the same phase. These forms differ in their molecular or crystal structure, and hence in their properties.

5.2g Two major categories of compounds are ionic and molecular (covalent) compounds.

5.2h Metals tend to react with nonmetals to form ionic compounds. Nonmetals tend to react with other nonmetals to form molecular (covalent) compounds. Ionic compounds containing polyatomic ions have both ionic and covalent bonding.

5.2i When a bond is broken, energy is absorbed. When a bond is formed, energy is released.

5.2j Electronegativity indicates how strongly an atom of an element attracts electrons in a chemical bond. Electronegativity values are assigned according to arbitrary scales.

5.2k The electronegativity difference between two bonded atoms is used to assess the degree of polarity in the bond.

5.2l Molecular polarity can be determined by the shape of the molecule and distribution of charge. Symmetrical (nonpolar) molecules include CO_2 , CH_4 , and diatomic elements. Asymmetrical (polar) molecules include HCl , NH_3 , and H_2O .

5.2m Intermolecular forces created by the unequal distribution of charge result in varying degrees of attraction between molecules. Hydrogen bonding is an example of a strong intermolecular force.

5.2n Physical properties of substances can be explained in terms of chemical bonds and intermolecular forces. These properties include conductivity, malleability, solubility, hardness, melting point, and boiling point.

**PERFORMANCE
INDICATOR 5.3**

Compare energy relationships within an atom's nucleus to those outside the nucleus.

Major Understandings:

5.3a A change in the nucleus of an atom that converts it from one element to another is called transmutation. This can occur naturally or can be induced by the bombardment of the nucleus with high-energy particles.

5.3b Energy released in a nuclear reaction (fission or fusion) comes from the fractional amount of mass that is converted into energy. Nuclear changes convert matter into energy.

5.3c Energy released during nuclear reactions is much greater than the energy released during chemical reactions.