UNIT 02 – PERIODIC TRENDS
UNIT PLAN

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UNIT NARRATIVE

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Unit Phenomenon Anchoring Event: Magnesium and calcium both cannot occur in pure elemental form in nature. After isolating calcium and magnesium as elements in the laboratory and reacting each one with water independently, they react in a similar way but at extremely different rates.
Why can magnesium and calcium never be alone in nature? Why do the reactions occur in a different way even though they are in the same family?

Unit 02 extends students' understanding of atomic structure by applying Coulomb's Law to explain the observable trends in the periodic table. Students investigate how the interplay between nuclear charge, core electron shielding, and valence electron attraction produces measurable and predictable patterns in atomic and ionic properties. Through this study, they learn that periodicity arises not from memorization of trends but from reasoning with underlying principles of atomic structure, enabling them to explain and predict behaviors of elements across the periodic table.

The anchoring event centers on the question of why calcium and magnesium, when reacting with water, show both similarities and differences. To launch the unit, students read about how these elements are never found alone in nature and observe their reactions with water. This event provides a concrete context that draws students into the unit by highlighting a puzzling contrast: two elements from the same group of the periodic table behave in ways that are clearly related but not identical. Teachers should emphasize that this is not simply an introductory demonstration but the guiding question that will sustain student curiosity and connect all lessons in the unit. By returning to this phenomenon repeatedly, students learn to use concepts like Coulomb's Law, electron shielding, and effective nuclear charge to explain observed patterns, reinforcing that scientific understanding grows through gathering evidence and building explanations rather than through memorizing rules.

The unit unfolds in a four-part progression: **Coulombic Forces Within the Atom**, **Ionization Energy Analysis**, **Photoelectron Spectroscopy Analysis,** and **Periodic Trends**. Each stage builds conceptually on the last, ensuring students understand not only *what* the trends are, but *why* those trends exist.

1. **Coulombic Forces Within the Atom:** The unit begins with a magnet investigation that models electron shielding and effective nuclear charge, where students learn that core electrons reduce the pull of the nucleus on valence electrons while effective nuclear charge represents the net attraction experienced by those valence electrons. This concept becomes the "why" that underlies every other periodic trend, as the strength of attraction depends on both the number of protons and the number of shielding electrons. Students must be able to interpret and analyze simple models (such as diagrams or representations of shielding) to connect conceptual forces to visual evidence and justify how attraction and repulsion affect the subatomic particles present, establishing the foundation for later analysis of ionization energies, radii, and electronegativity.

2. **Ionization Energy Analysis:** Building from effective nuclear charge, students investigate ionization energy by beginning with first ionization energy trends and then extending their reasoning to successive ionization energies, learning how large jumps in required energy reveal valence shell boundaries. These investigations make visible the predictive power of Coulomb's Law in explaining differences in required energy across elements and successive electrons removed, as students are asked not to recall values but to interpret representations of ionization energies and explain how nuclear charge and electron organization influence these patterns. They must connect conceptual models of effective nuclear charge to real experimental evidence, analyzing graphs of ionization energy data, identifying jumps or trends, and using these patterns to infer shell structure and periodic relationships. Students also must apply their understanding of effective nuclear charge and electron shielding to justify claims about electron placement within configurations, predict which electrons are removed in successive ionizations, and explain where large jumps will occur.
3. **Photoelectron Spectroscopy Analysis:** Students are introduced to photoelectron spectroscopy (PES) as an experimental model that provides direct evidence of electron configurations, where they analyze PES graphs to connect peak positions and heights to binding energies and electron counts, reinforcing how electron organization creates predictable periodic patterns. They extend PES analysis to ionic electron configurations and isoelectronic series, where the number of protons (rather than electron shielding) becomes the controlling factor in binding energy shifts. On the exam, students will not be asked to memorize graphs but to interpret PES spectra and explain how nuclear charge and electron organization influence spectral patterns by reasoning from forces to evidence. Interpreting PES graphs is central to success as students must analyze peak positions, compare relative heights, connect these features to subshell structure and periodicity, and evaluate how models of atomic structure align with PES data.
4. **Periodic Trends:** With forces and evidence established, students turn to observable properties (atomic and ionic radii, electronegativity, and electron affinity) using their understanding of effective nuclear charge and shielding to explain why radii decrease across a period and increase down a group, why cations shrink while anions grow, and why electronegativity and electron affinity follow predictable periodic trends. Students confront and resolve misconceptions such as assuming more electrons always means a larger atom, recognizing instead that size and attraction are governed by competing forces of nuclear charge and shielding. They must apply the principles of shielding and effective nuclear charge to justify periodic trends, explaining (not memorizing) why atoms get smaller or larger, why electronegativity increases or decreases, and why electron affinity follows a predictable pattern. The emphasis is on reasoning from forces to properties while applying science practices such as interpreting graphical trends, analyzing periodic tables or comparative models, and constructing written explanations that connect visual evidence to conceptual reasoning.

Do not skip the creation of a seamless explanation, as this specifically targets disciplinary literacy within science.

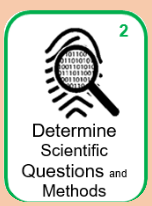
CONTENT STANDARDS

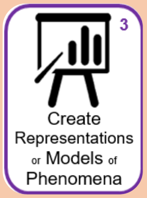
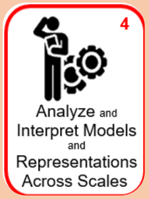
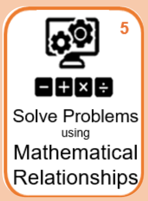
Below are the standards **taught** and **assessed** in this unit.

FIRST INSTRUCTION STANDARDS	
Learning Objectives	**Essential Knowledge**
2.2.A.1 Create and/or evaluate models that illustrate how molecular properties influence the type(s) of ~~intermolecular~~ force(s) present in a substance. **2.2.A.2** Create and/or evaluate a claim about the ~~type(s), strength(s), and~~ origin(s) of intermolecular forces present in a substance. *Note: The effective nuclear charge and electron shielding due atomic structure is the basis of all trends in the current unit. It is also the foundation for intramolecular and intermolecular forces.*	**2.2.A** Intermolecular forces occur between molecules and are the result of electrostatic interactions. **a.** ~~London dispersion forces are attractions among temporary dipoles created by the random movement of electrons; these attractions occur between all types of molecules. Molecules with more electrons tend to have stronger London dispersion forces~~. **b.** ~~Dipole–dipole forces are attractions among permanent dipoles on interacting molecules~~. **c.** ~~Hydrogen bonding forces exist when hydrogen atoms covalently bonded to highly electronegative atoms (N, O, or F) are attracted to the negative ends of dipoles formed by highly electronegative atoms (N, O, or F) in other molecules~~.

2.2.C.1 Describe trends in properties of elements based on their position in the periodic table and the shell model of the atom. *Note: First instruction includes all information about periodic trends.*	**2.2.C** The periodic table is an organizational tool for elements based on their properties. **a.** Patterns of behavior of elements are based on the number of electrons in the outermost shell (valence electrons). **b.** Important periodic trends include electronegativity and atomic radius
SPIRALED STANDARDS	
Learning Objectives	**Essential Knowledge**
2.1.A.1 Distinguish between atoms, ~~molecules, and compounds~~ at the particle level. **2.1.A.2** Create and/or evaluate models of pure substances. *Note: categorizing atoms, isotopes, and ions using subatomic particle distribution.*	**2.1.A** A pure substance always has the same composition. Pure substances include elements, molecules, and compounds. **a.** An element is composed of only one type of atom. **b.** ~~A molecule is a particle composed of more than one atom~~. **c.** ~~A compound is composed of two or more elements and has properties distinct from those of its component atoms~~.
2.2.C.1 Describe trends in properties of elements based on their position in the periodic table and the shell model of the atom. *Note: Electron configuration and shell model are not new.*	**2.2.C** The periodic table is an organizational tool for elements based on their properties. **a.** Patterns of behavior of elements are based on the number of electrons in the outermost shell (valence electrons). **b.** Important periodic trends include electronegativity and atomic radius.

FOCUS ON DISCIPLINARY LITERACY

Science Practices	**Skills**
 **Science Practice 1: Models and Representations** Describe models and representations, including across scales.	**1.A** Describe the components of and quantitative information from models and representations that illustrate particulate-level properties only. **1.B** Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties.
 **Science Practice 2: Question and Method** Determine scientific questions and methods.	**2.A** Identify a testable scientific question based on an observation, data, or a model. **2.B** Formulate a hypothesis or predict the results of an experiment. **2.C** Identify experimental procedures that are aligned to a scientific question (which may include a sketch of a lab setup). **2.D** Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate. **2.E** Identify or describe potential sources of experimental error. **2.F** Explain how modifications to an experimental procedure will alter results.

 **Science Practice 3: Representing Data and Phenomena** Create representations or models of chemical phenomena.	**3.A** Represent chemical phenomena using appropriate graphing techniques, including correct scale and units. **3.B** Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration). **3.C** Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).
 **Science Practice 4: Model Analysis** Analyze and interpret models and representations on a single scale or across multiple scales.	**4.A** Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations. **4.B** Explain whether a model is consistent with chemical theories. **4.C** Explain the connection between particulate-level and macroscopic properties of a substance using models and representations. **4.D** Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.
 **Science Practice 5: Mathematical Routines** Solve problems using mathematical relationships.	**5.A** Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables). **5.B** Identify an appropriate theory, definition, or mathematical relationship to solve a problem. **5.C** Explain the relationship between variables within an equation when one variable changes. **5.D** Identify information presented graphically to solve a problem. **5.E** Determine a balanced chemical equation for a given chemical phenomenon. **5.F** Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).
 **Science Practice 6: Argumentation** Develop an explanation or scientific argument.	**6.A** Make a scientific claim. **6.B** Support a claim with evidence from experimental data. **6.C** Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules. **6.D** Provide reasoning to justify a claim using chemical principles or laws or using mathematical justification. **6.E** Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels. **6.F** Explain the connection between experimental results and chemical concepts, processes, or theories. **6.G** Explain how potential sources of experimental error may affect the experimental results.

Major Content	Supporting & Additional Content
• Periodicity • Electron Shielding • Effective Nuclear Charge • First Ionization Energy • Successive Ionization Energy • Photoelectron Spectroscopy (PES) • Ionic Electron Configurations • Isoelectronic Series • Atomic and Ionic Radii • Electronegativity • Electron Affinity	• Periodic Table Organization • Periodicity • Shell Model of the Atom • Electron Configurations • Bohr Models • Data Analysis • Graph Interpretation

PACING GUIDE

Use this section to plan when each day of instruction will occur. Use the suggested timing table above to guide your pacing in the table below.

UNIT AT A GLANCE			
Lesson #	**Lesson Date**	**Topic**	**Pacing Notes**
01		Anchoring Event Introduction: Magnesium and Calcium	
02		Effective Nuclear Charge	
03		Ionization Energy and First Ionization Energy Trends	
04		Successive Ionization Energies	
05		PES and Periodicity	
06		PES Analysis for Atomic Structure	
07		Ionic Electron Configurations and Isoelectronic Series	
08		Investigating Periodic Trends Part 1 - Atomic and Ionic Radii	
09		Investigating Periodic Trends Part 2 - Electronegativity and Electron Affinity	
REV		Unit 02 Exam Review	
UE		Unit 02 Exam	
FLEX/ER		(Varies by Region)	

UNDERSTANDINGS AND QUESTIONS

Important big ideas and processes for the unit.

KEY UNDERSTANDINGS	TEACHER NOTES
❑ Phenomena are events or processes ("things that happen") that are observable by senses or detectable by instruments. ❑ An answerable scientific question cannot be answered with a yes/no response, is specific and focused, and is based on observable phenomena or patterns ❑ An answerable scientific question cannot be answered with a yes/no response, is specific and focused, and is based on observable phenomena or patterns. ❑ An initial hypothesis is a tentative explanation or prediction to an answerable scientific question based on prior knowledge and observations. ❑ The purpose of an initial hypothesis is to provide a starting point for scientific inquiry that will be revised, refined, or even rejected and rewritten over time as new data and insights are gathered during an investigation. ❑ Coulomb's Law states that the amount of attraction experienced between opposite charges is dependent on both the size of the charge and the distance between the charges. ❑ Electron shielding is when core electrons shield (or block) the attractive force of the nucleus from the valence electrons. ❑ The more core electrons an atom has, the more attractive force from the nucleus is shielded (or blocked) from acting on outer shell electrons. ❑ Effective nuclear charge is the attraction the valence electrons experience from the positively charged nucleus after all electron shielding has been taken into consideration. ❑ The amount of electron shielding is determined using only the number of core electrons. ❑ The effective nuclear charge is the difference between the number of protons in the nucleus and the number of core electrons. ❑ Behaviors of atoms can be estimated or predicted based on their placement in the periodic table, called periodic trends. ❑ Valence shell electrons are what changes when ions form in main group elements. ❑ Ions of main group elements form according to the octet rule; atoms with 5 valence shell electrons or more will gain electrons and atoms with 3 valence electrons or less will lose electrons to achieve a full octet in the least number of energetic steps. ❑ Cations are positively charged ions that result from losing electrons and therefore have more protons than electrons. ❑ Anions are negatively charged ions that result from gaining electrons and therefore have more electrons than protons. ❑ Ionization energy is the amount of energy it takes to remove an electron from the atom to form an ion. ❑ Ionization energy is always given in the form of removing an electron to form an anion, even if normally it would be a cation based on the octet rule. ❑ First ionization energy is the amount of energy it takes to remove the first electron from an atom, and it changes between elements. ❑ Atoms with a higher effective nuclear charge will require more energy to ionize due to being more strongly attracted to the nucleus. ❑ Successive ionization energies are the amount of energy it takes to remove additional electrons off the same atom and will increase for each subsequent electron being removed.	

❑ When an electron is removed from an atom, the same number of protons is attracting a smaller number of electrons, resulting in a stronger pull experienced by the remaining electrons and a smaller radius. ❑ Successive ionizations will require a greater amount of energy to ionize than the first one due to being more strongly attracted to the nucleus with a smaller radius, increasing the amount of energy needed to remove additional electrons. ❑ Large jumps in successive ionization energies are the result of a valence shell being fully ionized and the lower energy level now being the new valence shell with drastically less electron shielding. ❑ Photoelectron spectroscopy (PES) is an experimental technique used to determine the relative energies of electrons in atoms and molecules and how those energies are grouped. ❑ Repeating patterns of behavior in the periodic table, called periodicity, are directly related to the electron configuration of an element due to electron shielding and effective nuclear charge creating attraction within the atom itself. ❑ By using PES to evaluate energies of electrons, scholars will equate the electron configurations to the repeating patterns of energy and the large gaps separating subshells in repeating patterns of energy, elucidating how we know the way electrons group even though they are constantly moving. ❑ The height of each peak on PES indicates the number of electrons in that subshell, which the order and placement of subshells indicates which subshell those electrons are located in. ❑ Electrons closest to the nucleus on the left portion of the PES graph have the highest amount of energy due to being closest to the nucleus with no shielding, therefore experiencing full electron. ❑ Isoelectronic series are all the neutral atoms and ions that have the same number of electrons and therefore the same electron configuration. ❑ The change in the binding energy of 1s electrons between atoms and ions in an isoelectronic series can only be affected by the number of protons in the nucleus since electron shielding is not a factor. ❑ When analyzing a neutral atom with the same configuration of an ion in an isoelectronic series, the number of peaks and the height of those peaks will be the same, but all of the peaks will be shifted towards higher energy if the ion has more protons or lower energy if the ion has less protons. ❑ Electron shielding is not a factor in the changes in energy between atoms and ions in an isoelectronic series, because all of these atoms have the same number of core and valence electrons in the exact same configuration. ❑ The cause of the changing energies of electrons in an isoelectronic series while comparing PES graphs is the number of protons in the nucleus changing, not the amount of “blocking” the source is experiencing. ❑ The size of the radius of an atom or ion is determined by the distance from the nucleus that electrons could be found and is completely dependent on the amount of electron shielding and the resulting effective nuclear charge. ❑ The pattern for atomic radius is predictable and increases as you move left across a period and down a group due to the increase in core electrons (down) or decrease in positive pull (left). ❑ The less attraction the nucleus exhibits on the valence shell the larger the radius of an atom or ion will be because electrons can venture farther out. ❑ The most common misconception is that more electrons in an atom or ion equates to a bigger radius due to the increase in the amount of matter, but this cannot be true because electrons have negligible mass and that atom is mostly empty space. ❑ All periodic trends follow a predictable pattern on the periodic table due to the periodic nature of increasing core electrons, valence electrons, and protons that change the positive charge of the nucleus, the amount of electron shielding, and therefore the effective nuclear charge exhibiting attraction on the valence electrons.	

❑ Ions will grow or shrink their radius when compared to the neutral atom based on if electrons were lost and therefore there is a larger number of protons than the neutral atom or if electrons are gained and there are less protons than the neutral atom. ❑ Electronegativity and electron affinity are also a function of effective nuclear charge that follow a recognizable pattern on the periodic table. ❑ Electronegativity is how strongly an atom holds its own electrons. ❑ How strongly an atoms holds on to its own electrons follows the same trends that ionization energy will follow, because the electrons where it takes more energy to remove an electron experiencing a large electronegativity. ❑ Electron affinity is how strongly an atom attracts another atom's electrons. ❑ The same driving force that causes an atom to have a stronger hold on to its own electrons is the same thing that causes an atom or ion to be able to attract another atom's electrons more strongly and therefore have a higher electron affinity. ❑ Ionization energy, electronegativity, and electron affinity all follow the same periodic trend patterns because they are all directly correlated to the amount of effective nuclear charge. ❑ A seamless explanation for an unknown physical phenomenon integrates evidence from the unit of study, uses scientific concepts in the checklist provided, is comprehensive and includes both inclusionary and exclusionary reasoning for each piece of evidence, reflects understanding and critical thinking, and is clear and logical with no gaps in evidence or reasoning.	
KEY QUESTIONS	**TEACHER NOTES**
➢ How do I develop an answerable question for an observable, physical phenomena? ➢ How do I write an initial hypothesis for observable, physical phenomena? ➢ What is the intention and purpose of an initial hypothesis? ➢ How do electrons and protons interact with one another inside the atom? ➢ What is electron shielding and why does it occur? ➢ What is effective nuclear charge and why does it occur? ➢ How do I determine the ionic charge of the ion most likely to form from a neutral atom? ➢ What is ionization energy? ➢ How do first ionization energies change between different atoms? ➢ How do successive ionization energies change for a single atom as additional electrons are removed? ➢ What is photoelectron spectroscopy (PES)? ➢ What is periodicity? ➢ What does photoelectron spectroscopy (PES) tell us about the structure of the atom? ➢ Why does binding energy change for 1s electrons between atoms and ions in an isoelectronic series? ➢ Why do atomic and ionic radii change in diameter between atoms of different elements? ➢ Why is there a difference between the atomic radius and the ionic radius for the same element? ➢ What is electronegativity and what does it tell me about an atom's behavior? ➢ What is electron affinity and what does it tell me about an atom's behavior? ➢ How do I make predictions about different periodic trends using the periodic table? ➢ How do I annotate a periodic table to summarize trends of the atom? ➢ What are the two main contributing factor that influence all periodic trends?	

VERTICAL STANDARDS

This section details the **progression** of key scholar expectations/standards** in the courses **before** and **after** this course. This will help you understand what **prior knowledge skills to build upon** and guide you in knowing what **skills you are preparing your scholars** for in the subsequent course.

6th - 8th TEKS

Matter and Energy TEKS Introduction Vertical Alignment

Grade 6: Students build upon their knowledge of properties of solids, liquids, and gases and further explore their molecular energies. In Grade 6, students learn how elements are classified as metals, nonmetals, or metalloids based on their properties on the Periodic Table. Students have previous experience with mixtures in Grade 5. Grade 6 furthers their understanding by investigating the different types of mixtures. Subsequent grades will learn about compounds. In Grade 6, students compare the density of substances relative to fluids and identify evidence of chemical changes.

Grade 7: Students have prior experience with elements in Grade 6 and develop an understanding that compounds are also pure substances in Grade 7. Students investigate the differences between elements and compounds through observations, descriptions of physical properties, and chemical reactions. Students build upon their understanding of solutions by exploring aqueous solutions.

Grade 8: Students make connections between elements, compounds, and mixtures that were introduced in prior grade levels. Students examine the properties of water, acids, and bases. In addition, students understand the basic concept of conservation of mass using chemical equations.

TEKS Content Vertical Alignment

Standards format for TEKS is: Grade Levels.#(Letter)

6-8.1 Scientific and engineering practices. The student, for at least 40% of instructional time, asks questions, identifies problems, and plans and safely conducts classroom, laboratory, and field investigations to answer questions, explain phenomena, or design solutions using appropriate tools and models. The student is expected to:

- **6-8.1(A) Scientific and engineering practices.** Scientific inquiry is the planned and deliberate investigation of the natural world using scientific and engineering practices. Scientific methods of investigation are descriptive, correlative, comparative, or experimental. The method chosen should be appropriate to the grade level and question being asked. Student learning for different types of investigations includes descriptive investigations, which have no hypothesis that tentatively answers the research question and involve collecting data and recording observations without making comparisons; correlative and comparative investigations, which have a hypothesis that predicts a relationship and involve collecting data, measuring variables relevant to the hypothesis that are manipulated, and comparing results; and experimental investigations, which involve processes similar to comparative investigations but in which a hypothesis can be tested by comparing a treatment with a control.
- **6-8.1(B)** use scientific practices to plan and conduct descriptive, comparative, and experimental investigations and use engineering practices to design solutions to problems;
- **6-8.1(C)** use appropriate safety equipment and practices during laboratory, classroom, and field investigations as outlined in Texas Education Agency-approved safety standards
- **6-8.1(D)** use appropriate tools, such as graduated cylinders, metric rulers, periodic tables, balances, scales, thermometers, temperature probes, laboratory ware, timing devices, pH indicators, hot plates, models, microscopes, slides, life science models, petri dishes, dissecting kits, magnets, spring scales or force sensors, tools that model wave behavior, satellite images, weather maps [grade 8 only], hand lenses, and lab notebooks or journals;

6-8.2 Nature of science. Science, as defined by the National Academy of Sciences, is the "use of evidence to construct testable explanations and predictions of natural phenomena, as well as the knowledge generated through this process." This vast body of changing and increasing knowledge is described by physical, mathematical, and conceptual models. Students should know that some questions are outside the realm of science because they deal with phenomena that are not currently scientifically testable.

6-8.3 Scientific observations, inferences, hypotheses and theories. Students are expected to know that:

- ❖ **6-8.3(A)** observations are active acquisition of either qualitative or quantitative information from a primary source through the senses;
- ❖ **6-8.3(B)** inferences are conclusions reached on the basis of observations or reasoning supported by relevant evidence;
- ❖ **6-8.3(C)** hypotheses are tentative and testable statements that must be capable of being supported or not supported by observational evidence. Hypotheses of durable explanatory power that have been tested over a wide variety of conditions are incorporated into theories; and
- ❖ **6-8.3(D)** scientific theories are based on natural and physical phenomena and are capable of being tested by multiple independent researchers. Unlike hypotheses, scientific theories are well established and highly reliable explanations, but they may be subject to change as new areas of science and new technologies are developed.

6-8.4 Science and social ethics. Scientific decision making is a way of answering questions about the natural world involving its own set of ethical standards about how the process of science should be carried out. Students distinguish between scientific decision-making practices and ethical and social decisions that involve science.

6-8.5 Recurring themes and concepts. The student understands that recurring themes and concepts provide a framework for making connections across disciplines. The student is expected to:

- ❖ **6-8.5(A)** identify and apply patterns to understand and connect scientific phenomena or to design solutions;
- ❖ **3-8.5(B)** identify and investigate cause-and-effect relationships to explain scientific phenomena or analyze problems;
- ❖ **6-8.5(C)** analyze how differences in scale, proportion, or quantity affect a system's structure or performance;
- ❖ **3-8.5(D)** examine and model the parts of a system and their interdependence in the function of the system;
- ❖ **6-8.5(E)** analyze and explain how energy flows and matter cycles through systems and how energy and matter are conserved through a variety of systems;
- ❖ **6-8.5(F)** analyze and explain the complementary relationship between the structure and function of objects, organisms, and systems; and
- ❖ **6-8.5(G)** analyze and explain how factors or conditions impact stability and change in objects, organisms, and systems.

6-8.6 Matter and energy. Matter and energy. (6^{th}) The student knows that matter is made of atoms, can be classified according to its properties, and can undergo changes. (7^{th}-8^{th}) The student distinguishes between elements and compounds, classifies changes in matter, and understands the properties of solutions. The student is expected to:

- ❖ **8.5(A)** Describe the structure of atoms, including the masses, electrical charges, and locations, or protons and neutrons in nucleus and electrons in the electron cloud
- ❖ **8.5(B)** Identify that protons determine an element's identity and valence electrons determine its chemical properties, including reactivity
- ❖ **7.6(A)** compare and contrast elements and compounds in terms of atoms and molecules, chemical symbols, and chemical formulas;
- ❖ **8.6(A)** explain by modeling how matter is classified as elements, compounds, homogeneous mixtures, or heterogeneous mixtures;
- ❖ **6.6(B)** investigate the physical properties of matter to distinguish between pure substances, homogeneous mixtures (solutions), and heterogeneous mixtures;
- ❖ **7.6(B)** use the periodic table to identify the atoms and the number of each kind within a chemical formula;
- ❖ **8.6(B)** use the periodic table to identify the atoms involved in chemical reactions;

PreAP Biology

NGSS Science Practices

1. **Asking Questions** Scientific questions lead to explanations of how the natural world works and can be empirically tested using evidence.
   - ❖ Ask questions to develop or refine a model or explanation about the natural world.
   - ❖ Ask questions that can be answered using evidence from investigations or gathered by others.

2. **Developing and Using Models** A model is an abstract representation of phenomena that is a tool used to predict or explain the world. Models can be represented as diagrams, 3-D objects, mathematical representations, analogies or computer simulations.
   - ❖ Create models to explain and/or predict scientific phenomena, processes, or relationships.
   - ❖ Evaluate the merits and limitations of models.
3. **Planning and Carrying Out Investigations** An investigation is a systematic way to gather data about the natural world either in the field or in a laboratory setting.
   - ❖ Design investigations that will produce data that can be used to answer scientific questions. This includes determining the goal of the investigation, developing predictions, and designing procedures.
   - ❖ Identify and analyze experimental variables, controls and investigational methods (e.g., how many trials to do).
   - ❖ Conduct investigations to gather data (observations or measurements) using appropriate tools and methods.
4. **Analyzing and Interpreting Data** Analyzing and interpreting data includes making sense of the data produced during investigations. Because patterns are not always obvious, this includes using a range of tools such as tables, graphs and other visualization techniques.
   - ❖ Analyze and interpret data to determine patterns and relationships.
   - ❖ Represent data in tables and graphs to reveal patterns and relationships.
   - ❖ Consider the limitations of data analysis such as sources of error.
5. **Using Mathematics and Computational Thinking** Mathematical and computational thinking involves using tools and mathematical concepts to address a scientific question.
   - ❖ Describe, measure, compare, and estimate quantities (e.g., weight, volume) to answer a scientific question.
   - ❖ Organize data in graphs or charts.
   - ❖ Use mathematical concepts (e.g., ratios) to answer scientific questions.
   - ❖ Use digital tools to accomplish these goals when appropriate.
6. **Constructing Explanations** A scientific explanation is an explanatory account that articulates how or why a natural phenomenon occurs that is supported by evidence and scientific ideas.
   - ❖ Construct an explanation for a natural phenomenon.
   - ❖ Use evidence (e.g. measurements, observations) to construct or support an explanation.
   - ❖ Consider the qualitative or quantitative relationships between variables to explain a phenomenon.
   - ❖ Apply scientific ideas to construct or revise an explanation.
7. **Engaging in Argument from Evidence** Scientific argumentation is a process that occurs when there are multiple ideas or claims (e.g. explanations, models) to discuss and reconcile. An argument includes a claim supported by evidence and reasoning, and students engage in debates to evaluate and critique competing arguments.
   - ❖ Construct and refine arguments based on evidence and reasoning (understanding of disciplinary core ideas).
   - ❖ Critique arguments from peers and other sources by citing relevant evidence and providing scientific questions.
   - ❖ Compare and critique two arguments based on the quality of their evidence and reasoning.
8. **Obtaining, Evaluating, and Communicating Information** Obtaining, evaluating and communicating information occurs through reading and writing texts as well as communicating orally. Scientific information needs to be critically evaluated and persuasively communicated as it supports the engagement in the other science practices.
   - ❖ Read appropriate texts and related features (i.e. graphs) to obtain scientific information.
   - ❖ Evaluate the information gathered from texts and other sources.
   - ❖ Communicate scientific information in various formats in different modalities (writing, speaking). This characteristic makes explicit the features of communication in the other 7 scientific practices.

Content Essential Knowledge
ECO 1.2.1 Elements that are building blocks of macromolecules are transported from abiotic to biotic systems through gaseous and sedimentary cycles.
CELLS 7.1.1 Cellular respiration is a series of enzymatic reactions that utilize electron carrier molecules to synthesize ATP molecules.

AP Biology

Topic 1.2 Elements of Life

- **ENE–1** The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.
  - **ENE–1.A** Describe the composition of macromolecules required by living organisms.
    - **ENE–1.A.2** Atoms and molecules from the environment are necessary to build new molecules—
      - **a.** Carbon is used to build biological molecules such as carbohydrates, proteins, lipids, and nucleic acids. Carbon is used in storage compounds and cell formation in all organisms.
      - **b.** Nitrogen is used to build proteins and nucleic acids. Phosphorus is used to build nucleic acids and certain lipids.

Topic 2.2 Cell Structure and Function

- **SYI–1** Living systems are organized in a hierarchy of structural levels that interact.
  - **SYI–1.F** Describe the structural features of a cell that allow organisms to capture, store, and use energy..
    - **SYI–1.F.4** Membranes contain chlorophyll pigments and electron transport proteins that comprise the photosystems.

Topic 2.5 Membrane Permeability

- **ENE–2** Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.
  - **ENE–2.C** Explain how the structure of biological membranes influences selective permeability.
    - **ENE–2.C.4** Small nonpolar molecules, including N_2, O_2, and CO_2, freely pass across the membrane. Hydrophilic substances, such as large polar molecules and ions, move across the membrane through embedded channel and transport proteins.

Topic 2.7 Facilitated Diffusion

- **ENE–2** Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.
  - **ENE–2.G** Explain how the structure of a molecule affects its ability to pass through the plasma membrane.
    - **ENE–2.G.1** Membrane proteins are required for facilitated diffusion of charged and large polar molecules through a membrane—
      - **a.** Charged ions, including Na^+ and K^+, require channel proteins to move through the membrane.
      - **b.** Membranes may become polarized by movement of ions across the membrane.

Topic 2.9 Mechanisms of Transport

- **ENE–2** Cells have membranes that allow them to establish and maintain internal environments that are different from their external environments.
  - **ENE–2.J** Describe the processes that allow ions and other molecules to move across membranes.
    - **ENE–2.J.1** A variety of processes allow for the movement of ions and other molecules across membranes, including passive and active transport, endocytosis and exocytosis.

Topic 3.5 Photosynthesis

- **ENE–1** The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.
  - **ENE–1.J** Explain how cells capture energy from light and transfer it to biological molecules for storage and use.
    - **ENE–1.J.1** During photosynthesis, chlorophylls absorb energy from light, boosting electrons to a higher energy level in photosystems I and II.
    - **ENE–1.J.2** Photosystems I and II are embedded in the internal membranes of chloroplasts and are connected by the transfer of higher energy electrons through an electron transport chain (ETC).

- **ENE–1.J.3** When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) is established across the internal membrane.
- **ENE–1.J.4** The formation of the proton gradient is linked to the synthesis of ATP from ADP and inorganic phosphate via ATP synthase.

Topic 3.6 Cellular Respiration

- **ENE–1** The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules.
  - **ENE–1.K** Describe the processes that allow organisms to use energy stored in biological macromolecules.
    - **ENE–1.K.3** The electron transport chain transfers energy from electrons in a series of coupled reactions that establish an electrochemical gradient across membranes—
      - **b.** In cellular respiration, electrons delivered by NADH and FADH are passed to a series of electron acceptor2 s as they move toward the terminal electron acceptor, oxygen. In photosynthesis, the terminal electron acceptor is NADP+. Aerobic prokaryotes use oxygen as a terminal electron acceptor, while anaerobic prokaryotes use other molecules.
      - **c.** The transfer of electrons is accompanied by the formation of a proton gradient across the inner mitochondrial membrane or the internal membrane of chloroplasts, with the membrane(s) separating a region of high proton concentration from a region of low proton concentration. In prokaryotes, the passage of electrons is accompanied by the movement of protons across the plasma membrane.
      - **d.** The flow of protons back through membrane-bound ATP synthase by chemiosmosis drives the formation of ATP from ADP and inorganic phosphate. This is known as oxidative phosphorylation in cellular respiration, and photophosphorylation in photosynthesis.
  - **ENE–1.L** Explain how cells obtain energy from biological macromolecules in order to power cellular functions.
    - **ENE–1.L.3** In the Kreb's cycle, carbon dioxide is released from organic intermediates, ATP is synthesized from ADP and inorganic phosphate, and electrons are transferred to the coenzymes NADH and $FADH_2$.
    - **ENE–1.L.4** Electrons extracted in glycolysis and Krebs cycle reactions are transferred by NADH and $FADH_2$ to the electron transport chain in the inner mitochondrial membrane.
    - **ENE–1.L.5** When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) across the inner mitochondrial membrane is established.

AP Environmental Science

Science Practice: Mathematical Routines Apply quantitative methods to address environmental concepts.

- **6.A** Determine an approach or method aligned with the problem to be solved.
  - **Topic 8.12** Lethal Dose 50% (LD_{50})
- **6.B** Apply appropriate mathematical relationships to solve a problem, with work shown (e.g., dimensional analysis).
  - **Topic 3.5** Population Growth and Resource Availability
  - **Topic 7.7** Acid Rain
  - **Topic 8.2** Human Impacts on Ecosystems
  - **Topic 8.10** Waste Reduction Methods
  - **Topic 9.7** Ocean Acidification
- **6.C** Calculate an accurate numeric answer with appropriate units.
  - **Topic 1.10** Energy Flow and the 10% Rule
  - **Topic 6.2** Global Energy Consumption
  - **Topic 6.13** Energy Conservation

Math Skills:

- **Dimensional Analysis:** Using unit conversions to manipulate known quantities will always appear on the AP exam.
- ~~**Density:** Must understand density qualitatively and calculate with density quantitatively~~.
- ~~**pH:** Must know the basics of the pH scale, that each whole number on the pH scale is a factor of 10 change in hydrogen ion concentration~~.
- **Scientific Notation**. Will often use scientific notation in the givens of a problem and scholars must know how to understand what the number means and quantify larger or smaller numbers in scientific notation as well as multiply or divide with scientific notation using the calculator.
- **Percentages:** Must know how to add, subtract, multiply or divide using percentages without a calculator.
- ~~**Percent Change:** Must know how to calculate percent change with the same mathematical routine chemistry uses for percent yield~~.
- **Metric Conversion:** Convert between metric prefixes using dimensional analysis.
- ~~**Algebraic Equations:** Scholars must know how to identify givens and unknowns, rearrange algebraic equations to isolate a variable, and solve for the unknown value~~.

AP CHEMISTRY

Topic 1.5 Atomic Structure and Electron Configuration

- **SAP-1** Atoms and molecules can be identified by their electron distribution and energy.
    - **SAP-1.A** Represent the electron configuration of an element or ions of an element using the Aufbau principle.
        - **SAP-1.A.1** The atom is composed of negatively charged electrons and a positively charged nucleus that is made of protons and neutrons.

Topic 1.6 Photoelectron Spectroscopy

- **SAP-1** Atoms and molecules can be identified by their electron distribution and energy.
    - **SAP-1.B** Explain the relationship between the photoelectron spectrum of an atom or ion and (a) the electron configuration of the species (b) the interactions between the electrons and the nucleus:
        - **SAP-1.B.1** The energies of the electrons in a given shell can be measured experimentally with photoelectron spectroscopy (PES). The position of each peak in the PES spectrum is related to the energy required to remove an electron from the corresponding subshell, and the height of each peak is (ideally) proportional to the number of electrons in that subshell.

Topic 1.8 Valence Electrons and Ionic Compounds

- **SAP-2** The periodic table shows patterns in electronic structure and trends in atomic properties.
    - **SAP-2.B** Explain the relationship between trends in the reactivity of elements and periodicity.
        - **SAP-2.B.3** Typical charges of atoms in ionic compounds are governed by their location on the periodic table and the number of valence electrons.

Topic 2.2 Intramolecular Force and Potential Energy

- **SAP-3** Atoms or ions bond due to interactions between them, forming molecules.
    - **SAP-3.B** Represent the relationship between potential energy and distance between atoms, based on factors that influence the interaction strength.
        - **SAP-3.B.1** A graph of potential energy versus the distance between atoms is a useful representation for describing the interactions between atoms. Such graphs illustrate both the equilibrium bond length (the separation between atoms at which the potential energy is lowest) and the bond energy (the energy required to separate the atoms).
        - **SAP-3.B.2** In a covalent bond, the bond length is influenced by both the size of the atom's core and the bond order (i.e., single, double, triple). Bonds with a higher order are shorter and have larger bond energies.

- **SAP-3.B.3** Coulomb's law can be used to understand the strength of interactions between cations and anions.
  - **a.** Because the interaction strength is proportional to the charge on each ion, larger charges lead to stronger interactions.
  - **b.** Because the interaction strength increases as the distance between the centers of the ions (nuclei) decreases, smaller ions lead to stronger interactions.

Topic 2.3 Structure of Ionic Solids

- **SAP-3** Atoms or ions bond due to interactions between them, forming molecules.
  - **SAP-3.C** Represent an ionic solid with a particulate model that is consistent with Coulomb's law and the properties of the constituent ions.
    - **SAP-3.C.1** The cations and anions in an ionic crystal are arranged in a systematic, periodic 3-D array that maximizes the attractive forces among cations and anions while minimizing the repulsive forces.

Topic 2.5 Lewis Diagrams

- **SAP-4** Molecular compounds are arranged based on Lewis diagrams and Valence Shell Electron Pair Repulsion (VSEPR) theory.
  - **SAP-4.A** Represent a molecule with a Lewis diagram.
    - **SAP-4.A.1** Lewis diagrams can be constructed according to an established set of principles.

Topic 4.4 Physical and Chemical Changes

- **TRA-1** A substance that changes its properties, or that changes into a different substance, can be represented by chemical equations.
  - **TRA-1.D** Explain the relationship between macroscopic characteristics and bond interactions for (a) chemical processes (b) physical processes.
    - **TRA-1.D.1** Processes that involve the breaking and/or formation of chemical bonds are typically classified as chemical processes. Processes that involve only changes in intermolecular interactions, such as phase changes, are typically classified as physical processes.
    - **TRA-1.D.2** Sometimes physical processes involve the breaking of chemical bonds. For example, plausible arguments could be made for the dissolution of a salt in water, as either a physical or chemical process, involves breaking of ionic bonds, and the formation of ion-dipole interactions between ions and solvent.

VOCABULARY GLOSSARY

Domain-specific words and definitions for this unit.

Key Content Vocabulary
Definitions of key terms are listed below.
Accuracy: A measure of how close the average of all trials of for a measured value are to the true value of the measurement.
Anchoring Event: Specific instances of a phenomenon that require scholars to pull together a number of science ideas in order to explain.
Anion: Negatively charged ion.
Atom: The smallest particle of an element.
Atomic Number (Z): The number of protons in the nucleus of the atom. This determines the identity of the element of the atom.
Atomic Radius: The distance between the nucleus of an atom and the outermost shell or orbital of electrons in a neutral atom.
Attraction: The non-contact force or interaction that pulls two or more substances or particles toward each other.
Binding Energy: The amount of energy required to remove an electron from the subshell of an atom.
Cation: Positively charged ion.
Charge: The net charge of an atom found by comparing the number of electrons to the number of protons.

Claim: A statement made as an explanation of data collected and analyzed or as an answer to a question.
Core Electrons: Electrons that do not occupy the outermost energy level of an atom; electrons between the nucleus and the valence shell.
Coulomb's Law: Like charges repel; opposite charges attract. The force is proportional to the magnitude of the charges and inversely proportional to the square of the distance between them.
Effective Nuclear Charge (Z_{eff}): The actual amount of positive (nuclear) charge experienced by an electron in a multi-electron atom found by comparing the number of positive protons to the number of core electrons.
Electron: Subatomic particle found outside the nucleus of the atom that has negligible mass and a negative charge equal and opposite to the proton.
Electron Affinity: A measure of the attraction between the incoming electron and the nucleus; the stronger the attraction the more energy is released. The change in energy, measured in units of kJ/mole, experienced when an electron is added to a gaseous atom.
Electron Cloud: The region of negative charge surrounding an atomic nucleus that is associated with the locations where electrons have greater than 95% probability of existing. Since electrons are always moving it is impossible to know their exact location, only the most likely area they will be located within.
Electron Configuration: The arrangement of electrons around the nucleus of a particular atom or molecule.
Electron Shielding: The blocking of valence shell electron attraction by the nucleus, due to the presence of inner-shell (core) electrons.
Electronegativity: A measure of an atom's ability to attract shared electrons; how strongly a nucleus attracts the electrons of another atom.
Element Symbol: The letter designation for that element that will be found on the periodic table. This is usually one or two letters, with the first letter always being upper case and any subsequent letters present are lower case.
Element: Substance that is composed of a single type of atom; a substance that cannot be decomposed by a chemical change; determined by the number of protons in the atom.
Energy (E): The capacity to do work, usually measured in Joules (J).
Energy Level (aka Energy Shell): A fixed distance from the nucleus of an atom where electrons may be found.
Essential Question: A question developed from an anchoring event that is investigated in order to develop an underlying explanatory model for the phenomenon.
Evidence: Knowledge, facts, or data (qualitative or quantitative) that supports the claim.
Explanatory Model: A proposed explanation made based on limited evidence as a starting point for further investigation.
Family: A group of elements on the periodic table that share common properties.
First Ionization Energy: The energy required to remove the outermost, or least bound, electron from a neutral atom of the element.
Ground State: The most stable, lowest energy conformation of an atom's electron configuration. All electrons are in their most favorable and lowest energy positions.
Group: Vertical row of the periodic table.
Inference: A conclusion reached on the basis of evidence and reasoning.
Ion: An atom or group of atoms in which the number of electrons is different from the number of protons, causing a net positive or negative charge.
Ionic Configuration: The electron configuration of an ion, which is an atom or molecule with a net electrical charge.

Ionic Radius: The average distance between the nucleus of an ion and the outermost shell or orbital of electrons.
Ionization Energy: The amount of energy required to ionize a mole of atoms or molecules, usually as kilojoules per mole (kJ/mol) or kilocalories per mole (kcal/mol).
Ionization: The process of an atom gaining or losing electrons to become an ion.
Isoelectronic Series: A group of atoms and/or ions that have the same number of electrons and therefore the same electron configuration.
Isotope: Atoms that contain the same number of protons but different numbers of neutrons, resulting in atoms of the same element having different masses.
Law of Conservation of Energy: Energy can neither be created nor destroyed - only converted from one form of energy to another.
Law of Conservation of Mass: Matter can neither be created nor destroyed - only converted from one form of matter to another.
Mass Number: The number of protons and neutrons in the nucleus of an atom, measured in amu.
Mass: The amount of matter present; measured in the base SI unit of grams (g).
Meters: The SI unit of length, abbreviated “m”.
Molar Mass: The mass, in grams, of one mole of a substance expressed in units of grams per mole (g/mol). The average atomic mass determined using the natural abundance of all isotopes of an element is the same as the molar mass of an element.
Mole: A way to count the number of particles of a substance by group, similar to a “pair” or a “dozen”; the amount of substance containing the same number of atoms, molecules, ions, or other entities as the number of atoms in exactly 12 grams of ^{12}C.
Neutron: Subatomic particle found in the nucleus of the atom that as an approximate mass of 1 amu that is neutral (no charge).
Nucleus: The small, dense region consisting of protons and neutrons at the center of an atom.
Nuclear Charge: Total positive charge of the nucleus due to protons.
Observation: Any data collected using any of the five senses, can be quantitative or qualitative.
Octet Rule: The tendency of atoms to prefer to have eight electrons in the valence shell.
Particle: Any basic unit of matter such as atoms, ions, molecules, formula units, etc.
Period: Horizontal row of the periodic table.
Periodicity: The properties of the elements in the periodic table have a tendency to recur at intervals, can help you estimate the properties of atoms that haven't even been discovered yet.
Phenomenon: Events or processes (“things that happen”) that are observable by the senses, or detectable by instruments.
Photoelectron Spectroscopy (PES): An experimental technique used to determine the relative binding energies of electrons in particles.
Potential Energy: Stored energy based on position.
Precision: A measure of how close all trials for a measured value are to one another.
Proton: Subatomic particle found in the nucleus of the atom that as an approximate mass of 1 amu and positive charge equal and opposite to the electron.
Qualitative: The determination of non-numerical information about a chemical species, a reaction, a system, etc.
Quantitative: The determination of numerical information about a chemical species, a reaction, a system, etc.
Ratio: Numerical comparison or relationship between two or more values.

Reaction Rate: The speed at which the reaction moves forward; the concentration of reactant consumed or the concentration of product formed per unit time.
Reaction: The process that creates and transforms matter from one substance to another.
Reactivity: The degree to which a substance shows chemical change when mixed with another substance.
Reasoning: The explanation of the "how" or "why" the evidence you have chosen supports your claim.
Shell (Energy Level): A fixed distance from the nucleus of an atom where electrons may be found.
Subshell: The division of energy levels (such as n=1, n=2, and so on) into distinct shells of distinct positions different orbital types will occupy (1s, 2p, 3d, etc.).
Successive Ionization Energy: The amount of energy required to remove additional electrons after the first electron is removed.
Successive Ionization: The removal of additional electrons from the atom after the first electron is removed.
Trend: A recognizable pattern in a data set that communicates information about the data collected and associated processes.
Valence Electron: An electron located in the outermost shell (or valence shell) of an atom.
Volume: How much space an object or substance occupies.