Michigan Merit Curriculum

Course/Credit Requirements

CHEMISTRY

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1 Credit

MICHIGAN Department of Education

Welcome

This guide was developed to assist teachers in successfully implementing the Michigan Merit Curriculum. The identified content expectations and guidelines provide a useful framework for designing curriculum, assessments and relevant learning experiences for students. Through the collaborative efforts of Governor Jennifer M. Granholm, the State Board of Education, and the State Legislature, these landmark state graduation requirements are being implemented to give Michigan students the knowledge and skills to succeed in the 21st Century and drive Michigan's economic success in the global economy. Working together, teachers can explore varied pathways to help students demonstrate proficiency in meeting the content expectations and guidelines. This guide should be used in conjunction with the High School Content Expectations document for the discipline.

Curriculum Unit Design

One of the ultimate goals of teaching is for students to acquire transferable knowledge. To accomplish this, learning needs to result in a deep understanding of content and mastery level of skills. As educational designers, teachers must use both the art and the science of teaching. In planning coherent, rigorous instructional units of study, it is best to *begin with the end in mind*.

Engaging and effective units include

- appropriate content expectations
- students setting goals and monitoring own progress
- a focus on big ideas that have great transfer value
- focus and essential questions that stimulate inquiry and connections
- identified valid and relevant skills and processes
- purposeful real-world applications
- relevant and worthy learning experiences
- varied flexible instruction for diverse learners
- research-based instructional strategies
- explicit and systematic instruction
- adequate teacher modeling and guided practice
- substantial time to review or apply new knowledge
- opportunities for revision of work based on feedback
- student evaluation of the unit
- culminating celebrations

Relevance

Instruction that is clearly relevant to today's rapidly changing world is at the forefront of unit design. Content knowledge cannot by itself lead all students to academic achievement. Classes and projects that spark student interest and provide a rationale for why the content is worth learning enable students to make connections between what they read and learn in school, their lives, and their futures. An engaging and effective curriculum provides opportunities for exploration and exposure to new ideas. Real-world learning experiences provide students with opportunities to transfer and apply knowledge in new, diverse situations.

Student Assessment

The assessment process can be a powerful tool for learning when students are actively involved in the process. Both assessment *of* learning and assessment *for* learning are essential. Reliable formative and summative assessments provide teachers with information they need to make informed instructional decisions that are more responsive to students' needs. Engagement empowers students to take ownership of their learning and builds confidence over time.

Sound assessments:

- align with learning goals
- vary in type and format
- use authentic performance tasks
- use criteria-scoring tools such as rubrics or exemplars
- allow teachers and students to track growth over time
- validate the acquisition of transferable knowledge
- give insight into students' thinking processes
- cause students to use higher level thinking skills
- address guiding questions and identified skills and processes
- provide informative feedback for teachers and students
- ask students to reflect on their learning

Why Develop Content Standards and Expectations for High School?

To prepare Michigan's students with the knowledge and skills to succeed in the 21st Century, the State of Michigan has enacted a rigorous new set of statewide graduation requirements that are among the best in the nation. These requirements, called the Michigan Merit Curriculum, are the result of a collaborative effort between Governor Jennifer M. Granholm, the State Board of Education, and the State Legislature.

In preparation for the implementation of the new high school graduation requirements, the Michigan Department of Education's Office of School Improvement is leading the development of high school content expectations. An Academic Work Group of science experts chaired by nationally known scholars was commissioned to conduct a scholarly review and identify content standards and expectations. The Michigan Department of Education conducted an extensive field review of the expectations by high school, university, and business and industry representatives.

The Michigan High School Science Content Expectations (Science HSCE) establish what every student is expected to know and be able to do by the end of high school and define the expectations for high school science credit in Earth Science, Biology, Physics, and Chemistry.

An Overview

In developing these expectations, the Academic Work Group depended heavily on the *Science Framework for the 2009 National Assessment of Educational Progress* (National Assessment Governing Board, 2006). In particular, the group adapted the structure of the NAEP framework, including Content Statements and Performance Expectations. These expectations align closely with the NAEP framework, which is based on *Benchmarks for Science Literacy* (AAAS Project 2061, 1993) and the *National Science Education Standards* (National Research Council, 1996).

The Academic Work Group carefully analyzed other documents, including the Michigan Curriculum Framework Science Benchmarks (2000 revision), the Standards for Success report *Understanding University Success*, ACT's *College Readiness Standards*, College Board's *AP Biology, AP Physics, AP Chemistry,* and *AP Environmental Science Course Descriptions*, ACT's *On Course for Success*, South Regional Education Board's *Getting Ready for College-Preparatory/Honors Science: What Middle Grades Students Need to Know and Be Able to Do,* and standards documents from other states.

Organization of the Standards and Expectations

In the Science credit requirement documents, the expectations are organized by standard under content statement headings. The organization in no way implies an instructional sequence. Curriculum personnel and teachers are encouraged to organize these topics and expectations in a manner that encourages connections between concepts.

Earth Science	Biology
STANDARDS (and number of content statements in each standard)	
E1 Inquiry, Reflection, and Social Implications (2)	**B1 Inquiry, Reflection, and Social Implications** (2)
E2 Earth Systems (4)	**B2 Organization and Development of Living Systems** (6)
E3 Solid Earth (4)	**B3 Interdependence of Living Systems and the Environment** (5)
E4 Fluid Earth (3)	**B4 Genetics** (4)
E5 The Earth in Space and Time (4)	**B5 Evolution and Biodiversity** (3)

Physics	Chemistry
STANDARDS (and number of content statements in each standard)	
P1 Inquiry, Reflection, and Social Implications (2)	**C1 Inquiry, Reflection, and Social Implications** (2)
P2 Motion of Objects (3)	**C2 Forms of Energy** (5)
P3 Forces and Motion (8)	**C3 Energy Transfer and Conservation** (5)
P4 Forms of Energy and Energy Transformations (12)	**C4 Properties of Matter** (10)
	C5 Changes in Matter (7)

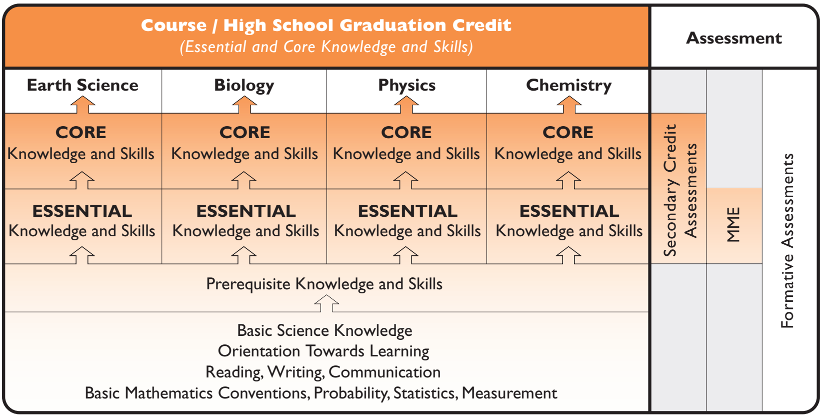
Useful and Connected Knowledge for All Students

This document defines expectations for Michigan High School graduates, organized by discipline: Earth Science, Biology, Physics, and Chemistry. It defines ***useful*** and ***connected knowledge*** at four levels:

- **Prerequisite knowledge**
  Useful and connected knowledge that all students should bring as a prerequisite to high school science classes. Prerequisite expectation codes include a "**p**" and an upper case letter (e.g., **E3.p1A**). Prerequisite content could be assessed through formative and/or large scale assessments.
- **Essential knowledge**
  Useful and connected knowledge for all high school graduates, regardless of what courses they take in high school. Essential expectation codes include an upper case letter (e.g., **E2.1A**). Essential content knowledge and performance expectations are required for graduation and are assessable on the Michigan Merit Exam (MME) and on future secondary credit assessments. Essential knowledge can also be assessed with formative assessments.
- **Core knowledge**
  Useful and connected knowledge for all high school graduates who have completed a discipline-specific course. In general core knowledge includes content and expectations that students need to be prepared for more advanced study in that discipline. Core content statement codes include an "x" and core expectation codes include a lower case letter (e.g., **B2.2x** Proteins; **B2.2f**) to indicate that they are NOT assessable on existing large-scale assessments (MME, NAEP), but will be assessed on future secondary credit assessments. Core knowledge can also be assessed with formative assessments.
- **Recommended knowledge**
  Useful and connected knowledge that is desirable as preparation for more advanced study in the discipline, but not required for graduation credit. Content and expectations labeled as recommended represent extensions of the core. Recommended content statement codes include an "**r**" and an "**x**"; recommended expectations include an "**r**" and a lower case letter (e.g., **P4.r9x Nature of Light**; **P4.r9a**). They will not be assessed on either the MME or secondary credit assessments.

Useful and connected knowledge is contrasted with ***procedural display***—learning to manipulate words and symbols without fully understanding their meaning. When expectations are excessive, procedural display is the kind of learning that takes place. Teachers and students "cover the content" instead of "uncovering" useful and connected knowledge.

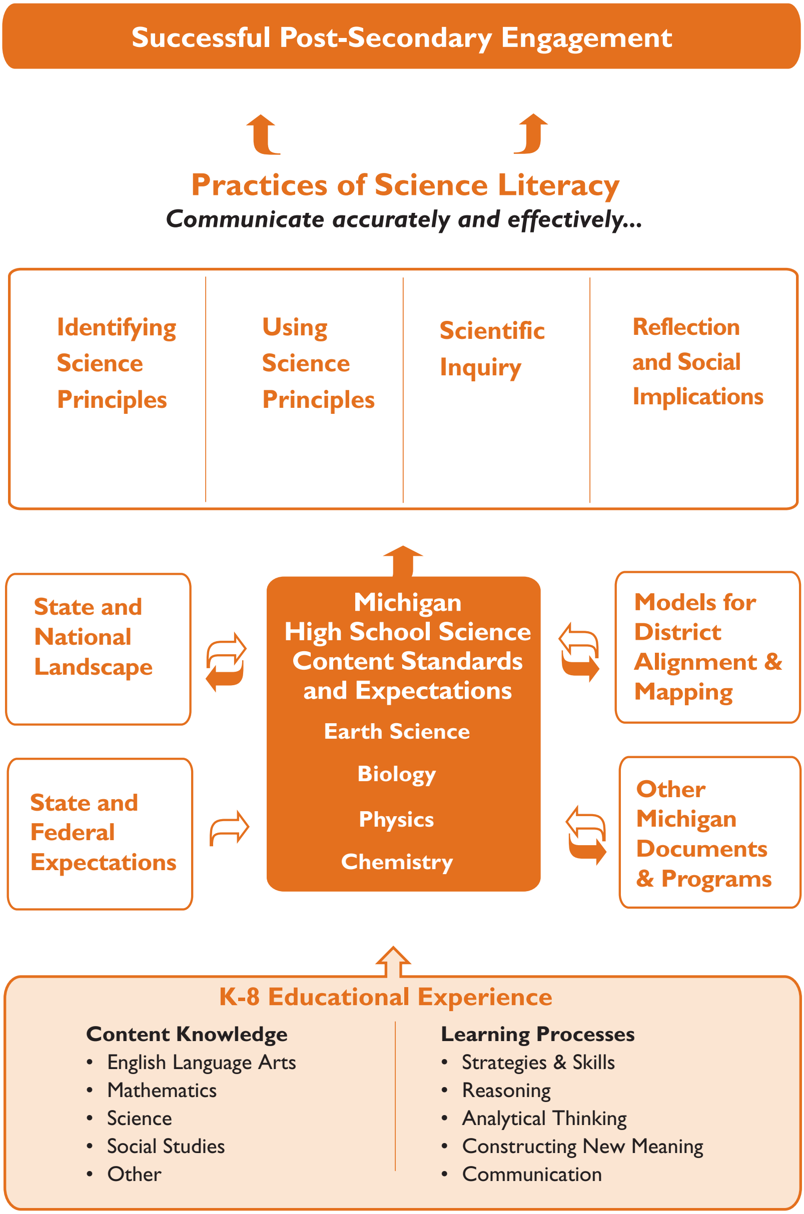
Credit for high school Earth Science, Biology, Physics, and Chemistry will be defined as meeting both essential and core subject area content expectations.



NOTE: Basic mathematics and English language arts skills necessary for meeting the high school science content expectations will be included in a companion document.

Preparing Students for Successful Post-Secondary Engagement

Students who have useful and connected knowledge should be able to apply knowledge in new situations; to solve problems by generating new ideas; to make connections among what they read and hear in class, the world around them, and the future; and through their work, to develop leadership qualities while still in high school. In particular, high school graduates with useful and connected knowledge are able to engage in four key practices of science literacy.



The above chart provides a structural overview of the information that follows on pages 8 - 14. The complete chart is printed on page 3 of the HSCE document.

Practices of Science Literacy

- **Identifying**
  Identifying performances generally have to do with stating models, theories, and patterns inside the triangle in Figure 1.

- **Using**
  Using performances generally have to do with the downward arrow in Figure 1—using scientific models and patterns to explain or describe specific observations.

- **Inquiry**
  Inquiry performances generally have to do with the upward arrow in Figure 1—finding and explaining patterns in data.

- **Reflection and Social Implications**
  Reflecting and Social Implications performances generally have to do with the figure as a whole (reflecting) or the downward arrow (technology as the application of models and theories to practical problems).

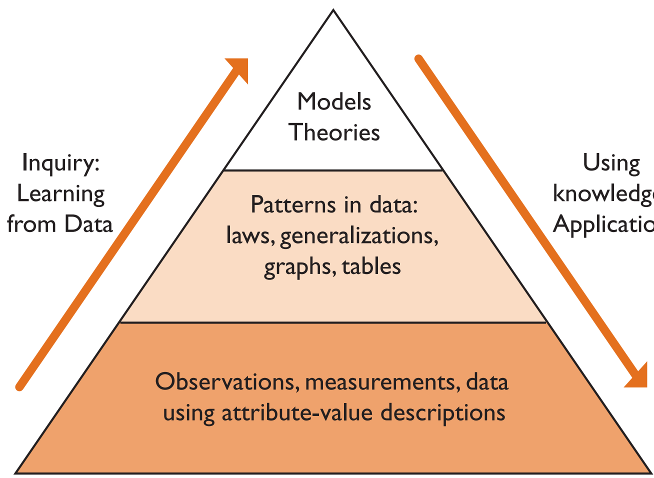


Figure 1: Knowledge and practices of model-based reasoning

Identifying Science Principles

This category focuses on students' abilities to recall, define, relate, and represent basic science principles. The content statements themselves are often closely related to one another conceptually. Moreover, the science principles included in the content statements can be represented in a variety of forms, such as words, pictures, graphs, tables, formulas, and diagrams (AAAS, 1993; NRC, 1996). Identifying practices include describing, measuring, or classifying observations; stating or recognizing principles included in the content statements; connecting closely related content statements; and relating different representations of science knowledge.

Identifying Science Principles comprises the following general types of practices:

- Describe, measure, or classify observations (e.g., describe the position and motion of objects, measure temperature, classify relationships between organisms as being predator/prey, parasite/host, producer/consumer).
- State or recognize correct science principles (e.g., mass is conserved when substances undergo changes of state; all organisms are composed of cells; the atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor).
- Demonstrate relationships among closely related science principles (e.g., statements of Newton's three laws of motion, energy transfer and the water cycle).
- Demonstrate relationships among different representations of principles (e.g., verbal, symbolic, diagrammatic) and data patterns (e.g., tables, equations, graphs).

Identifying Science Principles is integral to all of the other science practices.

Using Science Principles

Scientific knowledge is useful for making sense of the natural world. Both scientists and informed citizens can use patterns in observations and theoretical models to predict and explain observations that they make now or that they will make in the future.

Using Science Principles comprises the following general types of performance expectations:

- Explain observations of phenomena (using science principles from the content statements).
- Predict observations of phenomena (using science principles from the content statements, including quantitative predictions based on science principles that specify quantitative relationships among variables).
- Suggest examples of observations that illustrate a science principle (e.g., identify examples where the net force on an object is zero; provide examples of observations explained by the movement of tectonic plates; given partial DNA sequences of organisms, identify likely sequences of close relatives).
- Propose, analyze, and evaluate alternative explanations or predictions.

The first two categories—***Identifying Science Principles*** and ***Using Science Principles***—both require students to correctly state or recognize the science principles contained in the content statements. A difference between the categories is that Using Science Principles focuses on what makes science knowledge valuable—that is, its usefulness in making accurate predictions about phenomena and in explaining observations of the natural world in coherent ways (i.e., "knowing why"). Distinguishing between these two categories draws attention to differences in depth and richness of individuals' knowledge of the content statements. Assuming a continuum from "just knowing the facts" to "using science principles," there is considerable overlap at the boundaries. The line between the Identifying and Using categories is not distinct.

Scientific Inquiry

Scientifically literate graduates make observations about the natural world, identify patterns in data, and propose explanations to account for the patterns. Scientific inquiry involves the collection of relevant data, the use of logical reasoning, and the application of imagination in devising hypotheses to explain patterns in data. Scientific inquiry is a complex and time-intensive process that is iterative rather than linear. Habits of mind—curiosity, openness to new ideas, informed skepticism—are part of scientific inquiry. This includes the ability to read or listen critically to assertions in the media, deciding what evidence to pay attention to and what to dismiss, and distinguishing careful arguments from shoddy ones. Thus, Scientific Inquiry depends on the practices described above—Identifying Science Principles and Using Science Principles.

Scientific Inquiry comprises the following general types of performance expectations:

- Generate new questions that can be investigated in the laboratory or field.
- Evaluate the uncertainties or validity of scientific conclusions using an understanding of sources of measurement error, the challenges of controlling variables, accuracy of data analysis, logic of argument, logic of experimental design, and/or the dependence on underlying assumptions.
- Conduct scientific investigations using appropriate tools and techniques (e.g., selecting an instrument that measures the desired quantity—length, volume, weight, time interval, temperature—with the appropriate level of precision).
- Identify patterns in data and relate them to theoretical models.
- Describe a reason for a given conclusion using evidence from an investigation.
- Predict what would happen if the variables, methods, or timing of an investigation were changed.
- Based on empirical evidence, explain and critique the reasoning used to draw a scientific conclusion or explanation.
- Design and conduct a systematic scientific investigation that tests a hypothesis. Draw conclusions from data presented in charts or tables.
- Distinguish between scientific explanations that are regarded as current scientific consensus and the emerging questions that active researchers investigate.

Scientific inquiry is more complex than simply making, summarizing, and explaining observations, and it is more flexible than the rigid set of steps often referred to as the "scientific method." The *National Standards* makes it clear that inquiry goes beyond "science as a process" to include an understanding of the nature of science (p. 105).

It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, theoretical models, and the explanations proposed by other scientists. Evaluation includes reviewing the experimental procedures, examining the evidence, identifying faulty reasoning, pointing out statements that go beyond the evidence, and suggesting alternative explanations for the same observations (p. 171).

When students engage in Scientific Inquiry, they are drawing on their understanding about the nature of science, including the following ideas (see Benchmarks for Science Literacy):

- Arguments are flawed when fact and opinion are intermingled or the conclusions do not follow logically from the evidence given.
- A single example can never support the inference that something is always true, but sometimes a single example can support the inference that something is not always true.
- If more than one variable changes at the same time in an experiment, the outcome of the experiment may not be clearly attributable to any one of the variables.
- The way in which a sample is drawn affects how well it represents the population of interest. The larger the sample, the smaller the error in inference to the population. But, large samples do not necessarily guarantee representation, especially in the absence of random sampling.

Students can demonstrate their abilities to engage in Scientific Inquiry in two ways: students can *do* the practices specified above, and students can *critique examples* of scientific inquiry. In *doing*, practices can include analyzing data tables and deciding which conclusions are consistent with the data. Other practices involve hands-on performance and/or interactive computer tasks—for example, where students collect data and present their results or where students specify experimental conditions on computer simulations and observe the outcomes. As to *critiquing*, students can identify flaws in a poorly designed investigation or suggest changes in the design in order to produce more reliable data. Students should also be able to critique print or electronic media—for example, items may ask students to suggest alternative interpretations of data described in a newspaper article.

Scientific Reflection and Social Implications

Scientifically literate people recognize the strengths and limitations of scientific knowledge, which will provide the perspective they need to use the information to solve real-world problems. Students must learn to decide who and what sources of information they can trust. They need to learn to critique and justify their own ideas and the ideas of others. Since knowledge comes from many sources, students need to appreciate the historical origins of modern science and the multitude of connections between science and other disciplines. Students need to understand how science and technology support one another and the political, economic, and environmental consequences of scientific and technological progress. Finally, it is important that the ideas and contributions of men and women from all cultures be recognized as having played a significant role in scientific communities.

Scientific Reflection and Social Implications include the following general types of practices, all of which entail students using science knowledge to:

- Critique whether or not specific questions can be answered through scientific investigations.
- Identify and critique arguments about personal or societal issues based on scientific evidence.
- Develop an understanding of a scientific concept by accessing information from multiple sources. Evaluate the scientific accuracy and significance of the information.
- Evaluate scientific explanations in a peer review process or discussion format.
- Evaluate the future career and occupational prospects of science fields.
- Critique solutions to problems, given criteria and scientific constraints.
- Identify scientific tradeoffs in design decisions and choose among alternative solutions.
- Describe the distinctions between scientific theories, laws, hypotheses, and observations.
- Explain the progression of ideas and explanations that lead to science theories that are part of the current scientific consensus or core knowledge.
- Apply science principles or scientific data to anticipate effects of technological design decisions.
- Analyze how science and society interact from a historical, political, economic, or social perspective.

Organization of the Expectations

The Science Expectations are organized into Disciplines, Standards, Content Statements, and specific Performance Expectations.

Disciplines

Earth Science, Biology, Physics, and Chemistry

Organization of Each Standard

Each standard includes three parts:

- A standard statement that describes what students who have mastered that standard will be able to do.
- Content statements that describe Prerequisite, Essential, Core, and Recommended science content understanding for that standard.
- Performance expectations that describe Prerequisite, Essential, Core, and Recommended performances for that standard.

NOTE: Boundary statements that clarify the standards and set limits for expected performances, technical vocabulary, and additional discipline-specific inquiry and reflection expectations will be included in a companion document to be developed at a later date.

Standard Statement

The Standard Statement describes how students who meet that standard will engage in Identifying, Using, Inquiry, or Reflection for that topic.

Content Statements

Content statements describe the Prerequisite, Essential, Core, and Recommended *knowledge* associated with the standard.

Performance Expectations

Performance expectations are derived from the intersection of content statements and practices.

Performance expectations are written with particular verbs indicating the desired performance expected of the student. The action verbs associated with each practice are contextualized to generate performance expectations. For example, when the “conduct scientific investigations” is crossed with a states-of-matter content statement, this can generate a performance expectation that employs a different action verb, “heats as a way to evaporate liquids.”

High School Content Expectation Codes

To allow for ease in referencing expectations, each science expectation is coded by discipline, standard, content statement, and performance expectation. For example:

C2.3A

- **C:** The discipline of Chemistry
- **C2:** Standard 2 in the discipline of Chemistry
- **C2.3:** Content Statement 3 in Standard C2
- **C2.3A:** 1st expectation in the 3rd content statement of Standard C2

Upper case letters indicate essential expectations required for all students.

Lower case letters indicate core expectations for course/credit.

Properties of matter

All objects and substances in the natural world are composed of matter. All matter has two fundamental properties: matter takes up space, and matter has intertia – it changes motion only when under the influence of a non-zero net force. Matter can be characterized in terms of its physical and chemical properties. These properties can be explained through the particulate model of matter, which describes the particles as atoms or molecules that are continuously in motion. The extent of the motion can be used to explain the physical properties associated with the common states of matter, solid, liquid and gas, as well as the changes of state. Whether or not a particular substance will exist as a solid, liquid or a gas will depend on the force due to particle motion in comparison to the force of attraction between particles. The attractive forces between particles are explained by the detailed structure of molecules and the atoms that compose them.

The structure of an atom in terms of its component protons, neutrons and electrons provides the basis for a systematic description of the building blocks of matter and their organization in the Periodic Table of the Elements. The Periodic Table demonstrates the relationship between the number of protons in an element, which is the defining characteristic of each element, and the chemical and physical properties of the elements. The Periodic Table also provides a structure for inquiry into the characteristics of the elements, since the electronic structure of atoms is reflected in the arrangement of elements in the Periodic Table. It is the electronic structure of atoms, especially the outermost electrons, that explains the chemical properties of elements and the breaking and making of bonds between atoms in a chemical reaction. An understanding of the bonding between elements leads to the concept of molecules as particles with specific combinations of atoms. When a substance consists of only one type of molecule it is referred to as a compound, with each compound having unique chemical and physical pr operties due to the detailed structure of its component molecules.

Changes in matter

As a general principle, a great deal of understanding chemistry is in differentiating what Nobelist Roald Hoffmann deftly labeled as "the same and not the same." Chemistry is filled with comparisons that fall under this rubric. Isomerism, for instance, is built on this idea. Molecules have the same molecular formula, but have completely different properties (ethyl acetate and butyric acid). In photo- or thermal isomerization reactions, what constitutes the starting material and the product different on the basis of some observable property because here, too, the molecular formulas are the same. We create false dichotomies for the convenience of categorization (physical properties versus chemical properties, ionic versus covalent bonding), yet when you dissolve blue cobalt chloride in water, and the solution turns pick, it is hard to argue "dissolving is a simple act of physical change."

Are polymorphous crystalline forms that different? There are real property differences that we would traditionally include as "chemical" changes (spectroscopic differences, for instance). Is dissolving sodium chloride in water and then evaporating the water to get it back that different? Not really. Ionic networks or lattices are complex structures with billions and billions of degenerate isomeric forms. Add a sample of radio-labeled sodium chloride to a differently-labeled sample; crystallization accomplishes a cross-over experiment no matter how you look at it.

Changes in matter then, are not simple binary classifications, but derived from defining what is changing and the criteria by which those changes are judged, particularly those properties that are used to make the decision about what sort of change has taken place. A useful concept that helps sort through these relationships is "material kind," a term that us used when a substance is made up of a homogenous aggregate of atomic or molecular species (macroscopic "liquid water" is a "material kind," and differentiates it from the matter – molecular water: "HOH" – that comprises it). Solid water and liquid water are different material kinds, while the matter that makes them up is the same.

Forms of energy

From the chemical perspective it is critical that the student understand the role of energy in the breaking and formation of chemical bonds, since bond breaking/making is the fundamental process in a chemical reaction. Potential energy is stored energy resulting from the attraction between two objects. Students commonly only understand gravitational potential energy. Just as the force of gravity results in potential energy changes as objects are moved relative to the earth, there are changes in potential energy when any particles held by a force (gravitational, electrical, magnetic, strong) are moved relative to each other. Chemical bonds are the result of a decrease in potential energy from the increased electrostatic attractions between atoms. Chemical bonds will not form unless there is a decrease in potential energy compared to the unbonded state. The strength of a chemical bond is directly proportional to the energy released when the bond forms from the separated gaseous atoms (ions). Breaking a chemical bond always requires energy to overcome the attractive forces holding the particle (ions, atoms, molecules) together. At grade 8 the student should be able to describe physical changes (changes of state, dissolving) in terms of rearranging the atoms, molecules or ions). At grade 12 the student should be able to describe chemical changes in terms of bond making and bond breaking to demonstrate a deeper understanding of the term "chemical potential energy".

Energy transformations

The transfer of energy and the conservation of energy are of great explanatory and predictive value. Left on their own all systems will naturally move to a state of minimum energy and maximum randomness. Application of these two driving forces coupled with the conservation of matter and energy will allow students to explain and predict most chemical phenomena. Students will understand the tremendous energy released in nuclear reactions is a result of small amounts of matter being converted to energy.

Chemistry Content Statement Outline

STANDARD C1 Inquiry, Reflection, and Social Implications

C1.1 Scientific Inquiry

C1.2 Scientific Reflection and Social Implications

STANDARD C2 Forms of Energy

P2.p1 Potential Energy *(prerequisite)*

C2.1x Chemical Potential Energy

C2.2 Molecules in Motion

C2.2x Molecular Entropy

C2.3x Breaking Chemical Bonds

C2.4x Electron Movement

C2.5x Nuclear Stability

STANDARD C3 Energy Transfer and Conservation

P3.p1 Conservation of Energy *(prerequisite)*

C3.1x Hess's Law

P3.p2 Energy Transfer *(prerequisite)*

C3.2x Enthalpy

C3.3 Heating Impacts

C3.3x Bond Energy

C3.4 Endothermic and Exothermic Reactions

C3.4x Enthalpy and Entropy

C3.5x Mass Defect

STANDARD C4 Properties of Matter

P4.p1 Kinetic Molecular Theory *(prerequisite)*

P4.p2 Elements, Compounds, and Mixtures *(prerequisite)*

STANDARD C4		**Properties of Matter (cont.)**
	C4.1x	Molecular and Empirical Formulae
	C4.2	Nomenclature
	C4.3	Properties of Substances
	C4.3x	Solids
	C4.4x	Molecular Polarity
	C4.5x	Ideal Gas Law
	C4.6x	Moles
	C4.7x	Solutions
	C4.8	Atomic Structure
	C4.8x	Electron Configuration
	C4.9	Periodic Table
	C4.9x	Electron Energy Levels
	C4.10	Neutral Atoms, Ions, and Isotopes
	C4.10x	Average Atomic Mass
STANDARD C5		**Changes in Matter**
	P5.p1	Conservation of Matter *(prerequisite)*
	C5.r1x	Rates of Reactions *(recommended)*
	C5.2	Chemical Changes
	C5.2x	Balancing Equations
	C5.3x	Equilibrium
	C5.4	Phase Change/Diagrams
	C5.4x	Changes of State
	C5.5	Chemical Bonds – Trends
	C5.5x	Chemical Bonds
	C5.6x	Reduction/Oxidation Reactions
	C5.7	Acids and Bases
	C5.7x	Brønsted-Lowry
	C5.8	Carbon Chemistry

CONTENT EXPECTATIONS FOR CHEMISTRY

STANDARD C1: INQUIRY, REFLECTION, AND SOCIAL IMPLICATIONS

Students will understand the nature of science and demonstrate an ability to practice scientific reasoning by applying it to the design, execution, and evaluation of scientific investigations. Students will demonstrate their understanding that scientific knowledge is gathered through various forms of direct and indirect observations and the testing of this information by methods including, but not limited to, experimentation. They will be able to distinguish between types of scientific knowledge (e.g., hypotheses, laws, theories) and become aware of areas of active research in contrast to conclusions that are part of established scientific consensus. They will use their scientific knowledge to assess the costs, risks, and benefits of technological systems as they make personal choices and participate in public policy decisions. These insights will help them analyze the role science plays in society, technology, and potential career opportunities.

C1.1 Scientific Inquiry

Science is a way of understanding nature. Scientific research may begin by generating new scientific questions that can be answered through replicable scientific investigations that are logically developed and conducted systematically. Scientific conclusions and explanations result from careful analysis of empirical evidence and the use of logical reasoning. Some questions in science are addressed through indirect rather than direct observation, evaluating the consistency of new evidence with results predicted by models of natural processes. Results from investigations are communicated in reports that are scrutinized through a peer review process.

C1.1A Generate new questions that can be investigated in the laboratory or field.

C1.1B Evaluate the uncertainties or validity of scientific conclusions using an understanding of sources of measurement error, the challenges of controlling variables, accuracy of data analysis, logic of argument, logic of experimental design, and/or the dependence on underlying assumptions.

C1.1C Conduct scientific investigations using appropriate tools and techniques (e.g., selecting an instrument that measures the desired quantity—length, volume, weight, time interval, temperature—with the appropriate level of precision).

C1.1D Identify patterns in data and relate them to theoretical models.

C1.1E Describe a reason for a given conclusion using evidence from an investigation.

C1.1f Predict what would happen if the variables, methods, or timing of an investigation were changed.

C1.1g Based on empirical evidence, explain and critique the reasoning used to draw a scientific conclusion or explanation.

C1.1h Design and conduct a systematic scientific investigation that tests a hypothesis. Draw conclusions from data presented in charts or tables.

C1.1i Distinguish between scientific explanations that are regarded as current scientific consensus and the emerging questions that active researchers investigate.

C1.2 Scientific Reflection and Social Implications

The integrity of the scientific process depends on scientists and citizens understanding and respecting the "Nature of Science." Openness to new ideas, skepticism, and honesty are attributes required for good scientific practice. Scientists must use logical reasoning during investigation design, analysis, conclusion, and communication. Science can produce critical insights on societal problems from a personal and local scale to a global scale. Science both aids in the development of technology and provides tools for assessing the costs, risks, and benefits of technological systems. Scientific conclusions and arguments play a role in personal choice and public policy decisions. New technology and scientific discoveries have had a major influence in shaping human history. Science and technology continue to offer diverse and significant career opportunities.

C1.2A Critique whether or not specific questions can be answered through scientific investigations.

C1.2B Identify and critique arguments about personal or societal issues based on scientific evidence.

C1.2C Develop an understanding of a scientific concept by accessing information from multiple sources. Evaluate the scientific accuracy and significance of the information.

C1.2D Evaluate scientific explanations in a peer review process or discussion format.

C1.2E Evaluate the future career and occupational prospects of science fields.

C1.2f Critique solutions to problems, given criteria and scientific constraints.

C1.2g Identify scientific tradeoffs in design decisions and choose among alternative solutions.

C1.2h Describe the distinctions between scientific theories, laws, hypotheses, and observations.

C1.2i Explain the progression of ideas and explanations that lead to science theories that are part of the current scientific consensus or core knowledge.

C1.2j Apply science principles or scientific data to anticipate effects of technological design decisions.

C1.2k Analyze how science and society interact from a historical, political, economic, or social perspective.

STANDARD C2: FORMS OF ENERGY

Students recognize the many forms of energy and understand that energy is central to predicting and explaining how and why chemical reactions occur. The chemical topics of bonding, gas behavior, kinetics, enthalpy, entropy, free energy, and nuclear stability are addressed in this standard.

Chemistry students relate temperature to the average kinetic energy of the molecules and use the kinetic molecular theory to describe and explain the behavior of gases and the rates of chemical reactions. They understand nuclear stability in terms of reaching a state of minimum potential energy.

P2.p1 Potential Energy *(prerequisite)*

Three forms of potential energy are gravitational, elastic, and chemical. Objects can have elastic potential energy due to their compression or chemical potential energy due to the arrangement of the atoms. *(prerequisite)*

P2.p1A Describe energy changes associated with changes of state in terms of the arrangement and order of the atoms (molecules) in each state. *(prerequisite)*

P2.p1B Use the positions and arrangements of atoms and molecules in solid, liquid, and gas state to explain the need for an input of energy for melting and boiling and a release of energy in condensation and freezing. *(prerequisite)*

C2.1x Chemical Potential Energy

Potential energy is stored whenever work must be done to change the distance between two objects. The attraction between the two objects may be gravitational, electrostatic, magnetic, or strong force. Chemical potential energy is the result of electrostatic attractions between atoms.

C2.1a Explain the changes in potential energy (due to electrostatic interactions) as a chemical bond forms and use this to explain why bond breaking always requires energy.

C2.1b Describe energy changes associated with chemical reactions in terms of bonds broken and formed (including intermolecular forces).

C2.1c Compare qualitatively the energy changes associated with melting various types of solids in terms of the types of forces between the particles in the solid.

C2.2 Molecules in Motion

Molecules that compose matter are in constant motion (translational, rotational, vibrational). Energy may be transferred from one object to another during collisions between molecules.

C2.2A Describe conduction in terms of molecules bumping into each other to transfer energy. Explain why there is better conduction in solids and liquids than gases.

C2.2B Describe the various states of matter in terms of the motion and arrangement of the molecules (atoms) making up the substance.

C2.2x Molecular Entropy

As temperature increases, the average kinetic energy and the entropy of the molecules in a sample increases.

C2.2c Explain changes in pressure, volume, and temperature for gases using the kinetic molecular model.

C2.2d Explain convection and the difference in transfer of thermal energy for solids, liquids, and gases using evidence that molecules are in constant motion.

C2.2e Compare the entropy of solids, liquids, and gases.

C2.2f Compare the average kinetic energy of the molecules in a metal object and a wood object at room temperature.

C2.3x Breaking Chemical Bonds

For molecules to react, they must collide with enough energy (activation energy) to break old chemical bonds before their atoms can be rearranged to form new substances.

C2.3a Explain how the rate of a given chemical reaction is dependent on the temperature and the activation energy.

C2.3b Draw and analyze a diagram to show the activation energy for an exothermic reaction that is very slow at room temperature.

C2.4x Electron Movement

For each element, the arrangement of electrons surrounding the nucleus is unique. These electrons are found in different energy levels and can only move from a lower energy level (closer to nucleus) to a higher energy level (farther from nucleus) by absorbing energy in discrete packets. The energy content of the packets is directly proportional to the frequency of the radiation. These electron transitions will produce unique absorption spectra for each element. When the electron returns from an excited (high energy state) to a lower energy state, energy is emitted in only certain wavelengths of light, producing an emission spectra.

C2.4a Describe energy changes in flame tests of common elements in terms of the (characteristic) electron transitions.

C2.4b Contrast the mechanism of energy changes and the appearance of absorption and emission spectra.

C2.4c Explain why an atom can absorb only certain wavelengths of light.

C2.4d Compare various wavelengths of light (visible and nonvisible) in terms of frequency and relative energy.

C2.5x Nuclear Stability

Nuclear stability is related to a decrease in potential energy when the nucleus forms from protons and neutrons. If the neutron/proton ratio is unstable, the element will undergo radioactive decay. The rate of decay is characteristic of each isotope; the time for half the parent nuclei to decay is called the half-life. Comparison of the parent/daughter nuclei can be used to determine the age of a sample. Heavier elements are formed from the fusion of lighter elements in the stars.

C2.5a Determine the age of materials using the ratio of stable and unstable isotopes of a particular type.

C2.r5b Illustrate how elements can change in nuclear reactions using balanced equations. *(recommended)*

C2.r5c Describe the potential energy changes as two protons approach each other. *(recommended)*

C2.r5d Describe how and where all the elements on earth were formed. *(recommended)*

STANDARD C3: ENERGY TRANSFER AND CONSERVATION

Students apply the First and Second Laws of Thermodynamics to explain and predict most chemical phenomena.

Chemistry students use the term enthalpy to describe the transfer of energy between reactants and products in simple calorimetry experiments performed in class and will recognize Hess's Law as an application of the conservation of energy.

Students understand the tremendous energy released in nuclear reactions is a result of small amounts of matter being converted to energy.

P3.p1 Conservation of Energy *(prerequisite)*

When energy is transferred from one system to another, the quantity of energy before transfer equals the quantity of energy after transfer. *(prerequisite)*

P3.p1A Explain that the amount of energy necessary to heat a substance will be the same as the amount of energy released when the substance is cooled to the original temperature. *(prerequisite)*

C3.1x Hess's Law

For chemical reactions where the state and amounts of reactants and products are known, the amount of energy transferred will be the same regardless of the chemical pathway. This relationship is called Hess's law.

C3.1a Calculate the ΔH for a given reaction using Hess's Law.

C3.1b Draw enthalpy diagrams for exothermic and endothermic reactions.

C3.1c Calculate the ΔH for a chemical reaction using simple coffee cup calorimetry.

C3.1d Calculate the amount of heat produced for a given mass of reactant from a balanced chemical equation.

P3.p2 Energy Transfer *(prerequisite)*

Nuclear reactions take place in the sun. In plants, light from the sun is transferred to oxygen and carbon compounds, which, in combination, have chemical potential energy (photosynthesis). *(prerequisite)*

P3.p2A Trace (or diagram) energy transfers involving various types of energy including nuclear, chemical, electrical, sound, and light. *(prerequisite)*

C3.2x Enthalpy

Chemical reactions involve breaking bonds in reactants (endothermic) and forming new bonds in the products (exothermic). The enthalpy change for a chemical reaction will depend on the relative strengths of the bonds in the reactants and products.

C3.2a Describe the energy changes in photosynthesis and in the combustion of sugar in terms of bond breaking and bond making.

C3.2b Describe the relative strength of single, double, and triple covalent bonds between nitrogen atoms.

C3.3 Heating Impacts

Heating increases the kinetic (translational, rotational, and vibrational) energy of the atoms composing elements and the molecules or ions composing compounds. As the kinetic (translational) energy of the atoms, molecules, or ions increases, the temperature of the matter increases. Heating a sample of a crystalline solid increases the kinetic (vibrational) energy of the atoms, molecules, or ions. When the kinetic (vibrational) energy becomes great enough, the crystalline structure breaks down, and the solid melts.

C3.3A Describe how heat is conducted in a solid.

C3.3B Describe melting on a molecular level.

C3.3x Bond Energy

Chemical bonds possess potential (vibrational and rotational) energy.

C3.3c Explain why it is necessary for a molecule to absorb energy in order to break a chemical bond.

C3.4 Endothermic and Exothermic Reactions

Chemical interactions either release energy to the environment (exothermic) or absorb energy from the environment (endothermic).

C3.4A Use the terms endothermic and exothermic correctly to describe chemical reactions in the laboratory.

C3.4B Explain why chemical reactions will either release or absorb energy.

C3.4x Enthalpy and Entropy

All chemical reactions involve rearrangement of the atoms. In an exothermic reaction, the products have less energy than the reactants. There are two natural driving forces: (1) toward minimum energy (enthalpy) and (2) toward maximum disorder (entropy).

C3.4c Write chemical equations including the heat term as a part of equation or using ΔH notation.

C3.4d Draw enthalpy diagrams for reactants and products in endothermic and exothermic reactions.

C3.4e Predict if a chemical reaction is spontaneous given the enthalpy (ΔH) and entropy (ΔS) changes for the reaction using Gibb's Free Energy, $\Delta G = \Delta H - T\Delta S$ (Note: mathematical computation of ΔG is not required.)

C3.4f Explain why some endothermic reactions are spontaneous at room temperature.

C3.4g Explain why gases are less soluble in warm water than cold water.

C3.5x Mass Defect

Nuclear reactions involve energy changes many times the magnitude of chemical changes. In chemical reactions matter is conserved, but in nuclear reactions a small loss in mass (mass defect) will account for the tremendous release of energy. The energy released in nuclear reactions can be calculated from the mass defect using $E = mc^2$.

C3.5a Explain why matter is not conserved in nuclear reactions.

STANDARD C4: PROPERTIES OF MATTER

Compounds, elements, and mixtures are categories used to organize matter. Students organize materials into these categories based on their chemical and physical behavior. Students understand the structure of the atom to make predictions about the physical and chemical properties of various elements and the types of compounds those elements will form. An understanding of the organization the Periodic Table in terms of the outer electron configuration is one of the most important tools for the chemist and student to use in prediction and explanation of the structure and behavior of atoms.

P4.p1 Kinetic Molecular Theory *(prerequisite)*

Properties of solids, liquids, and gases are explained by a model of matter that is composed of tiny particles in motion. *(prerequisite)*

P4.p1A For a substance that can exist in all three phases, describe the relative motion of the particles in each of the phases. *(prerequisite)*

P4.p1B For a substance that can exist in all three phases, make a drawing that shows the arrangement and relative spacing of the particles in each of the phases. *(prerequisite)*

P4.p1C For a simple compound, present a drawing that shows the number of particles in the system does not change as a result of a phase change. *(prerequisite)*

P4.p2 Elements, Compounds, and Mixtures *(prerequisite)*

Elements are a class of substances composed of a single kind of atom. Compounds are composed of two or more different elements chemically combined. Mixtures are composed of two or more different elements and/or compounds physically combined. Each element and compound has physical and chemical properties, such as boiling point, density, color, and conductivity, which are independent of the amount of the sample. *(prerequisite)*

P4.p2A Distinguish between an element, compound, or mixture based on drawings or formulae. *(prerequisite)*

P4.p2B Identify a pure substance (element or compound) based on unique chemical and physical properties. *(prerequisite)*

P4.p2C Separate mixtures based on the differences in physical properties of the individual components. *(prerequisite)*

P4.p2D Recognize that the properties of a compound differ from those of its individual elements. *(prerequisite)*

C4.1x Molecular and Empirical Formulae

Compounds have a fixed percent elemental composition. For a compound, the empirical formula can be calculated from the percent composition or the mass of each element. To determine the molecular formula from the empirical formula, the molar mass of the substance must also be known.

C4.1a Calculate the percent by weight of each element in a compound based on the compound formula.

C4.1b Calculate the empirical formula of a compound based on the percent by weight of each element in the compound.

C4.1c Use the empirical formula and molecular weight of a compound to determine the molecular formula.

C4.2 Nomenclature

All compounds have unique names that are determined systematically.

C4.2A Name simple binary compounds using their formulae.

C4.2B Given the name, write the formula of simple binary compounds.

C4.2x Nomenclature

All molecular and ionic compounds have unique names that are determined systematically.

C4.2c Given a formula, name the compound.

C4.2d Given the name, write the formula of ionic and molecular compounds.

C4.2e Given the formula for a simple hydrocarbon, draw and name the isomers.

C4.3 Properties of Substances

Differences in the physical and chemical properties of substances are explained by the arrangement of the atoms, ions, or molecules of the substances and by the strength of the forces of attraction between the atoms, ions, or molecules.

C4.3A Recognize that substances that are solid at room temperature have stronger attractive forces than liquids at room temperature, which have stronger attractive forces than gases at room temperature.

C4.3B Recognize that solids have a more ordered, regular arrangement of their particles than liquids and that liquids are more ordered than gases.

C4.3x Solids

Solids can be classified as metallic, ionic, covalent, or network covalent. These different types of solids have different properties that depend on the particles and forces found in the solid.

C4.3c Compare the relative strengths of forces between molecules based on the melting point and boiling point of the substances.

C4.3d Compare the strength of the forces of attraction between molecules of different elements. (For example, at room temperature, chlorine is a gas and iodine is a solid.)

C4.3e Predict whether the forces of attraction in a solid are primarily metallic, covalent, network covalent, or ionic based upon the elements' location on the periodic table.

C4.3f Identify the elements necessary for hydrogen bonding (N, O, F).

C4.3g Given the structural formula of a compound, indicate all the intermolecular forces present (dispersion, dipolar, hydrogen bonding).

C4.3h Explain properties of various solids such as malleability, conductivity, and melting point in terms of the solid's structure and bonding.

C4.3i Explain why ionic solids have higher melting points than covalent solids. (For example, NaF has a melting point of 995°C while water has a melting point of 0° C.)

C4.4x Molecular Polarity

The forces between molecules depend on the net polarity of the molecule as determined by shape of the molecule and the polarity of the bonds.

C4.4a Explain why at room temperature different compounds can exist in different phases.

C4.4b Identify if a molecule is polar or nonpolar given a structural formula for the compound.

C4.5x Ideal Gas Law

The forces in gases are explained by the ideal gas law.

C4.5a Provide macroscopic examples, atomic and molecular explanations, and mathematical representations (graphs and equations) for the pressure-volume relationship in gases.

C4.5b Provide macroscopic examples, atomic and molecular explanations, and mathematical representations (graphs and equations) for the pressure-temperature relationship in gases.

C4.5c Provide macroscopic examples, atomic and molecular explanations, and mathematical representations (graphs and equations) for the temperature-volume relationship in gases.

C4.6x Moles

The mole is the standard unit for counting atomic and molecular particles in terms of common mass units.

C4.6a Calculate the number of moles of any compound or element given the mass of the substance.

C4.6b Calculate the number of particles of any compound or element given the mass of the substance.

C4.7x Solutions

The physical properties of a solution are determined by the concentration of solute.

C4.7a Investigate the difference in the boiling point or freezing point of pure water and a salt solution.

C4.7b Compare the density of pure water to that of a sugar solution.

C4.8 Atomic Structure

Electrons, protons, and neutrons are parts of the atom and have measurable properties, including mass and, in the case of protons and electrons, charge. The nuclei of atoms are composed of protons and neutrons. A kind of force that is only evident at nuclear distances holds the particles of the nucleus together against the electrical repulsion between the protons.

C4.8A Identify the location, relative mass, and charge for electrons, protons, and neutrons.

C4.8B Describe the atom as mostly empty space with an extremely small, dense nucleus consisting of the protons and neutrons and an electron cloud surrounding the nucleus.

C4.8C Recognize that protons repel each other and that a strong force needs to be present to keep the nucleus intact.

C4.8D Give the number of electrons and protons present if the fluoride ion has a -1 charge.

C4.8x Electron Configuration

Electrons are arranged in main energy levels with sublevels that specify particular shapes and geometry. Orbitals represent a region of space in which an electron may be found with a high level of probability. Each defined orbital can hold two electrons, each with a specific spin orientation. The specific assignment of an electron to an orbital is determined by a set of 4 quantum numbers. Each element and, therefore, each position in the periodic table is defined by a unique set of quantum numbers.

C4.8e Write the complete electron configuration of elements in the first four rows of the periodic table.

C4.8f Write kernel structures for main group elements.

C4.8g Predict oxidation states and bonding capacity for main group elements using their electron structure.

C4.8h Describe the shape and orientation of *s* and *p* orbitals.

C4.8i Describe the fact that the electron location cannot be exactly determined at any given time.

C4.9 Periodic Table

In the periodic table, elements are arranged in order of increasing number of protons (called the atomic number). Vertical groups in the periodic table (families) have similar physical and chemical properties due to the same outer electron structures.

C4.9A Identify elements with similar chemical and physical properties using the periodic table.

C4.9x Electron Energy Levels

The rows in the periodic table represent the main electron energy levels of the atom. Within each main energy level are sublevels that represent an orbital shape and orientation.

C4.9b Identify metals, non-metals, and metalloids using the periodic table.

C4.9c Predict general trends in atomic radius, first ionization energy, and electonegativity of the elements using the periodic table.

C4.10 Neutral Atoms, Ions, and Isotopes

A neutral atom of any element will contain the same number of protons and electrons. Ions are charged particles with an unequal number of protons and electrons. Isotopes are atoms of the same element with different numbers of neutrons and essentially the same chemical and physical properties.

C4.10A List the number of protons, neutrons, and electrons for any given ion or isotope.

C4.10B Recognize that an element always contains the same number of protons.

C4.10x Average Atomic Mass

The atomic mass listed on the periodic table is an average mass for all the different isotopes that exist, taking into account the percent and mass of each different isotope.

C4.10c Calculate the average atomic mass of an element given the percent abundance and mass of the individual isotopes.

C4.10d Predict which isotope will have the greatest abundance given the possible isotopes for an element and the average atomic mass in the periodic table.

C4.10e Write the symbol for an isotope, ${}^{A}_{Z}X$, where Z is the atomic number, A is the mass number, and X is the symbol for the element.

STANDARD C5: CHANGES IN MATTER

Students will analyze a chemical change phenomenon from the point of view of what is the same and what is not the same.

P5.p1 Conservation of Matter *(prerequisite)*

Changes of state are explained by a model of matter composed of tiny particles that are in motion. When substances undergo changes of state, neither atoms nor molecules themselves are changed in structure. Mass is conserved when substances undergo changes of state. *(prerequisite)*

P5.p1A Draw a picture of the particles of an element or compound as a solid, liquid, and gas. *(prerequisite)*

C5.r1x Rates of Reactions *(recommended)*

The rate of a chemical reaction will depend upon (1) concentration of reacting species, (2) temperature of reaction, (3) pressure if reactants are gases, and (4) nature of the reactants. A model of matter composed of tiny particles that are in constant motion is used to explain rates of chemical reactions. *(recommended)*

C5.r1a Predict how the rate of a chemical reaction will be influenced by changes in concentration, temperature, and pressure. *(recommended)*

C5.r1b Explain how the rate of a reaction will depend on concentration, temperature, pressure, and nature of reactant. *(recommended)*

C5.2 Chemical Changes

Chemical changes can occur when two substances, elements, or compounds interact and produce one or more different substances whose physical and chemical properties are different from the interacting substances. When substances undergo chemical change, the number of atoms in the reactants is the same as the number of atoms in the products. This can be shown through simple balancing of chemical equations. Mass is conserved when substances undergo chemical change. The total mass of the interacting substances (reactants) is the same as the total mass of the substances produced (products).

C5.2A Balance simple chemical equations applying the conservation of matter.

C5.2B Distinguish between chemical and physical changes in terms of the properties of the reactants and products.

C5.2C Draw pictures to distinguish the relationships between atoms in physical and chemical changes.

C5.2x Balancing Equations

A balanced chemical equation will allow one to predict the amount of product formed.

C5.2d Calculate the mass of a particular compound formed from the masses of starting materials.

C5.2e Identify the limiting reagent when given the masses of more than one reactant.

C5.2f Predict volumes of product gases using initial volumes of gases at the same temperature and pressure.

C5.2g Calculate the number of atoms present in a given mass of element.

C5.3x Equilibrium

Most chemical reactions reach a state of dynamic equilibrium where the rates of the forward and reverse reactions are equal.

C5.3a Describe equilibrium shifts in a chemical system caused by changing conditions (Le Chatelier's Principle).

C5.3b Predict shifts in a chemical system caused by changing conditions (Le Chatelier's Principle).

C5.3c Predict the extent reactants are converted to products using the value of the equilibrium constant.

C5.4 Phase Change/Diagrams

Changes of state require a transfer of energy. Water has unusually high-energy changes associated with its changes of state.

C5.4A Compare the energy required to raise the temperature of one gram of aluminum and one gram of water the same number of degrees.

C5.4B Measure, plot, and interpret the graph of the temperature versus time of an ice-water mixture, under slow heating, through melting and boiling.

C5.4x Changes of State

All changes of state require energy. Changes in state that require energy involve breaking forces holding the particles together. The amount of energy will depend on the type of forces.

C5.4c Explain why both the melting point and boiling points for water are significantly higher than other small molecules of comparable mass (e.g., ammonia and methane).

C5.4d Explain why freezing is an exothermic change of state.

C5.4e Compare the melting point of covalent compounds based on the strength of IMFs (intermolecular forces).

C5.5 Chemical Bonds — Trends

An atom's electron configuration, particularly of the outermost electrons, determines how the atom can interact with other atoms. The interactions between atoms that hold them together in molecules or between oppositely charged ions are called chemical bonds.

C5.5A Predict if the bonding between two atoms of different elements will be primarily ionic or covalent.

C5.4B Predict the formula for binary compounds of main group elements.

C5.5x Chemical Bonds

Chemical bonds can be classified as ionic, covalent, and metallic. The properties of a compound depend on the types of bonds holding the atoms together.

C5.5c Draw Lewis structures for simple compounds.

C5.5d Compare the relative melting point, electrical and thermal conductivity, and hardness for ionic, metallic, and covalent compounds.

C5.5e Relate the melting point, hardness, and electrical and thermal conductivity of a substance to its structure.

C5.6x Reduction/Oxidation Reactions

Chemical reactions are classified according to the fundamental molecular or submolecular changes that occur. Reactions that involve electron transfer are known as oxidation/reduction (or "redox").

C5.6a Balance half-reactions and describe them as oxidations or reductions.

C5.6b Predict single replacement reactions.

C5.6c Explain oxidation occurring when two different metals are in contact.

C5.6d Calculate the voltage for spontaneous redox reactions from the standard reduction potentials.

C5.6e Identify the reactions occurring at the anode and cathode in an electrochemical cell.

C5.7 Acids and Bases

Acids and bases are important classes of chemicals that are recognized by easily observed properties in the laboratory. Acids and bases will neutralize each other. Acid formulas usually begin with hydrogen, and base formulas are a metal with a hydroxide ion. As the pH decreases, a solution becomes more acidic. A difference of one pH unit is a factor of 10 in hydrogen ion concentration.

C5.7A Recognize formulas for common inorganic acids, carboxylic acids, and bases formed from families I and II.

C5.7B Predict products of an acid-base neutralization.

C5.7C Describe tests that can be used to distinguish an acid from a base.

C5.7D Classify various solutions as acidic or basic, given their pH.

C5.7E Explain why lakes with limestone or calcium carbonate experience less adverse effects from acid rain than lakes with granite beds.

C5.7x Brønsted-Lowry

Chemical reactions are classified according to the fundamental molecular or submolecular changes that occur. Reactions that involve proton transfer are known as acid/base reactions.

C5.7f Write balanced chemical equations for reactions between acids and bases and perform calculations with balanced equations.

C5.7g Calculate the pH from the hydronium ion or hydroxide ion concentration.

C5.7h Explain why sulfur oxides and nitrogen oxides contribute to acid rain.

C5.r7i Identify the Brønsted-Lowry conjugate acid-base pairs in an equation. *(recommended)*

C5.8 Carbon Chemistry

The chemistry of carbon is important. Carbon atoms can bond to one another in chains, rings, and branching networks to form a variety of structures, including synthetic polymers, oils, and the large molecules essential to life.

C5.8A Draw structural formulas for up to ten carbon chains of simple hydrocarbons.

C5.8B Draw isomers for simple hydrocarbons.

C5.8C Recognize that proteins, starches, and other large biological molecules are polymers.

Michigan Department of Education
Office of School Improvement
Dr. Yvonne Caamal Canul, Director
(517) 241-3147 www.michigan.gov/mde