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Chemistry

SYLLABUS AND MODEL CURRICULUM

COURSE DESCRIPTION

Chemistry is a high school level course, which satisfies the **Ohio Core** science graduation requirements of **Ohio Revised Code Section 3313.603**. This section of Ohio law requires a three-unit course with inquiry-based laboratory experience that engages students in asking valid scientific questions and gathering and analyzing information.

This course introduces students to key concepts and theories that provide a foundation for further study in other sciences as well as advanced science disciplines. Chemistry comprises a systematic study of the predictive physical interactions of matter and subsequent events that occur in the natural world. The study of matter through the exploration of classification, its structure and its interactions is how this course is organized.

Investigations are used to understand and explain the behavior of matter in a variety of inquiry and design scenarios that incorporate scientific reasoning, analysis, communication skills and real-world applications. An understanding of leading theories and how they have informed current knowledge prepares students with higher order cognitive capabilities of evaluation, prediction and application.

SCIENCE INQUIRY AND APPLICATION

During the years of grades 9 through 12, all students must use the following scientific processes with appropriate **laboratory safety techniques** to construct their knowledge and understanding in all science content areas:

- Identify questions and concepts that guide scientific investigations;
- Design and conduct **scientific investigations**;
- Use technology and mathematics to improve investigations and communications;
- Formulate and revise explanations and models using logic and evidence (critical thinking);
- Recognize and analyze explanations and models; and
- Communicate and support a scientific argument.

COURSE CONTENT

The following topics may be taught in any order. There is no ODE-recommended sequence.

STRUCTURE AND PROPERTIES OF MATTER

- Atomic structure
  - Evolution of atomic models/theory
  - Electrons
  - Electron configurations
- Periodic table
  - Properties
  - Trends
- Intramolecular chemical bonding
  - Ionic
  - Polar/covalent
- Representing compounds
  - Formula writing
  - Nomenclature
  - Models and shapes (Lewis structures, ball and stick, molecular geometries)
- Quantifying matter
- Phases of matter
- Intermolecular chemical bonding
  - Types and strengths
  - Implications for properties of substances
    - Melting and boiling point
    - Solubility
    - Vapor pressure

INTERACTIONS OF MATTER

- Chemical reactions
  - Types of reactions
  - Kinetics
  - Energy
  - Equilibrium
  - Acids/bases
- Gas laws
  - Pressure, volume and temperature
  - Ideal gas law
- Stoichiometry
  - Molar calculations
  - Solutions
  - Limiting reagents
- Nuclear Reactions
  - Radioisotopes
  - Nuclear energy

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CONTENT ELABORATION: STRUCTURE AND PROPERTIES OF MATTER

Atomic structure

The physical science syllabus included properties and locations of protons, neutrons and electrons, atomic number, mass number, cations and anions, isotopes and the strong nuclear force that hold the nucleus together. In this course, the **historical development of the atom** and the positions of electrons are explored in more detail.

Atomic models are constructed to explain experimental evidence and make predictions. The changes in the atomic model over time exemplify how scientific knowledge changes as new evidence emerges and how technological advancements like electricity extend the boundaries of scientific knowledge. Thompson's study of electrical discharges in cathode-ray tubes led to the discovery of the electron and the development of the plum pudding model of the atom. Rutherford's experiment, in which he bombarded gold foil with -particles, led to the discovery that most of the atom consists of empty space with a relatively small, positively charged nucleus. Bohr used data from atomic spectra to propose a planetary model of the atom in which electrons orbit the nucleus, like planets around the sun. Later, Schrödinger used the idea that electrons travel in waves to develop a model in which electrons travel randomly in regions of space called orbitals (quantum mechanical model).

Based on the quantum mechanical model, it is not possible to predict exactly where electrons are located but there is a region of space surrounding the nucleus in which there is a high probability of finding an electron (electron cloud or orbital). **Data from atomic spectra (emission and absorption)** gives evidence that electrons can only exist at certain discrete energy levels and not at energies between these levels. Atoms are usually in the ground state where the electrons occupy orbitals with the lowest available energy. However, the atom can become excited when the electrons absorb a photon with the precise amount of energy (indicated by the frequency of the photon) to move to an orbital with higher energy. Any photon without this precise amount of energy will be ignored by the electron. The atom exists in the excited state for a very short amount of time. When an electron drops back down to the lower energy level, it emits a photon that has energy equal to the energy difference between the levels. The amount of energy is indicated by the frequency of the light that is given off and can be measured. Each element has a unique emission and absorption spectrum due to its unique electron configuration and specific electron energy jumps that are possible for that element. Being aware of the quantum mechanical model as the currently accepted model for the atom is important for science literacy as it explains and predicts subatomic interactions, but details should be reserved for more advanced study.

Electron energy levels consist of sublevels (s, p, d and f), each with a characteristic number and shape of orbitals. The shapes of d and f orbitals will not be assessed in high school. Orbital diagrams and electron configurations can be constructed to show the location of the electrons in an atom using established rules. However, the names of these rules will not be assessed. Valence electrons are responsible for most of the chemical properties of elements. In this course, electron configurations (extended and noble gas notation) and orbital diagrams can be shown for any element in the first three periods.

Although the quantum mechanical model of the atom explains the most experimental evidence, other models can still be helpful. Thinking of atoms as indivisible spheres is useful in explaining many physical properties of substances, such as the state (solid, liquid or gas) of a substance at room temperature. Bohr's planetary model is useful to explain and predict periodic trends in the properties of elements.

Note: Quantum numbers and equations of de Broglie, Schrödinger and Plank are beyond the scope of this course.

Periodic Table

In the physical science syllabus, elements are placed in order of increasing atomic number in the periodic table such that elements with similar properties are placed in the same column. How the periodic table is divided into groups, families, periods, metals, nonmetals and metalloids also was in the physical science syllabus. In chemistry, with more information about the electron configuration of elements, similarities in the configuration of the valence electrons for a particular group can be observed. The electron configuration of an atom can be written from the position on the periodic table. The repeating pattern in the electron configurations for elements on the periodic table explain many of the trends in the properties observed. Atomic theory and bonding must be used to explain trends in properties across periods or down columns including atomic radii, ionic radii, first ionization energies, electronegativities and whether the element is a solid or gas at room temperature. Additional ionization energies, electron affinities and periodic properties of the transition elements, lanthanide and actinide series is reserved for more advanced study.

Intramolecular Chemical Bonding

In the physical science syllabus, atoms with unpaired electrons tend to form ionic and covalent bonds with other atoms forming molecules, ionic lattices or network covalent structures. In this course, electron configurations, electronegativity values and energy considerations will be applied to bonding and the properties of materials with different types of bonding.

Atoms of many elements are more stable as they are bonded to other atoms. In such cases, as atoms bond, energy is released to the surroundings resulting in a system with lower energy. An atom's electron configuration, particularly the valence elections, determines how an atom interacts with other atoms. Molecules, ionic lattices and network covalent structures have different, yet predictable, properties

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that depend on the identity of the elements and the types of bonds formed.

Differences in electronegativity values can be used to predict where a bond fits on the continuum between ionic and covalent bonds. The polarity of a bond depends on the electronegativity difference and the distance between the atoms (bond length). Polar covalent bonds are introduced as an intermediary between ionic and pure covalent bonds. The concept of metallic bonding also is introduced to explain many of the properties of metals (e.g., conductivity). Since most compounds contain multiple bonds, a substance may contain more than one type of bond. Compounds containing carbon are an important example of bonding, since carbon atoms can bond together and with other atoms, especially hydrogen, oxygen, nitrogen and sulfur, to form chains, rings and branching networks that are present in a variety of compounds, including synthetic polymers, fossil fuels and the large molecules essential to life. Detailed study of the structure of molecules responsible for life is reserved for more advanced courses.

Representing Compounds

Using the periodic table, formulas of ionic compounds containing specific elements can be predicted. This can include ionic compounds made up of elements from groups 1, 2, 17, hydrogen and oxygen and polyatomic ions if given the formula and charge of the polyatomic ion. Given the formula, a compound can be named using conventional systems that include Greek prefixes and Roman numerals where appropriate. Given the name of an ionic or covalent substance, formulas can be written.

Many different models can be used to represent compounds including chemical formulas, Lewis structures, and ball and stick models. These models can be used to visualize atoms and molecules and to predict the properties of substances. Each type of representation provides unique information about the compound. Different representations are better suited for particular substances. Lewis structures can be drawn to represent covalent compounds using a simple set of rules and can be combined with valence shell electron pair repulsion (VSEPR) theory to predict the three-dimensional electron pair and molecular geometry of compounds. Lewis structures and molecular geometries will only be constructed for the following combination of elements: hydrogen, carbon, nitrogen, oxygen, phosphorus, sulfur and the halogens. Organic nomenclature is reserved for more advanced courses.

Quantifying matter

In earlier grades, properties of materials were quantified with measurements that were always associated with some error. In this course, scientific protocols for quantifying the properties of matter accurately and precisely are studied. Using metric measuring systems, significant digits or figures, scientific notation, error analysis and dimensional analysis are vital to scientific communication.

There are three domains of magnitude in size and time: the macroscopic (human) domain, the cosmic domain and the submicroscopic (atomic and subatomic) domain. Measurements in the cosmic domain and submicroscopic domains require complex instruments and/or procedures.

Matter can be quantified in a way that macroscopic properties such as mass can reflect the number of particles present. Elemental samples are a mixture of several isotopes with different masses. The atomic mass of an element is calculated given the mass and relative abundance of each isotope of the element as it exists in nature. Because the mass of an atom is very small, the mole is used to translate between the atomic and macroscopic levels. A mole is used as a counting number, like a dozen. It is equal to the number of particles in exactly 12 grams of carbon – 12 atoms. The mass of one mole of a substance is equal to its formula mass in grams. The formula mass for a substance can be used in conjunction with Avogadro's number and the density of a substance to convert between mass, moles, volume and number of particles of a sample.

Phases of Matter

In middle school, solids, liquids and gases were explored in relation to the spacing of the particles, motion of the particles and strength of attraction between the particles that make up the substance. In this course, plasmas and Bose-Einstein condensates also are included. Plasmas occur when gases have so much energy that the electrons are stripped away; therefore, they are electrically charged. In Bose-Einstein condensation the atoms, when subjected to temperatures a few billionths of a degree above absolute zero, all coalesce to lose individual identity and become a "super atom." Just as plasmas are super-hot atoms, Bose-Einstein condensates are the opposite – super-cold atoms (see **Note**). The forces of attraction between particles that determine whether a substance is a solid, liquid or gas at room temperature are addressed in greater detail with intermolecular chemical bonding later in the course.

Note: The advancement of technology makes it possible to extend the boundaries of current knowledge and understanding. Consequently, Bose-Einstein condensates were only recently created in the laboratory (1995), although predicted more than 80 years ago. Detailed instruction of Bose-Einstein condensates or plasmas is not required at this grade level. This information is strictly for recognition that new discoveries are continually occurring, extending the realm of current understanding in science.

Intermolecular Chemical Bonding

In middle school, the concept of attractions between separate particles that hold molecules together in liquids and solids was introduced. These forces, called intermolecular attractions, are addressed in more detail in chemistry. Intermolecular attractions are generally weak when compared to intramolecular bonds, but span a wide range of strengths. The composition of a substance and the shape and polarity of a molecule are particularly important in determining the type and strength of bonding and intermolecular interactions. Types of intermolecular attractions include

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London dispersion forces (present between all molecules), dipole-dipole forces (present between polar molecules) and hydrogen bonding (a special case of dipole-dipole where hydrogen is bonded to a highly electronegative atom such as fluorine, oxygen or nitrogen), each with its own characteristic relative strengths.

The configuration of atoms in a molecule determines the strength of the forces (bonds or intermolecular forces) between the particles and therefore the physical properties (e.g., melting point, boiling point, solubility, vapor pressure) of a material. For a given substance, the average kinetic energy (and therefore the temperature) needed for a change of state to occur depends upon the strength of the intermolecular forces between the particles. Therefore, the melting point and boiling point depend upon the amount of energy that is needed to overcome the attractions between the particles. Substances that have strong intermolecular forces or are made up of three- dimensional networks of ionic or covalent bonds tend to be solids at room temperature and have high melting and boiling points. Nonpolar organic molecules are held together by weak London dispersion forces. However, substances with longer chains provide more opportunities for these attractions and tend to have higher melting and boiling points. Increased branching of organic molecules interferes with the intermolecular attractions that lead to lower melting and boiling points.

Substances will have a greater solubility when dissolving in a solvent with similar intermolecular forces. If the substances have different intermolecular forces, they are more likely to interact with themselves than the other substance and remain separated from each other. Water is a polar molecule and it is often used as a solvent since most ionic and polar covalent substances will dissolve in it. In order for an ionic substance to dissolve in water, the attractive forces between the ions must be overcome by the dipole-dipole interactions with the water. Dissolving of a solute in water is an example of a process that is difficult to classify as a chemical or physical change and it is not appropriate to have students classify it one way or another.

Evaporation occurs when the particles with enough kinetic energy to overcome the attractive forces separate from the rest of the sample to become a gas. The pressure of these particles is called vapor pressure. Vapor pressure increases with temperature. Particles with larger intermolecular forces have lower vapor pressures at a given temperature since the particles require more energy to overcome the attractive forces between them. Molecular substances often evaporate more due to the weak attractions between the particles and can often be detected by their odor. Ionic or network covalent substances have stronger forces and are not as likely to volatilize. These substances often have little if any odor. Liquids boil when their vapor pressure is equal to atmospheric pressure.

In solid water, there is a network of hydrogen bonds between the particles that gives it an open structure. This is why water expands as it freezes and why solid water has a lower density than liquid water. This has important implications for life (e.g., ice floating on water acts as an insulator in bodies of water to keep the temperature of the rest of the water above freezing.)

EXPECTATIONS FOR LEARNING: COGNITIVE DEMANDS

This section provides definitions for Ohio's science cognitive demands, which are intrinsically related to current understandings and research about how people learn. They provide a structure for teachers and assessment developers to reflect on plans for teaching science, to monitor observable evidence of student learning and to develop summative assessment of student learning of science.

VISIONS INTO PRACTICE

This section provides examples of tasks that students may perform; this includes guidance for developing classroom performance tasks. It is not an all-inclusive checklist of what should be done, but is a springboard for generating innovative ideas.

- Design an investigation to show that the volume of any liquid sample is constant when divided by its mass **(ACS Laboratory Assessment Activities).**
- Devise an investigation to show that the addition of a solute affects the density of a liquid **(ACS Laboratory Assessment Activities).**
- Investigate the volume of one drop of liquid from a Beral-type pipet. Devise a method. Defend the method with data and present it to a wider audience using multiple formats **(ACS Laboratory Assessment Activities)**.
- Investigate the variations and similarities between regular table sugar, high fructose corn syrup, Stevia, Aspartame (Equal®), saccharin (Sweet n' Low®), sucralose (Splenda®) and Agave. Draw a conclusion, based on data analysis regarding which compound is the most damaging for human consumption. Present your findings in multiple formats. Variation for this project could be made with oils (e.g., canola, coconut, olive, vegetable).
- Determine the percent by mass of water content in popcorn. Correlate its effect on the amount of popcorn produced (or time it takes to start the batch popping). Compare three brands, isolate other variables (e.g., popping method, use of different types of oil) and present findings in multiple formats (**http://faculty.coloradomtn.edu/jeschofnig/popcorn.htm**).
- Design an investigation to substantiate or negate the claims of a commercial product (e.g., ionic-tourmaline, a mineral that is said to emit quick-drying ions; a hair dryer; a shake weight dumbbell; a type of strong-bond glue). Determine function of, intent of and any potential bias with the product. Present findings in multiple formats.

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INSTRUCTIONAL STRATEGIES AND RESOURCES

This section provides additional support and information for educators. These are strategies for actively engaging students with the topic and for providing hands-on, minds-on observation and exploration of the topic, including authentic data resources for scientific inquiry, experimentation and problem-based tasks that incorporate technology and technological and engineering design. Resources selected are printed or Web-based materials that directly relate to the particular Content Statement. It is not intended to be a prescriptive list of lessons.

- **Chem4Kids, University of Colorado at Boulder,** and **Scientific American** have articles and websites devoted to providing more information about Bose-Einstein condensates.
- "**Ultra Cold Atoms**" is an interview with a scientist who studies Bose-Einstein condensates. He describes the process needed to form Bose-Einstein condensates and the unusual properties of super-cooled matter.
- "**How Low Can You Go**" is an interactive simulation of the process by which substances can be cooled to absolute zero.
- **ACS Small-Scale Laboratory Assessment Activities** were prepared by Robert G. Silberman and Lucy T. Eubanks in association with the American Chemical Society Division of Chemical Education Examinations Institute in 1996 and provide excellent inquiry laboratory assessments. The Visions into Practice examples referenced above have been adapted from activities presented in this book.
- "**Alkali metals**" Discover the explosive results when water and alkali metals come together - and the science behind the reaction. Video.
- **The Periodic Table of Data** is an interactive periodic table. Students can select the properties they wish to view.
- **Atoms and Molecules** is a program produced by Annenberg that deals with teaching the very first steps of chemistry. It introduces the basic building blocks – the atoms – which, through their properties, periodicity and binding, form molecules.
- **Masterminding Molecules** seeks to develop logic and reinforce the principles of fair testing. It introduces the importance of concepts such as size, polarity and drug-like properties in the discovery of new medicines.

Career Connection

Students will base their investigations (variations and similarities between regular table sugar, high fructose corn syrup, Stevia, Aspartame, saccharin, sucralose, and Agave) upon products produced by companies (e.g.: Heinz, Marzetti, Dannon). While researching the products and companies, they will also identify the professionals involved in similar processes within the companies and how they use chemistry in their work. Students will identify the connection between the classroom chemistry content and business practices relative to improving and modifying foods.

COMMON MISCONCEPTIONS

- Students think volume and mass measure the same thing. (Minstrell, J., & Krause, P., n.d.)
- Students think big means the same thing as heavy. (Horton, 2007)
- Students think there are 100 cm^3 in 1 m^3.Horton, 2007)

Students often think that:

- Every different substance (e.g., CO_2, H_2O, salt) is made from atoms of that substance, not understanding that all substances come from the same set of elements assembled in different combinations.
- There is only one correct model of the atom.
- Electrons in an atom orbit nuclei like planets orbit the sun.
- Electron clouds are pictures of orbits.
- Electrons can be in any orbit they wish.
- Hydrogen is a typical atom.
- Electrons are physically larger than protons.
- Electrons and protons are the only fundamental particles.
- Physicists currently have the "right" model of the atom.
- Atoms can disappear (decay).
- Substances that are not hard and rigid cannot be solids (Stavy & Stachel, 1985).
- Chemists do not agree on how the "mole" should be defined: three meanings are that a mole is an individual unit of mass, a mole is a portion of substance and a mole is a number. Suggested (Kind, 2004) is that students be shown elements in a whole-number mass ratio, show that the ratio remains fixed regardless of the number of atoms, introduce the masses in grams, then introduce Avogadro's number while reinforcing atom size.
- Compounds with ionic bonds behave as simple molecules; instead, explore students' understanding of simple events like water boiling, sodium chloride and sugar dissolving, and ice melting. Make the events explicit by carrying them out in the students' presence and using molecular models to probe thinking about which bonds break and form (Kind, 2004).
- The first element in a formula is responsible for bond formation; instead, use cognitive conflict to show why atoms form different types of bonds and that atoms form compounds in the most energetically favorable way (Kind, 2004).
- Atoms "want" to form bonds; instead, use electrostatics to explain bond formation (Kind, 2004).
- There are only two types of bonds – covalent and ionic; instead, be consistent in using bonding terminology like "induced dipole-dipole bonds" and "permanent dipole-permanent dipole bonds because it is much more descriptive and clearly explains the kind of interaction involved (Kind, 2004).

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DIVERSE LEARNERS

Strategies for meeting the needs of all learners including **gifted students**, **English Language Learners** (ELL) and students with **disabilities** can be found at the **Ohio Department of Education site**. Resources based on the Universal Design for Learning principles are available at **www.cast.org**.

CLASSROOM PORTALS

Macro to Micro Structures is a program produced by Annenberg that deals with the conceptualization of micro processes and environments. It involves teaching chemistry through macro phenomena, which can be observed, and micro processes, which occur on the molecular level and can only be imagined.

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CONTENT ELABORATION: INTERACTIONS OF MATTER

Chemical Reactions

In the physical science syllabus, coefficients were introduced to balance simple equations. Other representations including Lewis structures and three-dimensional models also were used and manipulated to demonstrate the conservation of matter in chemical reactions. In this course, more complex reactions will be studied, classified and represented with chemical equations and three-dimensional models. Classifying reactions into types can be a helpful organizational tool in recognizing patterns of what may happen when two substances are mixed (see **Note**). Some general types of chemical reactions are oxidation/reduction, synthesis, decomposition, single- replacement, double replacement (including precipitation reactions and some acid-base neutralizations) and combustion reactions. Some reactions can fit into more than one category. For example, a single replacement reaction also can be classified as an oxidation/reduction reaction. Identification of reactions involving oxidation and reduction as well as indicating what substance is being oxidized and what is being reduced are appropriate in this course. However, balancing complex oxidation/reduction reactions will be reserved for more advanced study.

Organic molecules release energy when undergoing combustion reactions and are used to meet the energy needs of society (e.g., oil, gasoline, natural gas) and to provide the energy needs of biological organisms (e.g., cellular respiration). When a reaction between two ionic compounds in aqueous solution results in the formation of a precipitate or molecular compound, the reaction often occurs because the new ionic or covalent bonds are stronger than the original ion-dipole interactions of the ions in solution. Laboratory experiences (3-D or virtual) with different types of chemical reactions must be provided.

Note: Teachers should be aware that 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 (e.g., exchanging partners), even though the underlying chemistry is not the same. However, they may be useful in making predictions about what may happen when two substances are mixed.

Reactions occur when reacting particles collide in an appropriate orientation and with sufficient energy. Not all collisions are effective. Stable reactants require the input of energy, the activation energy, to initiate a reaction. A catalyst provides an alternate pathway for a reaction, usually with a lower activation energy. With this lower energy threshold, more collisions will have enough energy to result in a reaction. An enzyme is a large organic molecule that folds into a unique shape by forming intermolecular bonds with itself. The enzyme's shape allows it to hold a substrate molecule in the proper orientation to result in an effective collision. The rate of a chemical reaction is the change in the amount of reactants or products in a specific period of time. Increasing the probability or effectiveness of the collisions between the particles increases the rate of the reaction. Therefore, changing the concentration of the reactants, the temperature or the pressure of gaseous reactants can change the reaction rate. Likewise, the collision theory can be applied to dissolving solids in a liquid solvent and can be used to explain why reactions are more likely to occur between reactants in the aqueous or gaseous state than between solids. The rate at which a substance dissolves should not be confused with the amount of solute that can dissolve in a given amount of solvent (solubility). Mathematical treatment of reaction rates are reserved for later study. Computer simulations can help visualize reactions from the perspective of the kinetic-molecular theory.

In middle school, the differences between potential and kinetic energy and the particle nature of thermal energy were introduced. For chemical systems, potential energy is in the form of chemical energy and kinetic energy is in the form of thermal energy. The total amount of chemical energy and/or thermal energy in a system is impossible to measure. However, the energy change of a system can be calculated from measurements (mass and change in temperature) from calorimetry experiments in the laboratory. Conservation of energy is an important component of calorimetry equations. Thermal energy is the energy of a system due to the movement (translational, vibrational and rotational) of its particles. The thermal energy of an object depends upon the amount of matter present (mass), temperature and chemical composition. Some materials require little energy to change their temperature and other materials require a great deal to change their temperature by the same amount. Specific heat is a measure of how much energy is needed to change the temperature of a specific mass of material a specific amount. Specific heat values can be used to calculate the thermal energy change, the temperature (initial, final or change in) or mass of a material in calorimetry. Water has a particularly high specific heat capacity, which is important in regulating Earth's temperature.

As studied in middle school, chemical energy is the potential energy associated with chemical systems. Chemical reactions involve valence electrons forming bonds to yield more stable products with lower energies. Energy is required to break interactions and bonds between the reactant atoms and energy is released when an interaction or bond is formed between the atoms in the products. Molecules with weak bonds (e.g., ATP) are less stable and tend to react to produce more stable products, releasing energy in the process. Generally, energy is transferred out of the system (exothermic) when the products have stronger bonds than the reactants and is transferred into the system (endothermic) when the reactants have stronger bonds than the products. Predictions of the energy requirements (endothermic or exothermic) of a reaction can be made given a table of bond energies. Graphic

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representations can be drawn and interpreted to represent the energy changes during a reaction, including the activation energy. The roles of energy and entropy in determining the spontaneity of chemical reactions are dealt with conceptually in this course. Avoid describing entropy as the amount of disorder since this leads to persistent misconceptions. Mathematical treatment of entropy and its influence on the spontaneity of reactions is reserved for advanced study.

All reactions are reversible to a degree and many reactions do not proceed completely toward products but appear to stop progressing before the reactants are all used up. At this point, the amounts of the reactants and the products appear to be constant and the reaction can be said to have reached dynamic equilibrium. In fact, the reaction has stopped because the rate of the reverse reaction is equal to the rate of the forward reaction so there is no apparent change in the reaction. If given a graph showing the concentration of the reactants and products over the time of reaction, the equilibrium concentrations and the time at which equilibrium was established can be determined. Some reactions appear to proceed only in one direction. In these cases, the reverse reaction can occur but is highly unlikely (e.g., combustion reactions). Such reactions usually release a large amount of energy and require a large input of energy to go in the reverse direction. If a chemical system at equilibrium is disturbed by a change in the conditions of the system (e.g., increase or decrease in the temperature, pressure on gaseous equilibrium systems, concentration of a reactant or product), then the equilibrium system will respond by shifting to a new equilibrium state, reducing the effect of the change (Le Chatelier's Principle). If products are removed as they are formed during a reaction, then the equilibrium position of the system is forced to shift to favor the products. In this way, an otherwise unfavorable reaction can be made to occur. Mathematical treatment of equilibrium reactions is reserved for advanced study. Computer simulations can help visualize the progression of a reaction to dynamic equilibrium and the continuation of both the forward and reverse reactions after equilibrium has been attained.

Properties of acids and bases and the ranges of the pH scale were introduced in middle school. In chemistry, the structural features of molecules are explored to further understand acids and bases. Acids often result when hydrogen is covalently bonded to an electronegative element and is easily dissociated from the rest of the molecule to bind with water to form a hydronium ion (H_3O^+). The acidity of an aqueous solution can be expressed as pH, where pH can be calculated from the concentration of the hydronium ion. Bases are likely to dissociate in water to form a hydroxide ion. Acids can react with bases to form a salt and water. Such neutralization reactions can be studied quantitatively by performing titration experiments. Detailed instruction about the equilibrium of acids and bases and the concept of Brønsted-Lowry and Lewis acids and bases will not be assessed at this level.

Gas laws

The kinetic-molecular theory can be used to explain the macroscopic properties of gases (pressure, temperature and volume) through the motion and interactions of its particles. When one of the three properties is kept constant, the relationship between the other two properties can be quantified, described and explained using the kinetic-molecular theory. Real-world phenomena (e.g., why tire pressure increases in hot weather, why a hot air balloon rises) can be explained using this theory. Problems also can be solved involving the changes in temperature, pressure and volume of a gas. When solving gas problems, the Kelvin temperature scale must be used since only in this scale is the temperature directly proportional to the average kinetic energy. The Kelvin temperature is based on a scale that has its minimum temperature at absolute zero, a temperature at which all motion theoretically stops. Since equal volumes of gases at the same temperature and pressure contain an equal number of particles (Avogadro's law), problems can be solved for an unchanging gaseous system using the ideal gas law ($PV = nRT$) where R is the ideal gas constant (e.g., represented in multiple formats, 8.31 Joules / (mole K). The specific names of the gas laws are not addressed in this course. Deviations from ideal gaseous behavior are reserved for more advanced study. Explore the relationships between the volume, temperature and pressure in the laboratory or through computer simulations or virtual experiments.

Stoichiometry

A stoichiometric calculation involves the conversion from the amount of one substance in a chemical reaction to the amount of another substance. The coefficients of the balanced equation indicate the ratios of the substances involved in the reaction in terms of both particles and moles.

Once the number of moles of a substance is known, amounts can be changed to mass, volume of a gas, volume of solutions and/or number of particles. Molarity is a measure of the concentration of a solution that can be used in stoichiometric calculations. When performing a reaction in the lab, the experimental yield can be compared to the theoretical yield to calculate percent yield. The concept of limiting reagents is treated conceptually and not mathematically. Molality and Normality are concepts reserved for more advanced study.

Nuclear Reactions

The basics of nuclear forces, isotopes, radioactive decay, fission and fusion were addressed in the physical science syllabus. In chemistry, specific types of radioactive decay and using nuclear reactions as a source of energy are addressed. Radioactive decay can result in the release of different types of radiation (alpha, beta, gamma, positron) each with a characteristic mass, charge and potential to ionize and

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penetrate the material it strikes. Beta decay results from the decay of a neutron and positron decay results from the decay of a proton. When a radioisotope undergoes alpha, beta or positron decay, the resulting nucleus can be predicted and the balanced nuclear equation can be written.

Nuclear reactions, such as fission and fusion, are accompanied by large energy changes that are much greater than those that accompany chemical reactions. These nuclear reactions can theoretically be used as a controlled source of energy in a nuclear power plant. There are advantages and disadvantages of generating electricity from fission and fusion.

EXPECTATIONS FOR LEARNING: COGNITIVE DEMANDS

This section provides definitions for Ohio's science cognitive demands, which are intrinsically related to current understandings and research about how people learn. They provide a structure for teachers and assessment developers to reflect on plans for teaching science, to monitor observable evidence of student learning and to develop summative assessment of student learning of science.

VISIONS INTO PRACTICE

This section provides examples of tasks that students may perform; this includes guidance for developing classroom performance tasks. It is not an all-inclusive checklist of what should be done, but is a springboard for generating innovative ideas.

- Devise an investigation, given five numbered samples of either acidic or basic solution and a sixth solution sample of phenolphthalein. Rank the samples in order of their concentration. Present methodology and results in multiple formats (adapted, Silberman, 1996).
- Design an investigation to determine the most effective antacid per gram for neutralizing stomach acid (HCl), baking soda ($NaHCO_3$) or magnesium hydroxide ($Mg(OH)_2$).
- No nuclear waste generated over the last 40 years has been permanently disposed. Determine the time required for a rock (uranium-238) with a rate constant for decay (4.5×10^9 years) to decompose to safe levels. Propose a method for containing this material until safe levels are achieved.

INSTRUCTIONAL STRATEGIES AND RESOURCES

This section provides additional support and information for educators. These are strategies for actively engaging students with the topic and for providing hands-on, minds-on observation and exploration of the topic, including authentic data resources for scientific inquiry, experimentation and problem-based tasks that incorporate technology and technological and engineering design. Resources selected are printed or Web-based materials that directly relate to the particular Content Statement. It is not intended to be a prescriptive list of lessons.

- **Teaching Entropy Analysis in the First Year Chemistry Class and Beyond** is an article that appeared in the Journal of Chemistry Education that discusses scientifically accurate ways to teach entropy to high school students. The sections from the beginning of the article to the bottom of page 1586, ending at *Advanced Students* is appropriate for the level of this chemistry course.
- **Indicators in Chemistry** is a teacher tube video that shows how the content of acids and bases can be integrated into a technological design activity.
- The Design Studio introduces the concepts of shape, enzyme inhibition, potency, drug-like properties and the need to achieve a balance of properties to discover effective medicines.
- **Oil strike** is an interactive, chemistry-themed game. Try and maximize your profits as you build your own refineries.

COMMON MISCONCEPTIONS

- Acids can burn and eat material away (Kind, 2004); introduce acids and bases alongside each other.
- Neutralization means an acid breaking down (Kind, 2004); show the difference between "strong" and "weak" and diluted and concentrated.
- A base/alkali inhibits the burning properties of an acid (Kind, 2004); introduce neutralization as a reaction involving an acid and a base reacting together.

DIVERSE LEARNERS

Strategies for meeting the needs of all learners including **gifted students**, **English Language Learners** (ELL) and students with **disabilities** can be found at the **Ohio Department of Education site**. Resources based on the Universal Design for Learning principles are available at **www.cast.org**.

CLASSROOM PORTALS

Energetics and Dynamics is a video-on-demand produced by Annenberg that emphasizes the importance of learning about energetics and dynamics in order to improve students' understanding of basic principles of chemistry.